THE EFFECTS OF BACKWARD LOCOMOTION AS PART OF A REHABILITATION PROGRAM ON THE FUNCTIONAL ABILITY OF PATIENTS FOLLOWING KNEE INJURY

BY

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DECLARATION

By submitting this thesis electronically, I declare that the entirety of the work contained therein is my own, original work, that I am the owner of the copyright thereof (unless to the extent explicitly otherwise stated) and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

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SUMMARY

Knee injuries are common among the physically active population and are often severe enough that it requires surgery. Rehabilitation specialists are on the constant look-out for the most efficient and cost-effective treatment alternatives to provide athletes with an early return to sport. The inclusion of backward locomotion in knee rehabilitation programs has been proposed since it is considered a safe closed kinetic chain exercise which has been found to increase *quadriceps* strength and power as well as cardiorespiratory fitness.

The primary aim of the study was to establish the efficacy of backward locomotion training during a knee rehabilitation program.

Thirty nine men and women (aged 18 to 59 years) with knee pathologies volunteered for the study and were randomly assigned to the experimental group (EXP, n = 20) and control group (CON, n = 19). All participants underwent a 24 session knee rehabilitation program which included 20 – 30 minutes of cardiorespiratory training, either in backward mode (EXP), or forward mode (CON). Aerobic fitness, *quadriceps* and *hamstrings* strength and power, single leg balance, lower limb circumferences, and lower limb flexibility were measured before and after the rehabilitation program.

Backward locomotion training resulted in a borderline statistical significant improvement in ventilatory threshold (VT) ($p = 0.07$) and a statistical significant improvement in peak power output (PPO) ($p < 0.05$). The VT and PPO of the backward locomotion group increased by 9 and 14%, respectively, compared to 0 and 4% in the forward locomotion group. Both groups showed statistically significant improvements in q*uadriceps* and *hamstrings* strength, except the *quadriceps* of the uninvolved leg of the forward locomotion group. Similarly, both groups showed a statistically significant improvement in q*uadriceps* and *hamstrings* average power, except the *quadriceps* of the uninvolved leg of the forward locomotion group. Single leg balance of the involved and uninvolved legs improved statistically significantly in both groups ($p < 0.05$). The differences in change between the two interventions were not statistically significantly different ($p > 0.05$) and the practical differences were small (ES ± 0.2). No statistically significant differences in the change in leg circumferences were observed between the two groups. Only the change in flexibility of the involved *soleus* was significantly different between the EXP and CON groups.

The results show that backward locomotion training result in greater improvements in aerobic fitness and equal or greater improvements in *quadriceps* and *hamstrings* muscle strength and power, compared to forward locomotion training. Backward locomotion as well as forward locomotion contributes to the recovery of knee injuries, however, the practical significance of backward locomotion is greater than for forward locomotion. The conclusion of this is that backward locomotion is a better alternative rehabilitation program for athletes as this will affect a quicker return to their sport.

OPSOMMING

Kniebeserings kom algemeen voor in die fisiek aktiewe bevolking en is dikwels so ernstig dat dit chirurgie vereis. Rehabilitasie-spesialiste is voortdurend op soek na die mees doeltreffende en koste-effektiewe alternatief vir behandeling om die atlete vinnig te laat terugkeer na hul sport. Die insluiting van agteruitbeweging in knie-rehabilitasieprogramme is al in die verlede voorgestel, aangesien dit beskou word as 'n veilige geslote-kinetiese-ketting oefening wat al geskik bevind is om *quadriceps* sterkte en krag, asook kardiorespiratoriese fiksheid te verbeter.

Die hoofdoel van die studie was om die effektiwiteit van agteruitbeweging-oefening in 'n knierehabilitasieprogram te bepaal.

Nege-en-dertig mans en vroue (tussen die ouderdom van 18 en 59 jaar) met kniepatologieë het vrywillig ingestem om aan die studie deel te neem en is lukraak verdeel in die eksperimentele groep (EXP, n = 20) en kontrole groep (CON, n = 19). Alle deelnemers het 24 sessies voltooi waarvan 20 – 30 minute kardiorespiratoriese oefeninge was. Dit het óf in die agteruitrigting (EXP), óf vorentoe-rigting (CON) plaasgevind. Aërobiese fiksheid, *quadriceps* en *hamstrings* sterkte en krag, eenbeenbalans, omtrekke van die onderste ledemaat, en soepelheid van die onderste ledemaat is gemeet, voor en na die rehabilitasieprogram.

Agteruitbeweging-oefening het 'n geringe verbetering in ventilatoriese draaipunt (VT) ($p = 0.07$) opgelewer wat grens aan 'n statisties betekenisvolle verbetering, asook 'n statisties betekenisvolle verbetering in piek kraguitset (PPO) ($p < 0.05$). Die VT en PPO van die agteruitbeweging groep het onderskeidelik verbeter met 9 en 14%, in vergelyking met 0 en 4% in die vorentoe-beweging groep. Beide groepe het statisties betekenisvolle verbeteringe in q*uadriceps* en *hamstrings* sterkte getoon, behalwe die *quadriceps* van die onbeseerde been van die vorentoe-beweging groep.

Soortgelyk daaraan het beide groepe statisties betekenisvolle verbeteringe in q*uadriceps* en *hamstrings* gemiddelde krag getoon, behalwe die *quadriceps* van die onbeseerde been van die vorentoe-beweging groep. Eenbeenbalans van die beseerde en onbeseerde bene het statisties betekenisvol verbeter in beide groepe ($p < 0.05$). Die verskil in verandering tussen die twee intervensies was nie statisties betekenisvol verskillend nie en die praktiese verskil was klein (ES ± 0.2). Geen statisties betekenisvolle verskille is waargeneem tussen die twee groepe in die verandering in beenomtrekke nie. Slegs die soepelheid van die beseerde *soleus* van die EXP groep het statisties betekenisvol verbeter tussen die twee groepe.

Die resultate toon dat agteruitbeweging-oefening tot groter verbetering gelei het in aërobiese fiksheid en gelyke of groter verbetering in *quadriceps* en *hamstrings* sterkte en krag, in vergelyking met vorentoe-beweging oefening. Agteruitbeweging-oefening sowel as vorentoe-beweging oefening dra by tot die herstel van kniebeserings, maar die praktiese beduidendheid van agteruitbeweging-oefening is groter as vorentoe-beweging oefening. Die gevolgtrekking van die studie is dat agteruitbeweging 'n beter alternatiewe rehabilitasieprogram vir atlete is, met 'n gevolglike vinniger terugkeer na hul sport.

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All the Glory to the Lord, our Saviour.

DEDICATION

I dedicate this dissertation to my late grandparents;
You were the ones that taught me that nobody
can take knowledge away from you.

LIST OF ABBREVIATIONS AND ACRONYMS

°	:	Degrees
$\bar{x}$	:	Mean
%	:	Percentage
ACL	:	Anterior cruciate ligament
ACSM	:	American College of Sports Medicine
APSI	:	anterior-posterior stability index
BIA	:	Bio-electrical Impedance Analysis
BMI	:	Body mass index
CKC	:	Closed kinetic chain
cm	:	Centimeter
CO_2	:	Carbon dioxide
CON	:	Control group
EMG	:	Electromyographic
ES	:	Effect size
EXP	:	Experimental group
GRF	:	Ground reaction force
HR	:	Heart rate
i.e.	:	For example
IMTP	:	Isokinetic muscle torque production
ISAK	:	International Society for the Advancement of Kinanthropometry
kg	:	Kilogram(s)
kHz	:	Kilo hertz
La	:	Blood lactate concentration
LCL	:	Lateral collateral ligament
MCL	:	Medial collateral ligament
MLSI	:	medial-lateral stability index
$ml.kg^{-1}.min^{-1}$	:	Milliliters per kilogram body weight per minute
mm	:	Millimeter
n	:	Sample size

N_2	:	Nitrogen
O_2	:	Oxygen
OKC	:	Open kinetic chain
OSI	:	Overall stability index
p	:	Probability
PCL	:	Posterior cruciate ligament
PFPS	:	Patellofemoral pain syndrome
PPO	:	Peak power output
r	:	Reliability
RER	:	Respiratory exchange ratio
RPE	:	Rate of perceived exertion
ROM	:	Range of motion
rpm	:	Revolutions per minute
s^{-1}	:	Per second
SD	:	Standard deviation
SEM	:	Standard error of the mean
SLR	:	Straight leg raise
µA	:	Micro ampere
VE	:	Minute ventilation
VO_2	:	Oxygen consumption
VO_{2peak}	:	Peak aerobic capacity
VT	:	Ventilatory threshold

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CHAPTER ONE
INTRODUCTION

The knee is an important part of the kinetic chain. It is affected by the forces transmitted from the foot, ankle and lower leg and in turn, needs to transmit those forces to the thigh and hip. The abnormal forces that cannot be transmitted to the proximal segments must be absorbed by the knee joint. The inability to dissipate the forces would result in a breakdown of the system, therefore making the knee joint highly susceptible to injury. To avoid knee injuries, athletes need to be in a highly conditioned state, especially the muscles surrounding the knee since they help stabilize the knee joint (Prentice, 2006:609,625). A healthy knee is characterized as stable, having good muscular strength, and allowing normal gait and functional activities (Shelbourne and Klotz, 2006).

Knee injuries are common among the physically active population. Certain injuries are more prevalent than others, such as ligament injuries and meniscus lesions which account for up to 44.8% of all knee injuries. Majewski *et al*. (2006) documented that up to 80% of patients with a ligament or meniscus injury underwent surgery. Most acute knee injuries occur while engaged in high risk sports, such as soccer (35%) and skiing (26%) (Majewski *et al*., 2006). Bradley *et al*. (2008) noted that 54% of football players had a history of sustaining a knee injury while playing football. Chronic overuse injuries such as patellar tendinopathy occur in up to 14% of elite athletes (Cook *et al*., 1997) and are more prevalent in basketball, football and athletics (Crossley *et al*., 2007).

Following a knee injury or knee surgery, a period of inactivity follows which results in a generalized loss of fitness, but specifically muscle strength, endurance, and coordination. Therefore, rehabilitation should start immediately after injury and the athlete should continue to exercise the entire body where possible. Restoring muscular strength is one of the most essential factors in the rehabilitation program. Strengthening of all musculature surrounding the knee joint is important to regain knee stability. Since a loss of *quadriceps* strength is associated with most knee injuries, the main focus should be on *quadriceps* strengthening. During the early stages of rehabilitation, isometric contractions are performed when the joint is immobilized. Atrophy of the thigh can therefore be limited while the joint is protected from full range of motion (ROM) activities. Progressive resistive exercises will follow isometric exercises and uses isotonic (concentric and eccentric) contractions (Tagesson *et al.*, 2008; Shaw *et al.*, 2005; Liu-Ambrose *et al.*, 2003; Lewek *et al.*, 2004), where force is generated while the muscle length is changing. Isokinetic exercise is usually incorporated later in the rehabilitation program where a fixed speed is used through a set range of motion (Sekir *et al.*, 2010; Mikkelsen *et al.*, 2000). Neuromuscular and proprioceptive training should also form part of the rehabilitation program (Liu-Ambrose *et al.*, 2003).

Depending on the type and severity of injury, rehabilitation programs can vary from 3 weeks to 6 months or longer (Tagesson *et al.*, 2008; Prentice, 2006:626-647; Mikkelsen *et al.*, 2000). However, the focus has shifted to accelerated rehabilitation programs that could result in an earlier return to sport. Most of these programs are employed following anterior cruciate ligament (ACL) reconstruction. Several authors have investigated an aggressive approach to rehabilitation programs which resulted in similar anterior knee laxity scores than conservative rehabilitation programs but allowed a quicker return to sport (Shelbourne and Klotz, 2006; Beynnon *et al.*, 2005; Aglietti *et al.*, 2004; Howell and Taylor, 1996; Glasgow *et al.*, 1993). Glasgow *et al.* (1993) documented that an early return to sport, two to six months postoperatively, does not predispose patients to re-injury and resulted in similar results compared to a seven to 14 months postoperative return to sport. Howell and Taylor (1996) allowed return to running at eight to 10 weeks postoperatively and return to sport at 16 weeks. Agglietti *et al.* (2004) allowed full weight bearing three to five weeks post operatively and return to running at three months. Return to competitive sport was allowed at six months. Beynnon *et al.* (2005) allowed full weight bearing two weeks postoperatively and return to sport at 24 weeks. There was no difference in anterior knee laxity compared to a more conservative program that only allowed full weight-bearing at week four and return to sport at week 32. Shelbourne and Klotz (2006) documented the use of a preoperative rehabilitation program that started at the time of injury and continued until surgery. The program included aggressive swelling reduction, hyperextension exercises to regain full range of motion, gait training with good leg control, and mental preparation. Postoperatively rehabilitation started on the day of surgery and allowed full weight-bearing two to four weeks postoperatively.

Although accelerated programs do result in a faster return to sport, additional cardiorespiratory training is necessary to obtain pre-injury fitness levels. It has been shown that for every week of detraining, it takes four weeks to regain endurance fitness (Powers and Howley, 2009:271). Therefore, not only does the injured athlete need to engage in dynamic, aerobic training as soon as possible after injury or operation, he or she also needs a training program that will give the best results in the shortest possible time.

Backward locomotion training has been shown to increase cardiorespiratory fitness more than forward locomotion (Terblanche *et al.*, 2004), since the energy expenditure during backward walking and running is higher when compared to forward walking and running at a similar speed (Terblanche *et al.*, 2004; Terblanche *et al.*, 2003; Minetti and Ardigò, 2001; Williford *et al.*, 1998; Chaloupka *et al.*, 1997; Myatt *et al.*, 1995; Flynn *et al.*, 1994). Backward locomotion is considered a safe closed kinetic chain exercise since the compressive forces at the patellofemoral joint are reduced (Flynn and Soutas-Little, 1995) and overstretching of the ACL is prevented (Mackie and Dean, 1984). Backward locomotion training has been found to increase *quadriceps* strength (Threkeld *et al.,* 1989) and power (Mackie and Dean, 1984). Therefore an athlete with a knee injury could rehabilitate using backward locomotion at an aerobic intensity sufficient enough to maintain or increase cardiorespiratory fitness, while strengthening the *quadriceps*.

CHAPTER TWO
KNEE INJURIES

A. INTRODUCTION

The knee is one of the most traumatized joints in the physically active population (Bradley *et al.*, 2008; Bathgate *et al.*, 2002). It has to provide stability during weight-bearing and simultaneously mobility in locomotion. Being the link between the distal and proximal part of the lower leg, it is subject to tremendous loading and forces which makes it susceptible to injury. This is especially prevalent during participation in contact sports when abnormal forces cannot be distributed evenly and result in acute traumatic injuries and chronic overuse injuries (Prentice, 2006:601; Woo *et al.*, 1999). A vast number of types of knee injuries occur of which some are unique to children and adolescents, whilst others are more prevalent in specific types of sport.

B. LIGAMENT INJURIES

The main stabilizing ligaments of the knee include the collateral ligaments and cruciate ligaments. Ligamentous injuries account for up to 30% of all knee injuries sustained in sport (Majewski *et al.*, 2006). A ligament injury may occur in isolation, but are most often associated with injuries to other ligaments or knee structures. The severity of ligament injuries may vary substantially, therefore it is classified as a grade I, II or III sprain.

1. Medial collateral ligament injury

The medial collateral ligament (MCL) reinforces the medial joint capsule and is the main stabilizer against valgus and external rotating forces (Prentice, 2006:605). The MCL is the most common injured ligament of the knee which usually results from a valgus force applied to the knee, or a combination of valgus and external rotating forces. MCL injuries occurring near the femoral origin are associated with stiffness, and loss of range of motion (ROM), whereas injuries close to the tibial attachment tend to be more lax and results in easier return of ROM (De Carlo and Armstrong, 2010).

A conservative approach for the treatment of grade I and II sprains are sufficient, but controversy exists regarding the treatment of complete ruptures of the MCL (grade III sprains). Palmer (1938) and O'Donoghue (1950) prescribed surgical repair for all grade III MCL sprains. However, Ellsaser *et al*. (1974) found a 93% success rate for a nonoperative treatment which involved crutch walking, but no bracing. The recovery time lasted three to eight weeks. Indelicato (1983) also found the nonoperative treatment to be sufficient for the healing of the MCL, as well as the recovery period to be significantly shorter. This nonoperative treatment involved six weeks in a cast brace, followed by crutch walking. Sandberg *et al*. (1987) found the nonoperative treatment of the completely ruptured MCL to give similar outcomes as operative treatment. Their nonoperative treatment involved an immobilization period of six weeks in a plaster cast, followed by full weight-bearing. Subsequent to these findings, Ballmer and Jakob (1988) found that immediate mobilization following a complete rupture of the MCL resulted in faster return to activity compared to plaster immobilization.

Since MCL injuries are regularly found with ACL ruptures, a number of studies have investigated whether complete ruptures of the MCL should be surgically repaired in combination with ACL reconstruction. Halinen *et al*. (2006) found that the nonoperative treatment of grade III MCL injuries led to similar results to those obtained with operative treatment; however, Halinen *et al*. (2009) found that the nonoperative treatment of the MCL resulted in faster recovery of ROM, as well as greater knee extension power.

2. Lateral collateral ligament injury

The lateral collateral ligament (LCL) stabilizes the knee laterally during knee extension (Prentice, 2006:605). The mechanism of LCL injury is usually hyperextension of the knee in combination with varus loading to the medial aspect of the knee. Isolated LCL injuries generally result in a disruption at the fibular head either with or without an avulsion fracture which is managed nonoperatively (De Carlo and Armstrong, 2010). Isolated injuries are rare due to the anatomical structures at the lateral aspect of the knee which protect the LCL from overstretching. The structures most often injured concomitant with an LCL injury includes the cruciate ligaments, the lateral capsule and the popliteus (Stannard *et al.*, 2005; Covey, 2001).

3. Anterior cruciate ligament injury

The anterior cruciate ligament (ACL) is considered the principal stabilizer against anterior tibial translation. It also prevents posterior movement of the femur during weight-bearing and acts as a secondary stabilizer to restrain varus and valgus stresses on the knee (Prentice, 2006:604; Karmani and Ember, 2003). Various mechanisms of injury exist of which the most common comprise a noncontact valgus force to the knee in conjunction with external rotation when the foot is planted on the ground. This mechanism usually involves injuries to the ACL, MCL and knee capsule. A similar movement pattern, but with internal rotation, mostly results in injury to the ACL, LCL and posterolateral capsule, whereas knee hyperextension with internal rotation involves an isolated ACL injury. According to Majewski *et al.* (2006), most ACL injuries occurred while engaged in soccer and skiing.

A number of treatment options exist for ACL injuries. A more conservative approach may be appropriate for individuals not involved in high-risk activities, but if instability persists, reconstructive surgery should be considered. Several authors have described the progressive deterioration of untreated ACL injuries, leading to stretching of the secondary restraints, meniscal tears and post-traumatic osteoarthritis (Gillquist and Messener, 1999). Therefore, most patients prefer an aggressive approach since the knee will remain instable and continue to “give way” during weight-bearing (De Carlo and Armstrong, 2010). The ACL reconstruction is performed by means of autografts, allografts or synthetic substitutes for the injured ligament. Various autologous tissues are used as ACL replacements, including the patellar tendon, semitendinosus tendon, gracilis tendon and rectus femoris tendon (Fu *et al*., 1999).

Controversy exists regarding the timing of the reconstruction following the acute injury. Early reconstruction has been proposed to have a higher rate of postoperative complications since the patient still have a quadriceps deficit in muscle strength (Petersen and Laprell, 1999). However, Raviraj *et al*. (2009) found similar outcomes regardless of timing of the reconstruction, as long as it is performed within the first six weeks following injury.

4. Posterior cruciate ligament injury

The posterior cruciate ligament (PCL) prevents hyperextension of the knee and prevents the femur from sliding forward during weight-bearing (Prentice, 2006:605). Isolated PCL injuries are relatively uncommon since most PCL injuries are associated with multiple ligament injuries or knee dislocation. The mechanisms of injury include a direct blow to the proximal tibia, a fall on the knee with the foot in a plantar-flexed position, or with hyperflexion of the knee. Hyperextension or combined rotational forces at the knee could also cause a PCL injury, but are less common.

PCL injuries may appear less severe than ACL injuries and activity could be resumed earlier than after an ACL injury. Unfortunately, injury to the PCL could result in a change in the kinematics of the knee, with subsequent degenerative changes in the patellofemoral joint and medial compartment of the knee (De Carlo and Armstrong, 2010; Heinzelmann and Barrett, 2009). Nonetheless, it still remains controversial whether operative treatment is necessary after PCL injury since stability of the knee is reserved in many patients and they remain symptom free (Dandy and Pusey, 1998).

As stated previously, isolated ligament injuries are rare. 90% of all knee ligament injuries include an ACL, MCL or a combination of ACL-MCL injuries (Majewski *et al.*, 2006; Miyasaka *et al.*, 1991). Controversy exists regarding the treatment of combined injuries, but a good outcome has been found with reconstruction of the ACL and conservative treatment of the MCL (Halinen *et al.*, 2009; Halinen *et al.*, 2006). Ligament injuries may also disrupt mechanoreceptors which may impair proprioceptive capabilities (Jerosch and Prymka, 1996). Regardless of the treatment option chosen, the goals of treatment should include restoration of knee stability and successful return to activity (Shelbourne, 1996).

C. MENISCAL INJURIES

The menisci are two C-shaped semilunar fibrocartilages positioned medially and laterally on the tibial tuberosity which function to provide lubrication and nutrition to the joint, shock absorption of the impact forces and act as a secondary stabilizer together with the knee ligaments. The menisci are most effective when the ligaments are intact. The medial meniscus is attached to the MCL which makes it more susceptible to injury than the lateral meniscus since mobility is reduced. The ratio of medial to lateral meniscus injuries is 3:1 (Majewski *et al.*, 2006). The medial meniscus is susceptible to injury during external rotation of the lower leg, whilst the lateral meniscus is vulnerable during internal rotation. The most common mechanism of injury comprises a twist on a slightly bent leg. Acute meniscal injuries usually occur in conjunction with ligament tears (De Carlo and Armstrong, 2010; McDermott and Amis, 2006). Meniscal tears may also result from degenerated meniscal cartilage which merely fails under simple load conditions. Tears can be longitudinal, oblique or transverse, of which the most common is a longitudinal tear of the anterior or posterior horn of the meniscus, called a “bucket handle” tear (Shakespeare and Rigby, 1983). The location of the meniscal tear in relationship to the joint capsule determines its healing capabilities, since proximity to the vascular capsule is required. The region of the meniscus adjacent to the vascular capsule is called the red zone, whereas the avascular, central area of the meniscus is called the white zone (Bernstein, 2010). Preservation of meniscal tissue is important to protect joint surfaces and prevent degeneration of the knee joint, and therefore an aggressive approach to meniscal repair exists. However, in some cases the torn meniscus is not deemed repairable in which case a meniscectomy is required where all or part of the torn meniscus is removed (Logan *et al.*, 2009; McDermott and Amis, 2006).

D. OSTEOARTHRITIS

Osteoarthritis is a degenerative joint disease that commonly occurs at the femorotibial and patellofemoral joints and is associated with articular cartilage damage. Any athlete that had a major knee injury has an increased risk to develop knee osteoarthritis later in life (Crema *et al.*, 2008). Messner and Maletius (1999) found that 64% of patients with a history of a partial ACL rupture had knee osteoarthritis 20 years after injury. However, this number increases to 87% in patients following a complete rupture of the ACL. The history of a meniscectomy increases the degree of severity of osteoarthritis. Lohmander *et al.* (2004) documented a 50% cartilage loss 9 years after a meniscus tear. These documented losses could result from gait modifications and degenerative changes that occurred (Bulgheroni *et al.*, 2007). Progression of the syndrome results in further degeneration of the joint, with consequential valgus or varus deformity. A varus deformity would most likely occur and could lead to abnormal gait mechanics and alteration of the knee extensor mechanism. Patients will usually present with quadriceps atrophy and weakness which is strongly associated with knee pain and may result in muscle inhibition due to pain, as well as limited range of motion and joint stiffness (O'Reilly *et al.*, 1998).

E. PATELLAR INJURIES

1. Patellar tendinopathy

Patellar tendinopathy are defined as overuse conditions of the patellar tendon which result in anterior knee pain and tenderness of the patellar tendon.

Patellar tendinopathy occurs in up to 14% of elite athletes depending on the type of sport (Lian *et al.*, 2005). Individuals participating particularly in sports involving rapid movements such as acceleration and deceleration, jumping and landing, cutting moves and kicking are more vulnerable to this type of injury. According to Cook *et al.* (1997), the average age of onset is 23.8 years, but in more than 50% of individuals the age of onset is before 20 years of age. Basketball, football and athletics are high risk sports for patellar tendinopathy. The average time of interference from sport is four weeks; however, it could take up to 12 months to recover. Recurrence of symptoms is common and repeated overuse may result in chronic inflammation that will eventually lead to tendon degeneration (Crossley *et al.*, 2007). Patellar tendinopathy usually responds well to conservative treatment, but a continuation of symptoms necessitates surgical treatment (Griffiths and Selesnick, 1997).

2. Patellofemoral pain syndrome

Patellofemoral pain syndrome (PFPS) is commonly caused by abnormal patellar tracking or patellar malalignment where the patella is unable to stay within the confines of the trochlea from 20 degrees (˚) of knee flexion (McConnell, 2007). Imbalances between the vastus medialis and vastus lateralis forces cause abnormal tracking of the patella, resulting in reduced contact areas and increased stress (Besier *et al.*, 2009). Patella instability may be an acute or recurrent injury. An acute injury usually results from rotation of the femur internally and the lower leg rotates externally whilst the quadriceps contract, creating a forced knee valgus resulting in displacement of the patella laterally. Recurrent injury typically results in patella subluxation and causes stretching of the medial capsule. The patella typically dislocates or subluxates laterally (De Carlo and Armstrong, 2010). Patella dislocations account for less than 5% of knee injuries sustained in the athletic population (Majewski *et al.*, 2006).

F. TOTAL KNEE ARTHROPLASTY

Total knee arthroplasty is indicated in individuals with a loss of knee function due to arthritis or injury where knee pain becomes unbearable during normal activities and conservative treatments are ineffective. Commonly known as knee replacement, knee arthroplasty involves the replacement of diseased or damaged joint surfaces of the knee joint with plastic and metal components. Reduced quadriceps strength is reported in individuals prior to total knee arthroplasty which may result from decreased voluntary activation. After total knee arthroplasty, failure of voluntary muscle activation occurs with a loss in quadriceps strength and a decrease in the quadriceps cross-sectional area (Mizner *et al.*, 2003; Mizner *et al.*, 2005).

G. CONCLUSION

Knee joint injury inevitably leads to a loss of ROM, knee stability, muscular strength and neuromuscular control. Treatment modalities, whether surgical or conservative, should focus on restoring full knee function whilst the rehabilitation goal should be a successful return to activity in a fully conditioned state.

CHAPTER THREE
KNEE REHABILITATION

A. INTRODUCTION

Rehabilitation is the process of restoring normal function following injury by providing evidence-based interventions. An effective rehabilitation program takes into consideration the anatomy of the involved structures, the biomechanics of the knee joint and the stage of healing, and is based on individual progress. The goal of rehabilitation should be successful return to activity by reducing pain and swelling, restoring ROM, improving strength and endurance, and enhancing proprioception and dynamic stability (De Carlo and Armstrong, 2010).

Knee joint rehabilitation is complex and changes constantly due to rapid advances in technology and surgical techniques, and increasing understanding of the knee joint. Rehabilitation techniques may vary depending on the type of injury as well as the severity of the injury. Specific rehabilitation programs exist for most knee injuries (Prentice, 2006:626-647). The time spent in each phase may depend on the type of injury and individual progress, but the rehabilitation of most injuries will involve three phases: Phase I which usually entails control of inflammation, modification of activities and increasing ROM; phase II includes restoring and maintaining full ROM, following a normal gait pattern, muscle strengthening, cardiorespiratory conditioning and proprioception training; and phase III consists of sport-specific functional activities.

B. A TYPICAL KNEE REHABILITATION PROGRAM

The following characteristics outline a typical rehabilitation program: immobilization, mobilization and range of motion, weight-bearing, muscular strengthening, proprioception training and cardiorespiratory fitness.

1. Immobilization

Immobilization of the knee joint is advised after an acute knee injury or surgery for the healing process to occur. Braces are usually employed to provide a stable environment for proper healing and tightening of the injured complex and are considered necessary after surgery to protect the joint from excessive strain in the early postoperative period (Risberg *et al*., 1999). A six weeks brace protection period has been suggested following grade III ligament injuries or surgery to the knee (Halinen *et al*., 2009; Halinen *et al*., 2006; Petersen and Laprell, 1999; Risberg *et al*., 1999). However, the adverse effects of immobilization are well documented. Complete removal of load through bracing or casting alters the morphologic, biochemical and biomechanical characteristics of the knee joint which results in a reduced energy-absorbing capacity of the knee complex and a reduced range of motion (Thomopoulos *et al*., 2008; Akeson et al., 1987; Noyes, 1977). Bracing also produces significantly more *quadriceps* atrophy and decreased *quadriceps* muscle strength than non-bracing. Ballmer and Jakob (1988) found that immediate mobilization following isolated complete ruptures of the MCL resulted in a faster return to activity compared to plaster immobilization. Risberg *et al*. (1999) found that a six to eight week bracing period following ACL reconstruction produced significantly more thigh atrophy early postoperatively and that prolonged bracing for one to two years produced a significant decrease in *quadriceps* muscle strength. There are no differences between bracing and non-bracing regarding knee joint laxity.

2. Mobilization and range of motion

A period of immobilization after knee injury or surgery can result in arthrofibrosis which inhibits the ROM at the knee. Mobilization is essential to reduce arthrofibrosis and restore normal ROM. Depending on the type of knee injury, stretching of the *quadriceps*, *hamstrings* and *gastrocnemius* muscles should be incorporated and manual therapy utilized to decrease joint stiffness and improve ROM. Restoration of ROM should progress non-painful.

Regaining full ROM, especially full extension, is critical in promoting a normal gait and improving *quadriceps* function. Extension exercises should be incorporated to minimize the potential problem of contractures. Maintaining full knee extension after surgery has been noted to be critical since a lack thereof often results in anterior knee pain, *quadriceps* weakness, and a poorly functioning knee (Beynnon *et al*., 2005).

3. Weight-bearing

Weight-bearing is essential to provide nourishment to articular cartilage and subchondral bone, as well as to regain proper gait mechanics. Depending on the severity of the injury, crutches can be used during partial weight-bearing and then progress to full weight-bearing as tolerated. Hydrotherapy is also effective to incorporate weight-bearing while unloading the knee. Normal gait training should begin as early as possible and should include activities such as heel-toe walking, backward walking and high knee actions which are important to regain *quadriceps* tone and leg control (Halinen *et al*., 2009). Early weight-bearing has been encouraged in an accelerated rehabilitation program as early as two weeks postoperatively and step-ups at six weeks postoperatively, compared to conservative treatment protocols which only allow it after four weeks and 12 weeks, respectively. Beynnon *et al*. (2005) found that the early weight-bearing program resulted in an early return to sport at 24 weeks postoperatively, compared to a return to sport at 32 weeks for the more conservative approach.

4. Muscular strengthening

A muscle strengthening program for the entire lower extremity is necessary following knee injury since imbalances in muscle strength may have contributed to the initial knee injury. However, most knee injuries result in strength losses of the *quadriceps*. The *quadriceps* functions as a shock absorber to dissipate forces from impact. If the *quadriceps* action is inhibited, larger forces are transferred to the knee joint and the passive restraints which compromise the knee joint stability (Palmieri-Smith *et al*., 2007; Grimby *et al*., 1980). Therefore *quadriceps* strength is considered a significant determinant of functional ability after knee injuries and *quadriceps* strengthening is emphasized during rehabilitation programs (Liu-Ambrose *et al.*, 2003; Lewek *et al.*, 2002).

Hurley and Scott (1998) found *quadriceps* strength to improve significantly in patients with knee osteoarthritis following 6 months of self-administered rehabilitation. The exercises used in this program consisted of isometric *quadriceps* contractions, concentric and eccentric *quadriceps* contractions with the use of a therapeutic resistance band, as well as functional exercises such as sit-to-stand and step-ups. Shaw *et al.* (2005) showed that early *quadriceps* strengthening, straight leg raises and isometric *quadriceps* contractions, throughout the first two postoperative weeks increased the recovery of knee ROM and stability.

Early *hamstrings* strengthening following knee surgery is a vital component of the rehabilitation program since it improves functional ability of patients. Sekir *et al.* (2010) found statistically significantly greater improvements in isometric strength of the *hamstrings* at 30˚ of knee flexion, as well as in the isokinetic strength of the *hamstrings* following daily isokinetic *hamstrings* strengthening three weeks after ACL reconstruction, compared to nine weeks after ACL reconstruction. Isometric strength of the *hamstrings* at 30˚ was statistically significantly greater at the first and second month postoperatively, and the isokinetic strength of the *hamstrings* at two, three, four and 12 months postoperatively. Furthermore, walking, stair-climbing and squatting received better scores following the early *hamstrings* strengthening (three weeks postoperatively) compared to the late *hamstrings* strengthening (nine weeks postoperatively).

Most rehabilitation programs start with isometric exercises and increase to progressive resistive exercises as tolerated by the individual. Isometric contraction of the *quadriceps* can be started as early as the first postoperative day or immediately after an acute injury (Risberg *et al.*, 1999). Straight leg raises (extension, flexion, abduction and adduction of the hip) are commonly utilized to strengthen the knee musculature since no knee joint movement occurs (Barber-Westin *et al.*, 1999).

Closed kinetic chain (CKC) exercises have been recommended for rehabilitation since it is considered safer than open kinetic chain (OKC) exercises (Halinen *et al.*, 2009). During CKC exercises, the distal segment of the limb is fixed and usually involves co-contraction of the *quadriceps* and *hamstrings*. CKC exercises focus on functional strengthening and are important to restore and enhance proprioception and neuromuscular control. During OKC exercises, weight is applied to the distal segment of the limb which is free to move and is utilized for isolated *quadriceps* muscle strengthening but should be used cautiously due to high joint reaction forces across the patellofemoral joint. However, it has been suggested that OKC exercises should be used in conjunction with CKC exercises, since CKC exercises alone results in problems regaining sufficient *quadriceps* muscle strength (De Carlo and Armstrong, 2010). Mikkelsen *et al.* (2000) has recommended the use of CKC exercises for the first six weeks after surgery, thereafter OKC exercises could be added. Andersen *et al.* (2006) examined the neuromuscular activation of conventional therapeutic exercises compared to resistance exercises and observed the highest level of neuromuscular activation during OKC resistance exercises. OKC exercises induce sufficient levels of neuromuscular activation to stimulate muscle growth and strength. Heijne and Werner (2007) found no differences in *quadriceps* strength following early (four weeks postoperatively) or late (12 weeks postoperatively) start of OKC exercises. Early start of OKC exercises after *hamstring* ACL reconstruction resulted in significantly increased anterior knee laxity. Tagesson *et al.* (2008) assessed the difference between a four month rehabilitation program supplemented with either CKC or OKC exercises as part of an ACL rehabilitation program and found the isokinetic *quadriceps* strength to be significantly greater in the OKC group compared to the CKC group.

5. Proprioception training

Maintaining postural balance involves the integration of multiple sensory, motor, and biomechanical components and necessitates coordination of the ankle, knee and hip joints along the kinetic chain. The components of balance include the musculoskeletal system, sensory organization, motor coordination, environmental adaptation, and perception of orientation (Horak, 1991). If one of these components is affected, an individual's ability to maintain equilibrium would be compromised. The musculoskeletal system and sensory system are usually affected following a knee injury or surgery. The sensory system receives input through sensory end-organs in the vestibular apparatus in the muscle spindles and Golgi tendon organs which sense the muscle and tendon position. The sensory input from touch and joint proprioception allows the muscles to make constant, automatic adjustments to maintain balance (Proske, 2006). Proprioceptive capabilities and joint position sense are impaired after knee joint injuries such as ACL or meniscus tears, and osteoarthritic knees (Carter *et al.*, 1997; Jerosch and Prymka, 1996). Proprioceptive training is important to improve neural activation, coordination and postural control. Neural activation is involved in the early stages of strength gains, whilst neuromuscular control is essential for knee joint stability.

Liu-Ambrose *et al.* (2003) found a 12-week proprioceptive training program that incorporated balance and agility exercises improved peak torque time following ACL reconstruction. Hurley and Scott (1998) found that six months proprioceptive training such as unilateral stance and balance boards improved knee joint position sense in patients with knee osteoarthritis. Ageberg *et al.* (2001) investigated the long term effects (12 months) of supervised neuromuscular training compared to non-supervised neuromuscular training on acute non-operated ACL injuries and found the functional performance, measured with the one-leg hop test, was restored by the supervised neuromuscular training but not with the non-supervised neuromuscular training.

6. Cardiorespiratory fitness training

The effects of detraining on cardiorespiratory fitness are well documented in the literature (Powers and Howley, 2009:271); therefore low impact cardiorespiratory exercises such as cycling and elliptical training are included from the early stages of the rehabilitation program (Risberg *et al.*, 1999). However, more functional cardiorespiratory exercises such as running and agility drills are only admitted in stage three of the rehabilitation program. Olivier *et al.* (2009) found that a six week single leg cycling program following ACL reconstruction significantly improved endurance performance and cardiorespiratory fitness compared to postoperative walking exercises.

C. CONCLUSION

As stated previously, the goal of rehabilitation should be successful return to activity in a fully conditioned state. Several techniques have been proposed to hasten the recovery process and allow for a quicker return to activity. Beynnon *et al.* (2005) and Halinen *et al.* (2006) found that accelerated rehabilitation programs permitting early weight-bearing combined with early use of the *quadriceps* lead to restoration of ROM and appear to have a similar effect on anterior knee laxity as programs that delay weight-bearing and use of *quadriceps*. Such programs with immediate full weight-bearing are also possible without affecting the healing process. However, a significant problem with knee rehabilitation programs is that athletes need several additional weeks of fitness training before they can start with sport again. Therefore rehabilitation specialists are constantly seeking alternative rehabilitation techniques which allow for quicker return to sport.

CHAPTER FOUR
BACKWARD LOCOMOTION

A. INTRODUCTION

The importance of exercise in the healing of soft tissue is well recognized in the literature (Buckwalter and Grodzinsky, 1999; Burroughs and Dahners, 1990). The focus of rehabilitative exercise gradually shifted from open kinetic chain exercises to closed kinetic chain exercises which are more effective, safe and functional. Walking, a closed kinetic chain (CKC) exercise, is widely used in lower limb rehabilitation programs since it permits early weight-bearing and mobilization which promotes the healing process. It has been suggested that backward walking may offer additional benefits beyond those experienced by forward walking (Terblanche *et al*., 2004; Terblanche *et al*., 2004; Flynn *et al*., 1993; Flynn *et al*., 1995; Flynn and Soutas-Little, 1993; Threkeld *et al*., 1989; Vilensky *et al*., 1987).

The difference in gait parameters and change in joint kinematics to produce backward locomotion will be discussed, as well as the muscle activation patterns, ground reaction forces and energy expenditure, and how these unique characteristics of backward locomotion may benefit knee rehabilitation.

B. GAIT PARAMETERS OF BACKWARD LOCOMOTION

A gait cycle during backward locomotion can be defined as toe-on of a limb to the subsequent toe-on of the same limb. This cycle duration during backward locomotion is shorter than forward locomotion at identical speeds mainly because of a shorter stride length (Grasso *et al.*, 1998; Duysens *et al.*, 1996; Vilensky *et al.*, 1987). Therefore, a higher stride frequency is needed to maintain the same speed as forward locomotion (Minetti and Ardigò, 2001; Arata, 1999; van Deursen *et al.*, 1998; Grasso *et al.*, 1998; Williford *et al.*, 1997; Flynn *et al.*, 1993; Devita and Stribling, 1991; Threkeld *et al.*, 1989;

Vilensky *et al.*, 1987). The shortened stride length could be attributed to the specific joint kinematics of backward locomotion which permits a smaller range of motion, but is also considered a protective strategy when stability is threatened, such as when walking backwards (Conrad *et al.*, 1983).

A gait cycle comprises primarily of a stance phase and swing phase. The stance phase is characterized by foot-contact with the ground and the swing phase by the foot moving through mid-air (Vilensky *et al.*, 1987).

1. Stance phase

The stance phase of backward locomotion starts with toe-on and ends with heel-off of the same leg. The absolute stance duration during backward locomotion is shorter than during forward locomotion (Threkeld *et al.*, 1989; Vilensky *et al.*, 1987). A number of studies have documented the duration spent in the stance phase. Although the magnitude of their results differed proportionately from each other, the stance phase generally extends over 60 to 70% of the total gait cycle (van Deursen *et al.*, 1998; Grasso *et al.*, 1998; Duysens *et al.*, 1996; Devita and Stribling, 1991; Threkeld *et al.*, 1989; Vilensky *et al.*, 1987). As backward locomotion velocity increases, the stance time decreases. Opposing these results, Arata (1999) documented greater stance duration in backward locomotion than forward locomotion, however, the participants' velocities were not indicated, and therefore comparisons cannot be made.

During the stance phase, there is a period of double support, where both feet are in contact with the ground. Vilensky *et al.* (1987) reported that the duration of double support is shorter in backward locomotion than forward locomotion.

2. Swing phase

The swing phase of backward locomotion starts at heel-off and ends with toe-on of the same leg. As with the stance phase, the absolute duration of the swing phase is shorter during backward locomotion, but still maintains a similar proportion of the total gait cycle in several studies (van Deursen *et al.*, 1998; Grasso *et al.*, 1998; Duysens *et al.*, 1996; Devita and Stribling, 1991; Threkeld *et al.*, 1989; Vilensky *et al.*, 1987).

C. KINEMATICS OF BACKWARD LOCOMOTION

The kinematics of backward locomotion is unique. During backward locomotion, the toes contact the ground first and the heel is lifted off the ground last (Grasso *et al.*, 1998; Vilensky *et al.*, 1987). This differs from forward locomotion where stance begins with heel-strike (initial ground contact) and ends with toe-off. It would easily be expected that any kinematic parameter of backward locomotion could be determined from the reversal of data from forward locomotion (Winter and Pluck, 1989). However, due to anatomical and functional asymmetry of the lower limb along the anteroposterior axis, angular (extension-flexion) movements of the lower limb during backward locomotion differ from forward locomotion (Grasso *et al.*, 1998; Vilensky *et al.*, 1987, Kramer and Reid, 1981).

1. The ankle joint

At initial contact (toe-on) of backward locomotion the ankle is in sharp dorsiflexion and then gradually plantarflexes through the remainder of the stance phase to a plantarflexed position at heel-off (Cipriani *et al.*, 1995; Devita and Stribling, 1991; Vilensky *et al.*, 1987). When ground contact takes place, weight acceptance occurs at the anterior aspect of the foot. No heel strike occurs during the initial loading of the lower extremity (van Deursen *et al.*, 1998; Threkeld *et al.*, 1989). The maximum ankle dorsiflexion is noticeably greater in backward locomotion than during forward locomotion and may result from yielding under the body weight transferred to the foot. The plantarflexed position at heel-off is significantly smaller than during forward locomotion. This plantarflexed position of the ankle is maintained during the initiation of the swing phase and during midswing until it dorsiflexes in preparation for the subsequent toe-on. Although the maximum ankle dorsiflexion angle is greater in backward locomotion, the plantarflexion angle is significantly smaller, resulting in a smaller range of ankle movement in backward locomotion compared to forward locomotion (van Deursen *et al.*, 1998; Devita and Stribling, 1991; Vilensky *et al.*, 1987).

2. The knee joint

The knee initially extends during toe-on in backward locomotion. It flexes almost monotonically during the stance phase and extends again with heel-off. The fully extended limb is used as support to propel the body backwards. The knee only start to flex after the heel is lifted from the ground and remains flexed during most of the swing phase. Knee flexion during the swing phase of backward locomotion tends to be less than during forward locomotion (Grasso *et al.*, 1998; Devita and Stribling, 1991; Vilensky *et al.*, 1987). During stance, more flexion occurs in backward locomotion than forward locomotion (Devita and Stribling, 1991; Vilensky *et al.*, 1987). The range of knee motion is less during backward locomotion and could be as a result of the limited knee flexion that occurs during the swing phase (Devita and Stribling, 1991; Vilensky *et al.*, 1987; Bates *et al.*, 1986).

3. The hip joint

The hip is extended during toe-on and flexes during the remainder of the stance phase. During the first part of the swing phase, the hip is in flexion and only starts to extend in preparation for weight acceptance of the subsequent toe-on (Vilensky *et al.*, 1987). The hip flexion prior to and during stance is necessary to propel the body backwards (Devita and Stribling, 1991). Less hip extension occurs in backward locomotion which could be the result of the shorter stride length (Vilensky *et al.*, 1987). Only minimal hip extension beyond the neutral position is present at initial contact of the stance phase (van Deursen *et al.*, 1998). The reduced hip extension leads to a smaller range of motion in the hip (van Deursen *et al.*, 1998; Devita and Stribling, 1991; Vilensky *et al.*, 1987; Bates *et al.*, 1986).

The range of motions in the ankle, knee and hip joints are less during backward locomotion which may cause the shorter stride length. The toe-on position at initial contact results in a more gradual loading of the lower extremity since no heel strike occurs. The knee is more flexed during the stance phase in backward locomotion, resulting in longer isometric contraction of the *quadriceps*.

D. MUSCLE ACTIVATION DURING BACKWARD LOCOMOTION

As stated earlier, the ankle, knee and hip joints are not structural mirror images along the anteroposterior axis of the joints. Although Winter and Pluck (1989) stated that the muscle activation patterns of forward locomotion could be reversed to produce backward locomotion, Thornstensson (1986) and Devita and Stribling (1991) found that the functional demands on the lower limb musculature during backward locomotion differ from forward locomotion. Grasso *et al.* (1998) also stated that even though the kinematics of backward locomotion are correlated to forward locomotion, the muscle activity patterns of backward locomotion do not resemble those of forward locomotion. Overall, electromyographic (EMG) activity tends to be higher in backward locomotion, and could result from longer activation of muscles (Flynn and Soutas-Little, 1993).

1. The ankle

The ankle is in a dorsiflexed position at initial ground contact and gradually plantarflexes through the stance phase, to be in a plantarflexed position at heel-off. Since the toes contact the ground first during backward locomotion, the ankle muscles need to absorb the impact shock (Devita and Stribling, 1991). The ankle plantarflexors are coactivated when the foot impacts the ground (Grasso *et al.*, 1998). According to Cipriani *et al.* (1995) the ankle plantarflexors, especially the *gastrocnemius*, function as decelerators of the foot and ankle during initial ground contact of backward locomotion. During the stance phase, the plantarflexors are continually activated to support the ankle (Thornstensson, 1986). The push-off from the stance phase to the swing phase occurs from the heel with the ankle in plantarflexion. The hip and knee extensors are mainly responsible for this heel-off action; consequently the powerful ankle plantarflexors play a secondary role (Grasso *et al.*, 1998; Devita and Stribling, 1991; Vilensky *et al.*, 1987). Van Deursen *et al.* (1998) suggested that the ankle dosiflexors might even mediate the push-off by using the calcaneus as a lever.

According to EMG studies, the *gastrocnemius*, an ankle plantarflexor, is activated at initial ground contact, and the *tibialis anterior*, a dorsiflexor, activated later in the stance phase and during the swing phase to maintain ankle flexion (Grasso *et al.*, 1998; Duysens *et al.*, 1996; Flynn and Soutas-Little, 1993). A decrease in peak activation of these muscles is found in backward locomotion (van Deursen *et al.*, 1998) and the ankle moment and power during the stance phase is also smaller (Devita and Stribling, 1991). The decreased ankle plantarflexor moment could be as a result of the limited plantarflexion during the push-off phase. An eight-week backward locomotion training program showed no changes in the peak isokinetic torque of the ankle dorsiflexors or plantarflexors (Threkeld *et al.*, 1989). Van Deursen *et al.* (1998) noted no activity of the *gastrocnemius lateralis* during backward locomotion.

2. The knee

From an initial extension position before ground contact, the knee is flexed at ground contact and remains flexed throughout the stance phase until it extends to propel the body backward. During the early swing phase it flexes to shorten the limb, until midswing where it extends to lower the foot and prepare for ground contact. The muscle contractions are concentric to lower the foot at ground contact, to propel the body upward and backward during the push-off phase and to shorten the limb until midswing. During the stance phase, the knee flexes isometrically to support the body’s centre of mass. Only a small eccentric flexor moment occurs in the early swing phase to stop knee extension (Devita and Stribling, 1991).

Based on EMG studies of the knee extensors, the *rectus femoris*, *vastus lateralis* and *vastus medialis oblique* are activated at initial contact and remain activated during the main part of stance to support the limb. The *biceps femoris* and *semitendinosus* which are knee flexors, are only activated later in stance and function mostly to initiate knee flexion in the swing phase (van Deursen *et al.*, 1998; Grasso *et al.*, 1998; Duyssens *et al.*, 1996; Flynn and Soutas-Little, 1993). Peak activation of the *rectus femoris* and *vastus lateralis* occurs at initial ground contact, of which the *rectus femoris* activation is markedly higher in backward locomotion than forward locomotion. *Vastus lateralis* activity is relatively similar in backward and forward locomotion, but the *vastus lateralis* tends to be activated for a longer duration during backward locomotion. The *biceps femoris* shows a decrease in peak activation during backward locomotion (van Deursen *et al.*, 1998). Since a large power output is required for the backward thrust of the body, torque and power demands on the knee extensors are increased (Grasso *et al.*, 1998; Devita and Stribling, 1991).

A number of studies have investigated whether a backward locomotion training program affected *quadriceps* and *hamstrings* muscle strength or power. Mackie and Dean (1984) found significant increases after a three month training program in the power of the knee extensors and flexors, but the strength decreased in most of the subjects, which all had ligamentous instability. Threkeld *et al.* (1989) noted a significant increase in knee extensor (*quadriceps*) isokinetic muscular torque production, but no difference in knee flexor (*hamstrings*) torque production after an eight week program in male and female runners. Anderson *et al.* (1995) found borderline significant improvements in the eccentric *quadriceps* and concentric and eccentric *hamstrings* muscle strength in healthy, female runners following a six week training program, whereas Terblanche *et al.* (2004) found no improvement in isokinetic strength of the knee extensors and flexors in healthy women after a six week training program.

3. The hip

The hip follows a similar pattern than the knee from the swing to stance phase. The hip initially extends for the foot to contact the ground, but is flexed at ground contact and remains flexed throughout the stance phase and during the first part of the swing until it reaches midswing where it starts extending to prepare for weight acceptance (Grasso *et al.*, 1998). The hip flexion prior to and during the stance phase is produced by a hip flexor moment acting concentrically at a low power level, which is needed to propel the body backward (Devita and Stribling, 1991). However, the main backward thrust from the push-off is produced by the hip extensors. The hip joint functions almost entirely concentrically during the stance phase. During the swing, the hip extensors and flexors act eccentrically to stop forward rotation, and extension of the limb (Grasso *et al.*, 1998). According to EMG studies, the *rectus femoris*, a hip flexor, is activated during toe-strike and remains active during early and mid stance, whereas the biceps femoris and *gluteus maximus* are only activated in mid stance phase (Grasso *et al.*, 1998; Flynn and Soutas-Little, 1993).

At initial contact, the ankle plantarflexors are coactivated with the dorsiflexors to absorb the impact shock. Since the knee is flexed at initial contact and during the stance phase, the knee extensors need to contract isometrically to support the body. Peak activation of the *rectus femoris* is markedly higher during backward locomotion and the *vastus lateralis* is activated for longer compared to forward locomotion.

E. GROUND REACTION FORCE DURING BACKWARD LOCOMOTION

Ground reaction force (GRF) is the force exerted by the ground on the body and can be divided into a longitudinal and a vertical ground reaction force. The longitudinal ground reaction force is directed forward at initial contact, almost zero during mid stance, and directed backward during late stance of backward locomotion. The vertical ground reaction force of backward locomotion displays two main peaks: when the body mass is directed upward during double support, and downward during single support in mid stance (Grasso *et al.*, 1998). The peak vertical ground reaction force is significantly less in backward locomotion and the vertical impulse which occurs from foot strike to the onset of peak force is also smaller (Threkeld *et al.*, 1989). This finding could be explained by the slower rate of loading which occurs due to a reduced stride length and by the more equal distribution of forces since the toe-on mechanism of backward locomotion causes coactivation of the ankle plantarflexors which absorb some of the impact shock (Grasso *et al.*, 1998; Flynn and Soutas-Little, 1995; Threkeld *et al.*, 1989; Vilensky *et al.*, 1987).

F. ENERGY EXPENDITURE DURING BACKWARD LOCOMOTION

It has been reported in numerous studies that the metabolic cost and cardiopulmonary demand of backward locomotion are higher than forward locomotion. Specifically, the oxygen uptake (VO_2), minute ventilation (VE), heart rate (HR), respiratory coefficient and blood lactate concentration (La) have been noted to be higher during backward locomotion compared to forward locomotion when performed under similar conditions (Terblanche *et al.*, 2003; Minetti and Ardigò, 2001; Williford *et al.*, 1998; Chaloupka *et al.*, 1997; Myatt *et al.*, 1995; Flynn *et al.*, 1994). Factors that have been proposed to contribute to this difference include (1) decreased stride length and increased stride frequency, (2) shorter duration of double support phase (3) the concentric actions of the *quadriceps* muscle group and (4) the economy of a novel activity.

1. Decreased stride length and increased stride frequency

During backward locomotion, the stride length decreases and the stride frequency increases compared to forward locomotion at a similar velocity. A shortened stride length has been suggested to be part of a protective strategy when stability is threatened (Conrad *et al.*, 1983). According to Cavanaugh and Williams (1982), modification of a person's chosen stride length will result in an increase in oxygen uptake.

2. Shorter duration of double support phase

The double support phase is essential for mechanical energy conservation. The elastic energy cycle store and release energy during walking at no metabolic cost. An important requisite for elastic storage and release is the tension development in the Achilles tendon by the *gastrocnemius*. During backward locomotion the *gastrocnemius* is activated less which results in a reduction of stored and released energy. The double support phase is also shortened during backward locomotion due to the higher stride frequency; therefore less energy is conserved during backward locomotion (Minetti and Ardigò, 2001).

3. Concentric actions of the *quadriceps* muscle group

The muscle firing patterns during backward and forward locomotion differ significantly. Backward locomotion requires greater sustained muscle activity of the *quadriceps* muscles, which acts primarily as isometric stabilizers and concentric accelerators. This pattern differs from forward walking where the primary action of the *quadriceps* muscles is eccentric deceleration (Flynn and Soutas-Little, 1993; Devita and Stribling, 1991). It has been shown that concentric contraction has a higher energy cost than eccentric contraction (Abbott *et al.*, 1952). Thus the metabolic cost of backward locomotion is higher than forward locomotion.

4. Economy of a novel activity

Backward locomotion is considered a novel activity for most individuals. A novel activity requires the recruitment of extra motor units, which will increase the oxygen demand (Flynn *et al.,* 1994). However, backward locomotion practice will lead to motor learning, which would result in more efficient recruitment of motor units so that the energy cost decreases (Heath *et al.*, 2001). According to Childs *et al.* (2002) at least 12 practice sessions are needed to decrease the energy expenditure of a novel task. Consequently, the contribution of increased motor unit activation during backward locomotion to energy expenditure is probably limited to the first 12 practice sessions.

G. BACKWARD LOCOMOTION AND KNEE REHABILITATION

Backward locomotion imposes several unique effects on the limbs, joints and muscles of the lower body which may benefit knee rehabilitation; therefore it is regularly included in rehabilitation programs.

1. Reduced loading of the patellofemoral joint

A repetitive high rate of loading during initial contact and high patellofemoral joint compressive force has been associated with knee disorders such as patellofemoral pain syndrome (Riskowski *et al.*, 2005; Insall, 1979; Outerbridge, 1961). However, a significantly lower peak patellofemoral joint compressive force and a significantly slower rate of loading have been found during backward locomotion (Flynn and Soutas-Little, 1995). Consequently, trauma to the articular cartilage is reduced during backward locomotion; therefore it could be used as a mode of training after sustaining injuries to the lower limb.

2. Prevention of overstretching of the ACL

During the healing stages following ACL reconstruction, excessive stretching of the ACL is contraindicated due to the risk of a recurring rupture. During backward locomotion overstretching of the ACL by excessive quadriceps action is avoided (Mackie and Dean, 1984).

3. Increased activation of the *quadriceps*

Backward locomotion could be an effective tool to increase *quadriceps* strength after immobilization or surgery since the *quadriceps* are activated for a longer period. Although not statistically significant, Anderson *et al.* (1995) found an increase in *quadriceps* strength of healthy individuals after six weeks of backward running. On the other hand, isokinetic knee extensor torque production in healthy individuals has been noted to increase significantly by Threkeld *et al.* (1989) after eight weeks of training. Mackie and Dean (1984) found a significant increase in the power of the knee extensors of individuals with knee ligament instability after a three month backward training regimen.

4. Maintenance of cardiorespiratory fitness

Several studies (Terblanche *et al.*, 2004; Terblanche *et al.*, 2003; Minetti and Ardigò, 2001; Williford *et al.*, 1998; Chaloupka *et al.*, 1997; Myatt *et al.*, 1995; Flynn *et al.*, 1994) have documented higher energy expenditure during backward walking and running when compared to forward walking and running at a similar speed. Flynn *et al.* (1994) found the metabolic cost of backward walking comparable to that of forward running which suggests that an athlete with a knee injury could rehabilitate using backward locomotion at an aerobic intensity sufficient to maintain cardiorespiratory fitness.

H. CONCLUSION

Backward locomotion could be utilized as a mode of training during knee rehabilitation since excessive loading of the joint and overstretching of the ligaments are prevented whilst *quadriceps* strength and cardiovascular fitness are improved.

CHAPTER FIVE
PROBLEM STATEMENT

A. BACKWARD LOCOMOTION AND ITS CONTEXT TO KNEE REHABILITATION

The knee is one of the most injured joints in the physically active population and up to 25% of knee injuries require surgical treatment (Bradley *et al.*, 2008). Following severe knee injuries or surgery, a period of immobilization is necessary which inevitably leads to a loss of *quadriceps* strength, cardiorespiratory fitness and range of motion in the joint, therefore extensive rehabilitation is required before a return to sport is allowed. Numerous studies have documented the use of an aggressive approach to knee rehabilitation to accelerate the rehabilitation period (Shelbourne and Klotz, 2006; Aglietti *et al.*, 2004; Barber-Westin *et al.*, 1999; Howell and Taylor, 1996; Glasgow *et al.*, 1993). The inclusion of backward locomotion in knee rehabilitation programs has also been proposed since it is considered a safe closed kinetic chain exercise. During backward locomotion there are reduced compressive forces at the patellofemoral joint (Flynn and Soutas-Little, 1995) and overstretching of the ACL is prevented (Mackie and Dean, 1984). Backward locomotion training has been found to increase *quadriceps* strength (Threkeld *et al.,* 1989) and power (Mackie and Dean, 1984), as well as cardiorespiratory fitness (Terblanche *et al.*, 2004). Therefore backward locomotion could be employed during the early phases of rehabilitation to aid an early return to sport.

B. EXISTING LITERATURE ON BACKWARD LOCOMOTION TRAINING

Several studies have observed the effects of backward walking and running during a single bout of exercise, however limited studies have examined the effects of a backward walk or run training program (Terblanche *et al.*, 2004;

Childs *et al*., 2002; Heath *et al*., 2001; Anderson *et al*., 1995; Threkeld *et al*., 1989; Mackie and Dean, 1984).

Most backward locomotion training protocols involved four to eight weeks of training (Terblanche *et al*., 2004; Childs *et al*., 2002; Heath *et al*., 2001; Anderson *et al*., 1995; Threkeld *et al*., 1989), with only one study extending to three months (Mackie and Dean, 1984). Subjects were assessed for cardiorespiratory fitness (Terblanche *et al*., 2004), *quadriceps* and *hamstring* muscle strength (Anderson *et al*., 1995; Threkeld *et al*., 1989; Mackie and Dean, 1984) and the motor learning effect of backward locomotion (Childs *et al*., 2002; Heath *et al*., 2001).

Most individuals that have been included in the studies were healthy, habitually active subjects (Terblanche *et al*., 2004; Childs *et al*., 2002; Heath *et al*., 2001) and two studies were performed on runners (Anderson *et al*., 1995; Threkeld *et al*., 1989). Only one study investigated the effects of backward locomotion training on injured subjects with knee ligament instability (Mackie and Dean, 1984). Since the literature shows that backward locomotion training increases *quadriceps* strength and power, and cardiorespiratory fitness in healthy subjects, it could be beneficial in the recovery of individuals with knee injuries.

C. THE AIMS OF THE CURRENT STUDY

The primary aim of the study was to establish the efficacy of backward locomotion training during a knee rehabilitation program.

Specific aims

To determine if backward walk / run training causes greater increases in: (1) aerobic fitness, (2) *quadriceps* and *hamstrings* muscle strength and power, (3) single leg balance, (4), flexibility of the lower limb and (5) circumferences of the lower limb, than forward walk / run training as part of a knee rehabilitation program.

CHAPTER SIX
METHODOLOGY

A. STUDY DESIGN

This study used a randomized controlled trial to determine the effects of backward locomotion as part of a 24-session knee rehabilitation program on the functional ability of patients following knee injuries. Outcome variables were measured before and after the intervention period.

B. PARTICIPANTS

Subjects were recruited through advertisements in the local press, at various sport clubs in Stellenbosch and Paarl regions and through references from orthopaedic surgeons situated in Stellenbosch. Thirty-nine men and women with knee injuries, aged between 18 and 59 years, volunteered to take part in the study. Participants were randomly assigned to the experimental group (EXP, n = 21) and control group (CON, n = 18). Since it was impossible to blind participants to the intervention (backward locomotion), they were never informed of the true purpose of the study. This was an attempt to avoid biased views towards the specific intervention which may have affected the intensity of their workouts during the intervention period.

Inclusion and exclusion criteria

A purposive sampling method was used. Participants were men and women with knee pathologies between the ages of 18 and 59 years. Participants had no current metabolic, cardiorespiratory or endocrine disorders. Musculo-skeletal disorders were limited to the knee joint. Participants were included in the study if they had knee injury or -surgery in the previous 12 months or an ongoing knee problem limiting their activities of daily living. In the latter case, subjects had to present with a deficit of 10% or more in *quadriceps* strength. Participants were excluded from the study if they planned to participate in any additional lower body or cardiorespiratory exercises during the study's intervention period.

1. Assumptions

It was assumed that the basic knee rehabilitation program (excluding the backward or forward cardiorespiratory exercises) had a similar effect on participants in the two groups. It was also assumed that gender and ethnicity did not have an effect on the responses to the training program. It was further assumed that the participants did not partake in any form of physical activity other than activities of daily living during the intervention period.

2. Delimitations

The study was limited to participants close to Stellenbosch since they had to attend two to three training sessions per week at the Sport Science Department.

3. Limitations

The intervention period was limited to 24 sessions (8 - 12 weeks). It is conceded that expected improvements will be greater after 3 - 6 months of knee rehabilitation and cardiorespiratory training. Participants with a number of different knee injuries were included in the study and it is possible that the magnitude and response time of different types of injuries to an intervention program may be different.

C. EXPERIMENTAL DESIGN

Participants performed baseline and post intervention testing, as well as 24 knee rehabilitation sessions at the Exercise Physiology Laboratory, Stellenbosch University and the Stellenbosch Biokinetics Centre. All testing was done at temperatures between 18 and 20˚C.

1. Laboratory visits

1.1 Visit 1

The study protocol was explained verbally and in writing to the volunteers and written informed consent (Appendix A) was acquired from each individual. A health questionnaire (Appendix B) was completed and the history of their knee injuries obtained. Participants' body composition, peak aerobic capacity (VO_{2peak}), *quadriceps* and *hamstrings* leg strength, single leg balance and flexibility were tested to obtain baseline values.

1.2 Visit two to 25

The participants attended 24 knee rehabilitation sessions, two to three times a week for eight to 10 weeks. All participants followed the same basic rehabilitation program which was adjusted three times during the intervention period to ensure progression. The experimental group did the cardiorespiratory training in the backward mode, whereas the control group did it in the forward mode.

1.3 Visit 26

All the baseline tests were repeated, in the same order and using the same equipment during the last visit. Subjects were blinded to the outcome measures, as no results were discussed and no reports were given.

2. Ethical aspects

The study protocol was approved by the Ethics Committee of Research Subcommittee A of Stellenbosch University (Reference number 155 / 2009; Appendix C). Care was taken that each subject understood the study protocol and what was required from them before they were asked to sign the consent form. It was emphasized that participation was voluntary and that they could withdraw from the study at any time, without any consequences.

D. MEASUREMENTS AND TESTS

The primary outcome variables were aerobic capacity (VO_{2peak}), knee flexor and extensor strength and power, single leg balance and flexibility. The secondary outcome variable was the anthropometric measurements.

1. Anthropometric measurements

Subjects were bare footed and dressed in light-weight clothing for the anthropometric measurements. The recommendations of the International Society for the Advancement of Kinanthropometry (ISAK, Australia) were followed during the measurements. The stretched stature, body mass and circumference measurements were taken twice.

1.1 Stretched stature

The subject was positioned with heels together and upper back, buttocks and heels against a wall. The subject's head was placed in the Frankfort plane, with the lower edge of the eye socket (Orbitale) in the same horizontal plane as the notch just above the tragus of the ear (Tragion). The subject was asked to take a deep breath when the measurement was taken from the inferior aspect of the feet to the highest point of the skull (Vertex). A sliding steel anthropometer (Siber-Hegner GPM, Switzerland) was used, and the reading was taken to the nearest 0.1 centimeter (cm).

1.2 Body Mass

Body mass was determined with a calibrated electronic scale (UWE BW – 150 freeweight, 1997 model, Brisbane, Australia) and recorded to the nearest 0.1 kilogram (kg). Subjects had to stand in the middle of the scale, distributing their weight evenly on both legs and looking straight ahead.

1.3 Circumferences

All circumferences were taken by the same investigator, in the anatomical position, according to ISAK guidelines. Four girths were taken on both limbs to the nearest millimeter (mm). Girths were measured with a spring-loaded, non-extensible anthropometric tape measure (*Rosscraft*, Canada). The measuring tape was held horizontally, at right angles to the limb and tension in the tape was held constant. A cross-hand technique was used, with the zero mark located more lateral than medial on the subject. The subject stood upright, with legs apart and weight distributed evenly. The subject stood on a 40 cm anthropometrical box, so that the measurements could be taken at eye level. Circumference deficit was calculated by determining the percentage deficit in circumference between the involved and uninvolved legs at each measurement site.

(i) Calf

The anthropometric tape was placed around the calf, perpendicular to the long axis of the limb. The middle fingers were used to move the tape up-and-down until the maximal girth was identified.

(ii) Distal thigh

The measurement was made with the anthropometric tape placed around the lower thigh, five cm proximal to the upper border of the patella.

(iii) Mid-thigh

The measurement was taken midway between the trochanterion and lateral border of the tibia, at the mid-trochanterion-tibiale laterale site.

(iv) Proximal thigh

The measurement was made with the anthropometric tape placed around the upper thigh, one cm distal to the gluteal fold.

1.4 Bio-electrical Impedance Analysis (BIA)

The subjects' lean and fat mass were measured with a portable body composition monitor (Bodystat 4.05® Quadscan 2007, Isle of Man). The BIA procedure involves sending a very small electric current of 800 µA at 50 kHz through the body which measures the resistance of the tissue. Lean mass consists of the bony skeleton, muscle mass, innards and entire water content of the body. Fat mass consists only of adipose tissue. The rationale behind BIA is that one can distinguish between lean mass and fat mass because of the differences in the resistance against the electrical current. Lean mass will provide less resistance than fat mass, because of its greater composition of water and electrolytes.

Subjects had to lie in a supine position with limbs not touching each other, or the centre of the body. After the skin was wiped with an alcohol swab, the electrodes were placed on the standard anatomical sites. Two electrodes were placed on the dorsal side of the hand, one centimeter proximal to the knuckle of the middle finger and on the wrist between the head of the ulna and radius. The remaining two electrodes were placed on the dorsal side of the bare foot, one centimeter proximal to the hallux and third phalange, and between the lateral and medial malleoli. The leads were attached to the electrodes and the analyzer switched on. The resistance and reactance were then recorded. Subjects were asked to refrain from exercise or drinking diuretics such as caffeine or alcohol for at least 12 hours prior to the testing, and had to void their bladders before testing. These measures are taken to improve the reliability and validity of the measurements.

2. Aerobic capacity (VO_{2peak}) test

A progressive incremental exercise test to exhaustion was performed on the Lode Excalibur Sport Cycle Ergometer to determine VO_{2peak}. Performance was measured with a cycling test since jogging and running are contraindicated in the early phases of several knee injuries due to the increased impact force and loading on the knee which increases the risk for a recurrent injury. The cardio-pulmonary metabolic system (Cosmed *Quark CPET*, Rome, Italy) used breath-by-breath analysis of the expired gases together with a telemetric heart rate monitor (Cosmed®, Rome, Italy) to calculate and record exercise intensity and selected cardiorespiratory parameters continuously throughout the test. The gas analyzers were calibrated prior to each test with known gas concentrations (16% 0_2, 5% CO_2, balance N_2) and the turbine flow meter was calibrated with a three liter calibration syringe.

2.1 VO_{2peak} protocol

The subject was positioned on the Lode cycle ergometer by adjusting sitting height, arms and upper body length until the subject was in a comfortable position. Prior to the test subjects warmed up for five minutes at a resistance of 60 Watts and a cadence of 80 – 100 revolutions per minute (rpm). Subjects were then allowed to drink water before the heart rate monitor and the soft face mask were fitted. The test started at 80 watts. The speed had to be kept constant at 80 – 100 rpm, while the resistance increased by 30 Watts every three minutes. The subject was not allowed to stand upright during any stage of the test. The test was terminated when the subject reached exhaustion and could not maintain the speed above 80 rpm. The maximum response was verified if two or more of the following occurred: (i) the VO_2 did not increase by more than 150 milliliter per successive workload, (ii) a respiratory quotient (RER) value of 1.15 or above was reached, (iii) heart rate was higher than 90% of the age-predicted maximal heart rate or (iv) the rating of perceived exertion (RPE) was above 19 on the 6 – 20 Borg Scale.

2.2 Ventilatory Threshold (VT)

The ventilatory threshold (VT) was detected simultaneously with the VO_{2peak} during the incremental maximal exercise test through the specialized computer software (Cosmed *Quark CPET*, Rome, Italy). VT was defined as the point at which a non-linear increase in minute ventilation (VE, $ml.kg^{-1}.min^{-}$

^{1}) occurred in relation to oxygen consumption (VO_2, $ml.kg^{-1}.min^{-1}$). VT was expressed as the percentage of VO_{2peak}.

3. Isokinetic knee extension-flexion test

A $120°.s^{-1}$ concentric/concentric knee extension-flexion isokinetic test was performed to determine knee flexor and extensor strength and power. Tests were done on the Biodex System 3 isokinetic dynamometer (Biodex Corporation, Shirley, NY). The reliability (trial-to-trial reliability: r=0.99; day-to-day reliability: r=0.99) and validity (r=0.99) of the Biodex System 3 has been reported by Drouin *et al*. (2004).

Prior to testing, the subject was allowed a five minute warm-up on a stationary cycle ergometer and the *quadriceps* and *hamstrings* muscle groups were stretched. The subject was seated on the dynamometer, with a hip flexion angle of 80°. The dynamometer rotational axis was aligned with the lateral femoral condyle. Restraints straps were applied to the subject's upper torso, pelvis and distal thigh, providing body stabilization and ensuring movement only from the intended joint of interest. The dynamometer lever length was adjusted to the subject's limb length, with the shin pad attached just above the lateral malleolus. A gravitational torque measurement was taken near the extended-knee horizontal position, at 30° of knee flexion. The range of motion was set within the subject's achievable range, i.e. without pain or discomfort.

The subject received brief and simple instructions on the maximal isokinetic test and was given two practice efforts. The test comprised of 10 repetitions of maximal knee flexion and extension at an angular speed of $120°.s^{-1}$. The subject's uninvolved leg was tested first, followed immediately by the involved leg. Verbal encouragement was given throughout the test to ensure maximal performance. Muscle strength was measured by means of Peak torque production in Newton-meter and average power measured in Watts.

Figure 1: Subject strapped onto the Biodex System 3 isokinetic dynamometer, prior to test (photograph by L. Engelbrecht).

4. Single leg balance test

The Athlete Single Leg Balance Test was performed on the Biodex Balance System SD to determine an overall stability index (OSI), anterior-posterior stability index (APSI) and medial-lateral stability index (MLSI). The reliability (OSI reliability: r=0.94; APSI reliability: r=0.95; MLSI reliability: r=0.93) of the Biodex Balance System SD has been reported by Cachupe *et al*. (2001).

The subject was positioned with one leg on the Biodex Balance System SD platform. The subject had to find his/her centre of gravity in the middle of the completely firm surface and had to maintain an upright standing position. Each subject was given the same instructions before commencing the test. Dynamic balance was assessed during the Athlete Single Leg Balance Test. The test comprised of three 20 second trials at a spring resistance level of four. Spring resistance levels range from 1 (least stable) to 12 (most stable). Between each set, a rest period of 10 seconds was allowed. During the test, the subject was not allowed to hold onto the railings and limbs were not to touch each other. Continuous biofeedback was given with on-screen visuals of their weight displacements from the centre. Results were reported as scores on an OSI, APSI and MLSI, which could range from zero to 20. A score closer to zero is considered better.

Figure 2: Subject performing a single leg balance test on the Biodex Balance System SD (photograph by M. Brink).

5. Flexibility and range of motion tests

5.1 *Quadriceps* flexibility test

The Modified Thomas Test was used to assess the passive length of the *quadriceps* of both legs. The subject sat on the end of a plinth and rolled back, holding both knees to the chest. The non-test leg was held in maximal hip flexion, whilst the test leg was lowered to the floor. The subject was asked to relax the hip and thigh muscles, so a passive end-point was obtained from gravity only. The knee flexion angle was determined by positioning the goniometer at the centre of the lateral knee joint line. The fixed arm of the goniometer was aligned with the length of the femur toward the greater trochanter and the mobile arm pointed towards the lateral malleolus of the fibula. The subject was given one practice trial. On the second trial, the angle was measured with the goniometer to the nearest degree (˚).

5.2 *Hamstrings* flexibility test

The passive Straight Leg Raise (SLR) was used to assess the passive length of the *hamstrings* of both legs. The subject had to lie supine on a plinth with arms at the side and legs straight. The subject's tested leg was raised to the barrier of hip flexion. The opposite leg had to remain in a neutral position. The goniometer was aligned with the fixed arm parallel to the horizontal and the mobile arm parallel to the mid-thigh, pointing to the lateral malleolus. The first attempt was measured to the nearest degree (˚).

5.3 Ankle flexibility test: Dorsiflexion (*Gastrocnemius*)

The *gastrocnemius* flexibility was tested on both legs of the subject. The subject stood barefoot in the stride position and had to maintain knee extension while keeping the heel in contact with the floor. The angle was measured with the fixed arm of the goniometer perpendicular to the horizontal and the mobile arm pointing to the lateral aspect of the head of the fibula. The first attempt was measured to the nearest degree (˚).

Figure 3: Measurement of *gastrocnemius* flexibility (photograph by P. Zeelie).

5.4 Ankle flexibility test: Dorsiflexion (*Soleus*)

The *soleus* flexibility was tested on both legs of the subject. The subject stood barefoot in the stride position, maintaining heel contact with the floor. The subject was instructed to bend the back knee forward in line with the second toe until heel contact could not be maintained or discomfort was experienced in the ankle. The angle was measured with the fixed arm of the goniometer perpendicular to the horizontal and the mobile arm pointing to the lateral aspect of the head of the fibula. The first attempt was measured to the nearest degree (˚).

Figure 4: Measurement of *soleus* flexibility (photograph by P. Zeelie).

5.5 Sit-and-reach test

A portable wooden sit-and-reach box was used to assess the *hamstrings* and lower back flexibility. The subject sat on the horizontal plane of the apparatus with legs extended and heels against the vertical plane of the apparatus. The subject had to place one hand over the other, flex the trunk forward and push the indicator as far as possible with both hands. That position had to be held for 3 seconds. The best of 3 trials was considered the flexibility score, measured in cm.

Figure 5: A sit-and-reach *hamstrings* and lower back flexibility test (photograph by M. Brink).

E. KNEE REHABILITATION EXERCISE SESSIONS

All subjects completed 24 knee rehabilitation exercise sessions (Appendix D) under the supervision of the researcher, a qualified Biokineticist. All participants followed the same basic rehabilitation program plus either the backward or forward cardiorespiratory exercises. The latter exercises included walking and running on a treadmill and elliptical trainer. The rehabilitation program was adjusted three times during the intervention period. The workload of the exercises in the program was relative to each participant's body mass.

The intervention was divided into four phases of six sessions each. After each phase, adaptations were made to allow for progression. Phase I and II included 20 minutes of cardiorespiratory exercises, Phase III 25 minutes of cardiorespiratory exercises and Phase IV 30 minutes of cardiorespiratory exercises.

The sessions consisted of the following:

- 20 – 30 min cardiorespiratory training
- 20 min strengthening exercises (upper and lower legs)
- 5 min balance and proprioception
- 5 - 10 min stretching

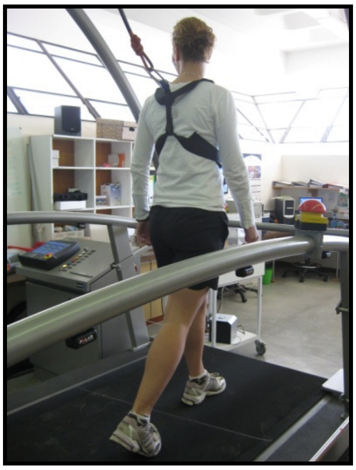


Figure 6: Participant in experimental group familiarized with backward locomotion (photograph by M. Brink).

F. STATISTICAL ANALYSIS

Statistical analysis was performed with Microsoft Excel (Windows®, 2003; USA) and STATISTICA® 9.0 (Statsoft, Inc; 2009, USA). Descriptive data are reported as mean ($\bar{x}$) and standard deviation (±SD), unless otherwise specified. Dependent Student's *t*-tests were performed to reveal the significant changes between the pre and post-test results and independent Student's *t*-tests were performed to determine the significance of changes between the experimental and control group. The level of significance was set at $p \leq 0.05$ for all analyses. Furthermore, effect sizes (ES) were calculated for pre and post-test results in each group, as well as for differences between the two groups to determine practical significance. Effect sizes (expressed as Cohen's *d*-value) can be interpreted as follows: an ES of more or less 0.2 is small, an ES of more or less 0.5 is moderate and an ES of more or less 0.8 is large (Cohen, 1988). Based on the sample size calculator of Hopkins (http://www.sportsci.org/resource/stats/index.html), for the difference in the means in a controlled trial and with a power of 80% and a type I error of 5%, the minimum sample size needed was 34 with 17 in the EXP group and 17 in the CON group.

CHAPTER SEVEN
RESULTS

A. DESCRIPTIVE CHARACTERISTICS

1. Participants

Fifty-five subjects volunteered to participate in the study and underwent the screening procedure. Those who met the inclusion criteria were invited to participate in the rehabilitation program. Eleven of the volunteers could not be included in the study as they did not comply with the inclusion criteria. A further two subjects withdrew due to time constraints and a further two because of orthopaedic injuries. Thirty nine men and women (26 men and 13 women) with knee pathologies were randomly assigned to the experimental group (n = 21) and control group (n = 18). Both groups followed a knee rehabilitation program with the only difference that the experimental group performed backward walk / run training, while the control group performed the exercises in the forward mode. Table 1 depicts the physical and fitness characteristics of the two groups and shows that there were no significant differences between the two groups for any of the baseline characteristics ($p > 0.05$).

Table 1: Physical and fitness characteristics (mean ± SD, range) of the experimental (EXP) and control (CON) groups.

Characteristic	EXP (n = 21)				CON (n =18)			
	Mean	±	SD	Range	Mean	±	SD	Range
Age (years)	29.6	±	12.3	18 - 54	29.6	±	13.6	18 - 59
Height (cm)	176.1	±	9.0	161 – 192	173.6	±	10.8	155 - 195
Body mass (kg)	84.9	±	15.6	61 – 121	76.4	±	16.5	44 – 100
BMI ($kg.m^{-2}$)	27.3	±	3.8	21 – 34	25.2	±	4.4	18 – 34
Body fat (%)	24.0	±	10.5	8 – 44	20.1	±	7.9	12 – 42
VO_{2peak} ($ml.kg^{-1}.min^{-1}$)	40.5	±	10.4	19 – 56	39.2	±	10.4	24 – 62
PPO (Watts)	214.2	±	52.6	133 - 297	206.8	±	61.5	115 - 290

BMI, body mass index; VO_{2peak}, peak aerobic capacity; PPO, peak power output

Table 2 depicts the deficit in isokinetic muscle torque production (IMTP) between the involved and uninvolved legs for the *quadriceps* and *hamstrings* muscle groups. There were no significant differences for the baseline *quadriceps* deficit and *hamstrings* deficit between the EXP and CON groups ($p > 0.05$). Overall stability of the involved leg as well as the uninvolved leg also showed no statistical difference between the EXP and CON groups ($p > 0.05$). Two participants in the EXP group and two in the CON group had a negative *hamstrings* deficit where the strength in the uninvolved leg was greater than that of the involved leg.

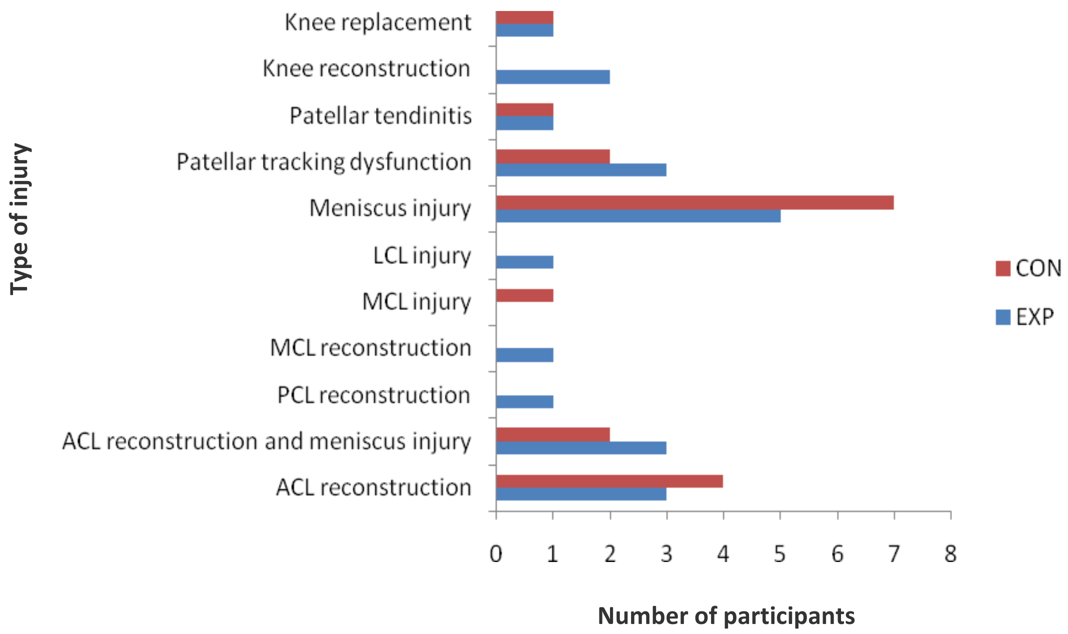
Table 2: Leg strength deficit and balance ability (mean ± SD, range) of the experimental (EXP) and control (CON) groups.

Variable	EXP (n = 21)				CON (n =18)			
	Mean	±	SD	Range	Mean	±	SD	Range
Quadriceps deficit (%)	28.6	±	15.4	9 – 57	25.8	±	17.0	7 – 68
Hamstrings deficit (%)	19.8	±	18.5	-10 – 68	12.7	±	15.6	-25 - 44
Overall stability involved leg	2.8	±	1.6	1 – 7	2.5	±	1.4	1 – 6
Overall stability uninvolved leg	2.9	±	1.8	1 – 9	2.4	±	1.5	1 – 7

Involved, injured leg; uninvolved; uninjured leg

2. Knee pathology of participants

The type of knee injuries and incidence of these injuries in the EXP and CON groups are illustrated in figure 7. The most common knee injury was a meniscal injury, followed by an ACL injury that necessitated a reconstruction and a meniscus injury in combination with an ACL reconstruction.



LCL, lateral collateral ligament; MCL, medial collateral ligament; PCL, posterior cruciate ligament; ACL, anterior cruciate ligament

Figure 7: The incidence of type of knee injuries in the EXP and CON groups.

3. Exercise intervention

All participants performed 24 knee rehabilitation sessions. The EXP group completed the sessions over a period of 10 weeks (70 days ± 14 days) and the CON group completed the sessions over a period of 10 weeks and 2 days (72 days ± 13 days). Thirty-three percent of the EXP group and 29% of the CON group kept to the three times a week schedule, whereas the other changed to twice a week sessions. The cardiorespiratory training during each session was performed at an intensity of more than 60% of HR_{max}.

B. CHANGES IN PHYSIOLOGICAL AND PHYSICAL PARAMETERS

The change from pre to post-test results are reported as mean ($\bar{x}$) and standard error of the mean (±SEM), unless otherwise specified.

1. Aerobic fitness

The VO_{2peak}, ventilatory threshold (VT) and peak power output (PPO) were used to describe the change in aerobic fitness of the participants. Figure 8 depicts the change in VO_{2peak} values. There was a slight, but not statistically significant decrease in VO_{2peak} values in the EXP group (1 ± 3%; ES < 0.2) and CON group (2 ± 3%; ES < 0.2). The changes in VO_{2peak} after the intervention were not significant between the two groups, while the practical difference was small to moderate (ES = 0.3).

The changes in VT are depicted in figure 9. The EXP group showed a tendency towards a statistically significant improvement (p = 0.07) and a strong practical significant change (ES = 0.8). The CON group showed no statistical significant or practical significant change for VT (p > 0.05; ES < 0.2). The EXP group improved their VT by 9 ± 5%, while the VT of the CON group remained relatively unchanged (0 ± 2%). Although the difference in the change of VT between the interventions were not statistically significantly different, there was a moderate to strong practical difference (ES = 0.7).

Figure 10 depicts the change in PPO obtained during the maximal exercise test. There was a statistically significant improvement in PPO for the EXP group (p = 0.004; ES = 0.5), but not for the CON group (p > 0.05; ES < 0.2). The EXP group increased their PPO by 14 ± 3%, while the CON group increased their PPO by only 4 ± 3%. The difference in change between the two interventions was statistically significant (p = 0.04), and resulted in a strong practical difference (ES = 0.8).

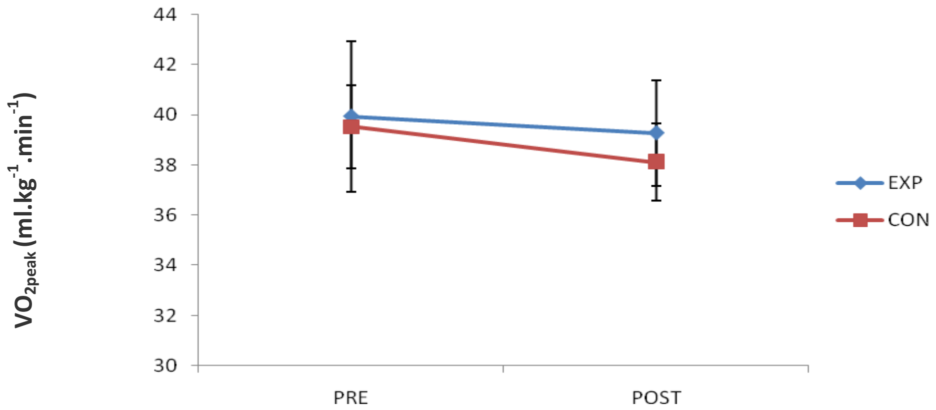


Figure 8: Changes in average VO_{2peak} values. The practical difference in the effects of the intervention was small to moderate (ES = 0.3)

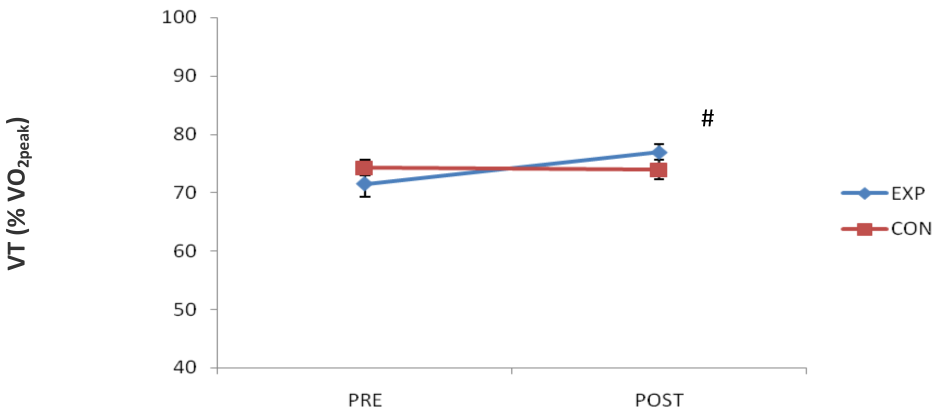


Figure 9: Changes in ventilatory threshold expressed as a percentage of VO_{2peak}. #Tendency towards significant difference from baseline ($p = 0.07$). There was a moderate to strong practical difference (ES = 0.7) between the two interventions.

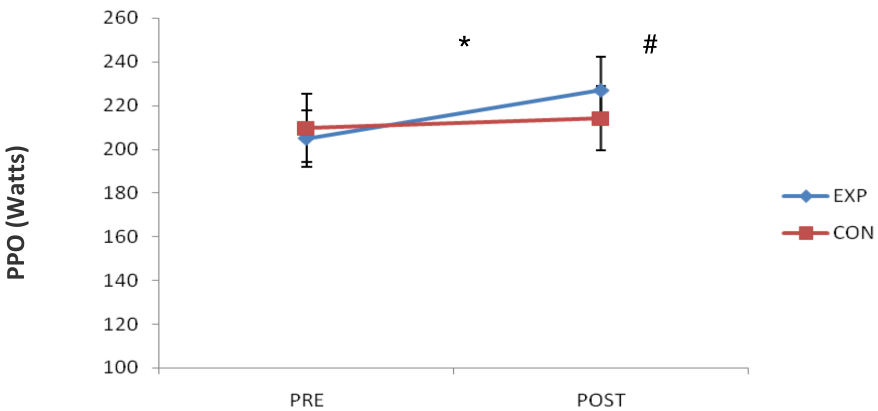


Figure 10: Changes in peak power output (PPO). *Significantly different between EXP group and CON group, $p < 0.05$; #Significantly different from baseline ($p < 0.05$). There was a strong practical difference between the two interventions (ES = 0.8).

2. Leg strength and power

Leg strength and power were determined by assessing the isokinetic muscle torque production (IMTP) of the *quadriceps* and *hamstrings* during a knee extension-flexion isokinetic test at a speed of $120°.s^{-1}$.

2.1 Leg strength

The changes in peak isokinetic muscle torque production (IMTP) of the *quadriceps* and *hamstrings* are depicted in Figure 11. The involved *quadriceps* (Figure 11A) of both the EXP group (27 ± 6%) and the CON group (16 ± 23%) improved significantly as a result of the intervention program ($p < 0.05$). This constitutes a moderately practical significant improvement for the EXP group (ES = 0.6), whilst the change for the CON group was only small to moderately practically significant (ES = 0.3). Although the difference in improvements between the interventions was not statistically significant, it was a practical difference of moderate strength (ES = 0.5).

The uninvolved *quadriceps* (Figure 11B) improved significantly in the EXP group (13 ± 3%), whilst the CON group remained relatively unchanged (1 ± 2%). The practical significance was small to moderate for the EXP group (ES = 0.3) and very small for the CON group (ES < 0.2). The difference between the interventions bordered on statistically significance ($p = 0.056$), but resulted in a very strong practical difference (ES > 0.8).

The involved *hamstrings* (Figure 11C) as well as the uninvolved *hamstrings* (Figure 11D) improved significantly in the EXP and CON groups (EXP: 17 ± 3%; CON: 22 ± 10%; EXP: 36 ± 9; CON: 31 ± 10%). The practical significances for the two groups were both moderate to strong for the involved *hamstrings* (EXP: ES = 0.7; CON: ES = 0.6) and small to moderate for the uninvolved *hamstrings* (EXP: ES = 0.4; CON: ES = 0.3). The differences in improvements between the interventions were not statistically significant for either the involved *hamstrings* ($p > 0.05$; ES < 0.2) or uninvolved *hamstrings* ($p > 0.05$; ES = 0.2).

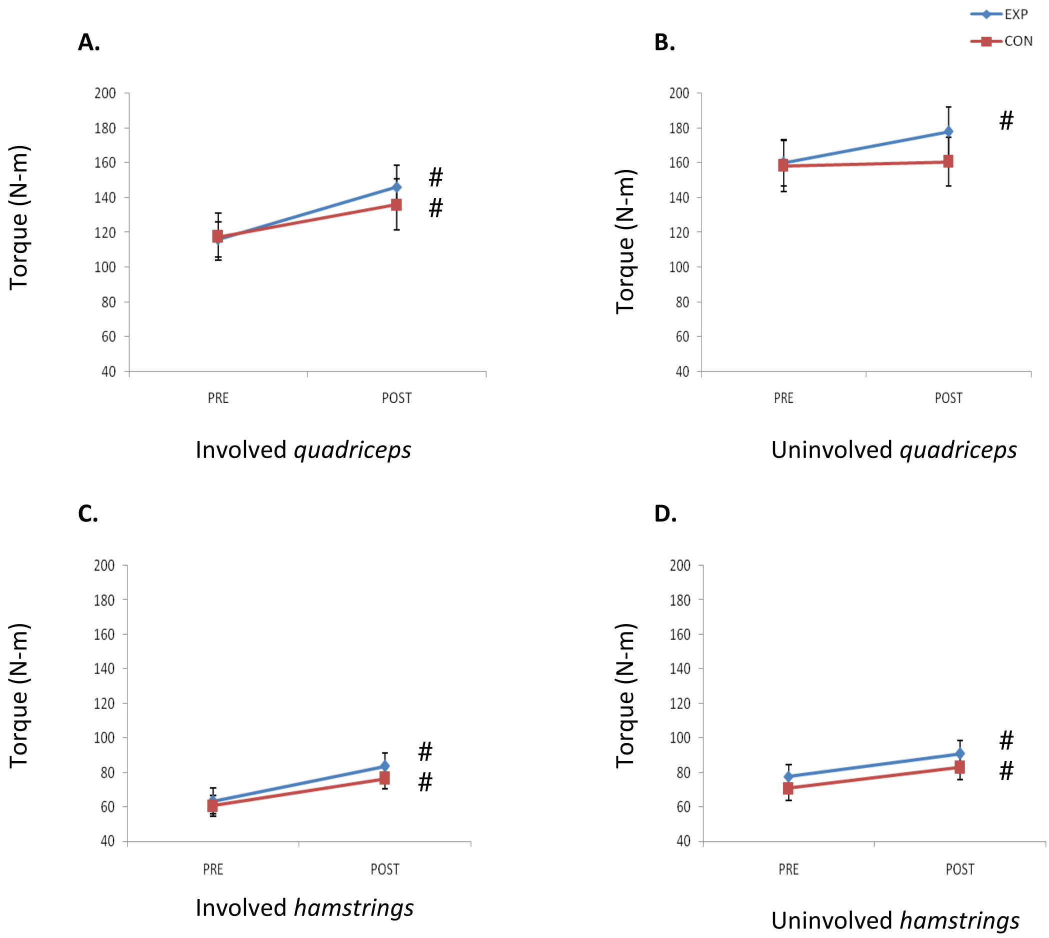


Figure 11: Changes in peak isokinetic muscle torque production of the involved and uninvolved *quadriceps* and *hamstrings.* #Significantly different from baseline ($p < 0.05$).

Figure 12 summarizes the percentage changes in the *quadriceps* and *hamstrings* strength for the involved and uninvolved legs as a result of the interventions. Only the *quadriceps* of the CON group did not improve in strength after the intervention. In both groups, the improvements for the *quadriceps* were the largest.

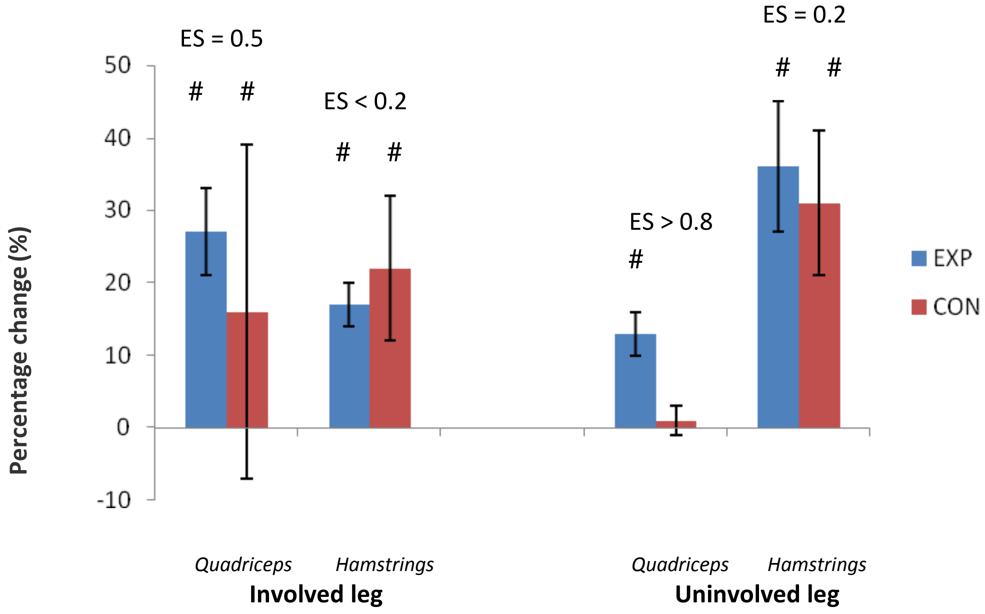


Figure 12: Percentage changes in muscle strength of the involved and uninvolved legs. #Significantly different from baseline ($p < 0.05$). ES, effect size of the difference between interventions.

2.2 Leg power

The change in average power of the *quadriceps* and *hamstrings* are depicted in Figure 13. The average power increased significantly in the *quadriceps* and *hamstrings* of both legs for the EXP group and CON group ($p < 0.05$), except for the uninvolved *quadriceps* of the CON group. The practical significance of the changes in the uninvolved *quadriceps* was very small (ES < 0.2) and differed from the rest which ranged from moderate to strong (ES = 0.5 to 0.8). There were no statistically significant differences between the interventions for the change in average power of either the *quadriceps* or *hamstrings* of the involved and uninvolved legs. However, the EXP group showed greater increases in the average power of the uninvolved quadriceps (EXP: 15 ± 6%; CON: 5 ± 4%; $p = 0.1$), as well as the involved *hamstrings* (EXP: 58 ± 15%; CON: 34 ± 7%; $p = 0.09$) and uninvolved *hamstrings* (EXP: 28 ± 7%; CON: 18 ± 5%; $p = 0.1$). Similar changes (EXP: 25 ± 9%; CON: 25 ± 9%; $p = 0.8$) were observed for the involved *quadriceps*. The practical differences between the interventions were very small for the involved *quadriceps* (ES < 0.2) and moderate for the uninvolved *quadriceps*, involved *hamstrings* and uninvolved *hamstrings* (ES = 0.4 to 0.5).

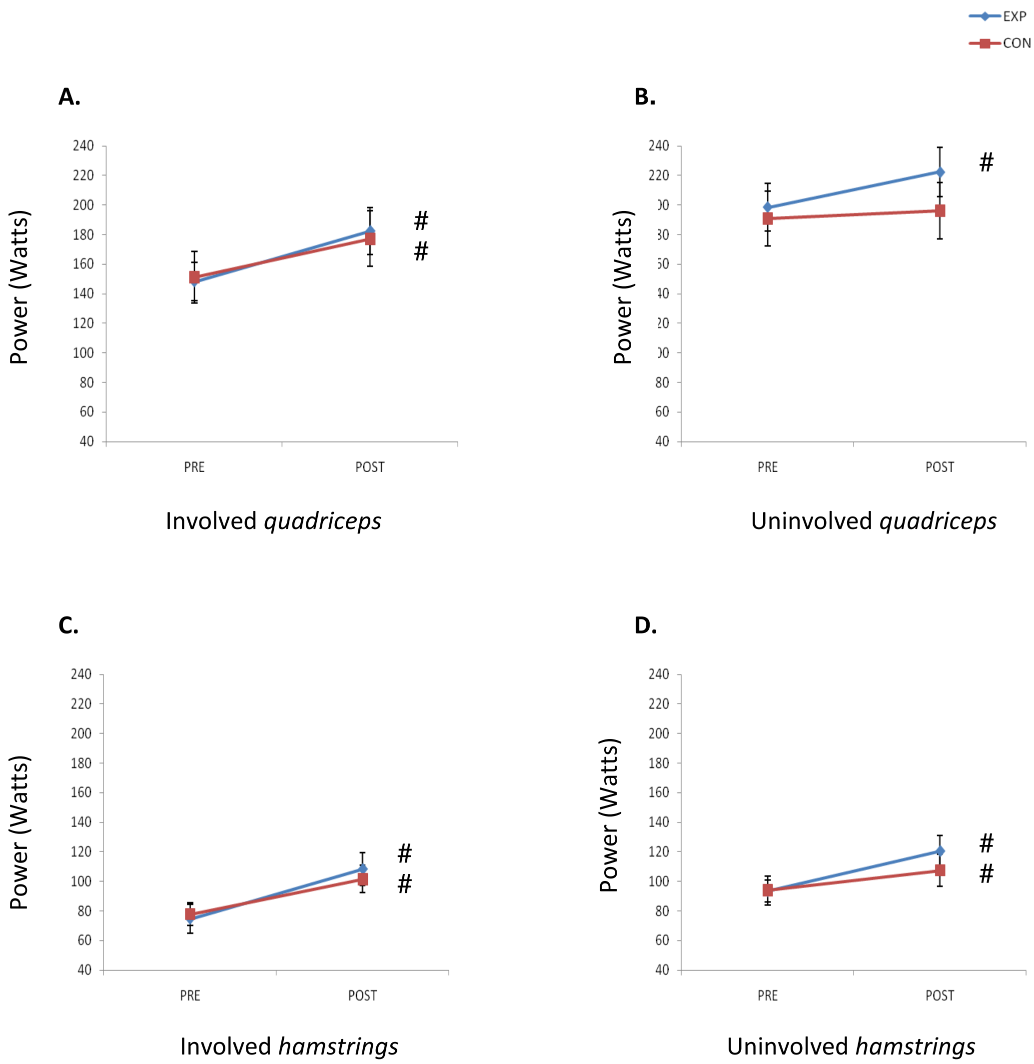


Figure 13: Changes in average power of the involved and uninvolved *quadriceps* and *hamstrings*. #Significantly different from baseline ($p < 0.05$).

Figure 14 summarizes the percentage changes in the *quadriceps* and *hamstrings* power for the involved and uninvolved legs as a result of the interventions. Only the *quadriceps* of the CON group did not improve in power after the intervention. In both groups, the improvements for the *hamstrings* were the largest.

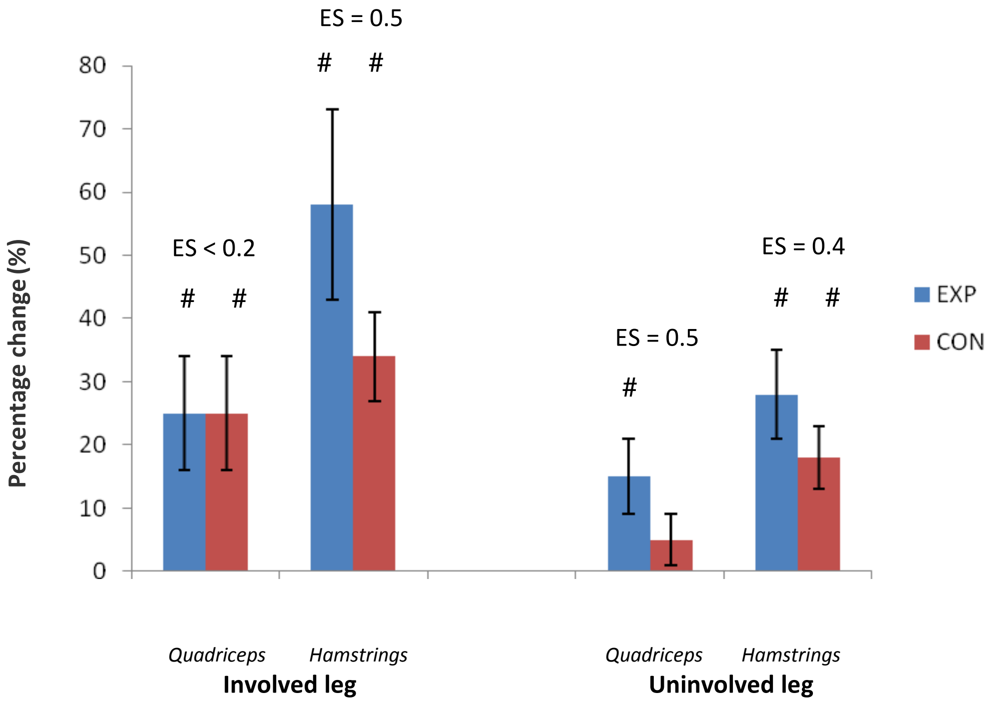


Figure 14: Percentage changes in the average power of the involved leg and uninvolved leg. # Significantly different from baseline ($p < 0.05$). ES, effect size of the difference between interventions.

3. Balance

3.1 Involved leg

Figure 15A depicts the percentage changes in the balance of the involved legs of the EXP and CON groups. The overall stability (EXP: 35 ± 5%; CON: 36 ± 5%), anterior-posterior stability (EXP: 32 ± 5%; CON: 37 ± 4%) and medial-lateral stability (EXP: 33 ± 5%; CON: 34 ± 7%) of both groups improved statistically significantly ($p < 0.05$) and the practical significances were large (ES ± 0.8). However, the differences in change between the interventions were not statistically significantly different and the practical differences were small (ES ± 0.2).

3.2 Uninvolved leg

Figure 15B depicts the percentage changes in the balance of the uninvolved legs of the EXP and CON groups. The overall stability (EXP: 32 ± 5%; CON: 28 ± 9%), anterior-posterior stability (EXP: 30 ± 6%; CON: 9 ± 20%) and medial-lateral stability (EXP: 31 ± 5%; CON: 34 ± 6%) of both groups improved statistically significantly ($p < 0.05$). The practical significances of these improvements were large to very large (ES ≥ 0.8). However, the differences in change between the interventions were not statistically significantly different and the practical differences were small (ES ± 0.2).

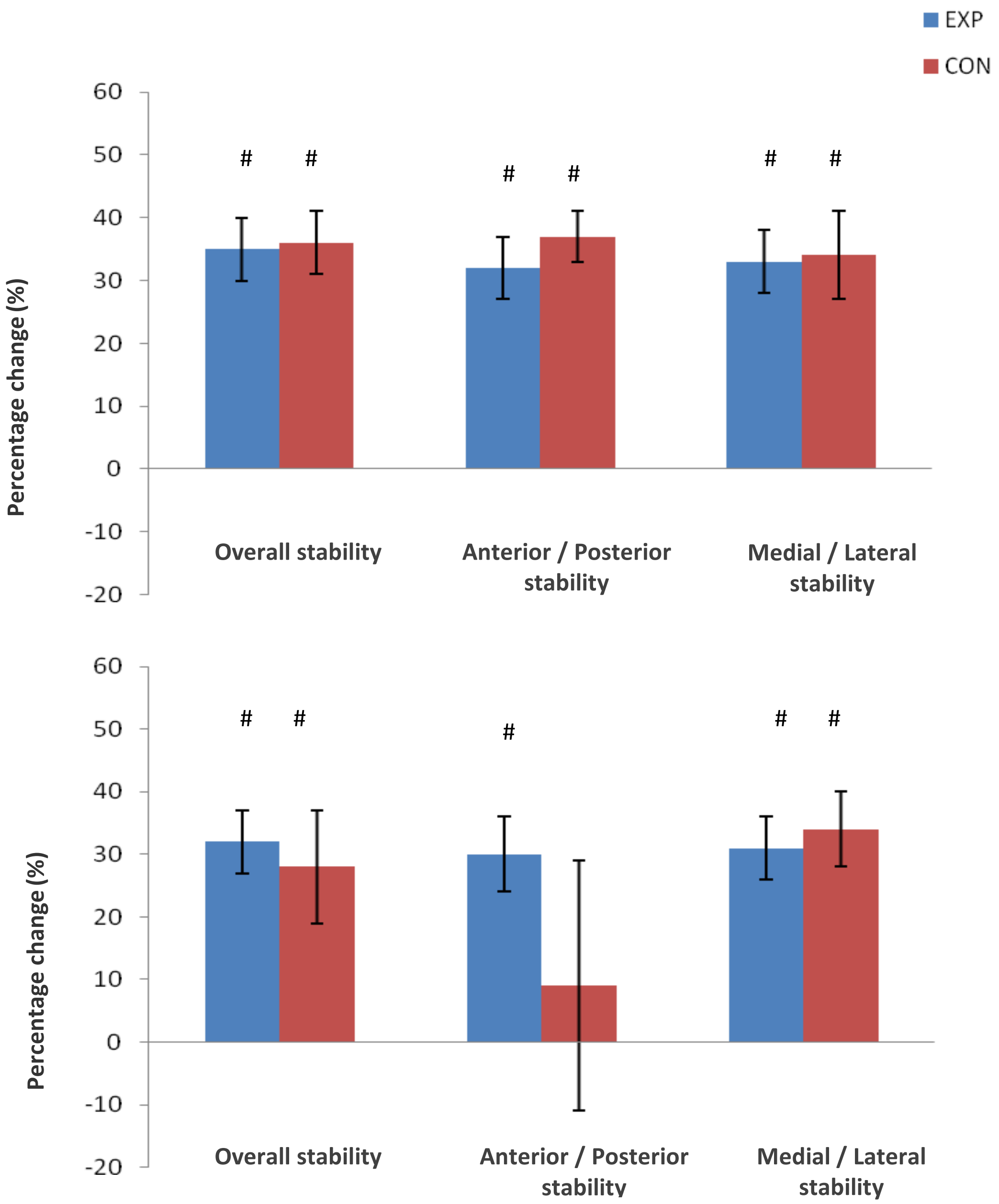


Figure 15: Percentage change in balance of the involved and uninvolved legs. #Significantly different from baseline ($p < 0.05$).

4. Leg circumference

4.1 Involved leg

The changes in circumferences of the involved legs are depicted in Figure 16A. The EXP and CON groups showed statistically significant increases at all sites ($p < 0.05$), except at the calf for the EXP group. The practical significances were very small to small (ES ≤ 0.2). The differences in change between the interventions were not statistically significantly different ($p > 0.05$). The change in the proximal and calf site showed a moderate practical difference between the interventions (ES = 0.4 to 0.5).

4.2 Uninvolved leg

The changes in circumferences of the uninvolved legs are depicted in Figure 16B. The EXP group showed a statistically significant increase for the mid-thigh, whereas the CON group showed statistically significant increases at the proximal and distal sites ($p < 0.05$). The practical significances were very small to small (ES ≤ 0.2). Only the change in circumference of the mid-thigh was statistically significantly different between the two interventions and was the only site that showed a large practical significant improvement (ES = 0.8).

There were three outliers in the EXP group and two outliers of the CON group in the distal thigh of the involved leg. There were also two outliers in the CON group in the calf of the uninvolved leg. However, these outliers did not affect the outcomes of the statistical tests.

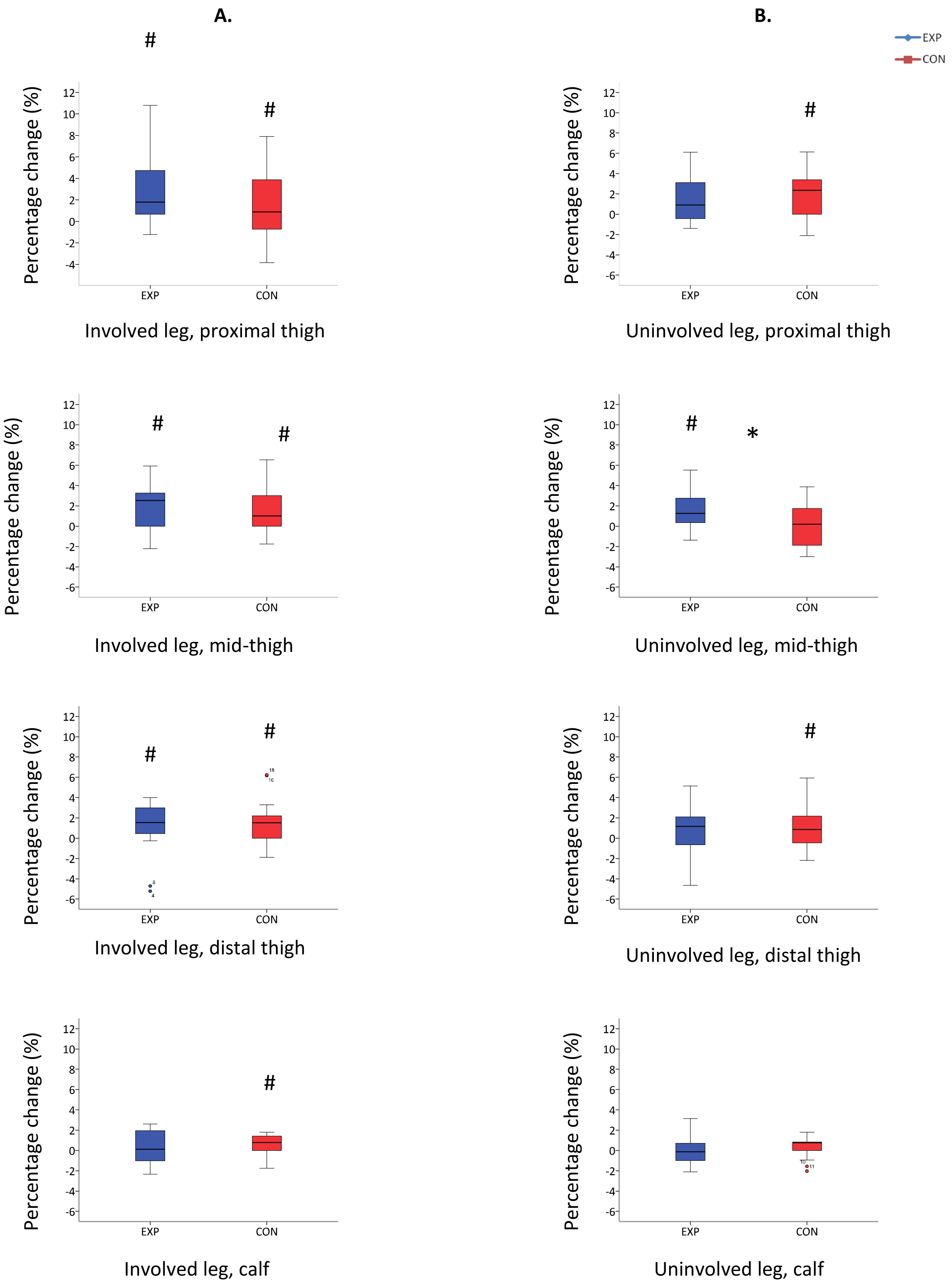


Figure 16: Percentage change in circumferences of the involved and uninvolved leg. #Significantly different from baseline ($p < 0.05$); *Significantly different between EXP group and CON group ($p < 0.05$). The horizontal line in the box indicates the median.

Table 3 depicts the deficit in circumference between the involved and uninvolved legs. Only the proximal thigh of the EXP group showed a statistical significant ($p < 0.05$) decrease in the circumference deficit.

Table 3: Percentage deficit in circumferences of the involved and uninvolved legs of the experimental (EXP) and control (CON) groups.

Circumference sites	**EXP (n = 21)**		**CON (n = 18)**	
	PRE	**POST**	**PRE**	**POST**
	Mean ± SEM	**Mean ± SEM**	**Mean ± SEM**	**Mean ± SEM**
Proximal thigh	2 ± 0	0 ± 1 #	1 ± 1	1 ± 0
Mid-thigh	2 ± 1	2 ± 1	2 ± 1	1 ± 1
Distal thigh	2 ± 1	2 ± 1	1 ± 0	1 ± 1
Calf	1 ± 0	1 ± 0	1 ± 0	1 ± 0

#Significantly different from baseline, $p < 0.05$

5. Flexibility

Table 4 presents the results for the flexibility tests. The following variables improved statistically significantly for the EXP group: involved *quadriceps*, involved and uninvolved *hamstrings*, involved and uninvolved *soleus* and sit-and-reach test ($p < 0.05$). The CON group showed a statistically significant improvement in the involved and uninvolved *hamstrings* and sit-and-reach test ($p \leq 0.05$). The involved and uninvolved *hamstrings* of the EXP group and CON group, as well as the uninvolved *soleus* showed a moderate to strong practical significant improvement. The differences in change between the interventions were not statistically different for any flexibility test, except for the involved *soleus* ($p < 0.05$). There was a moderate practical difference between the interventions for the flexibility of the involved *quadriceps* (ES = 0.5) and a strong practical difference for the flexibility of the involved *soleus* (ES = 0.8).

Table 4: The effect of the intervention programs on flexibility.

Flexibility Test	EXP (n = 21)		CON (n = 18)	
	PRE	POST	PRE	POST
	Mean ± SEM	Mean ± SEM	Mean ± SEM	Mean ± SEM
Involved *Quadriceps* (°)	56 ± 2	53 ± 3 #	55 ± 2	55 ± 2
Uninvolved *Quadriceps* (°)	56 ± 2	54 ± 3	57 ± 3	54 ± 2
Involved *Hamstrings* (°)	75 ± 3	83 ± 2 #	79 ± 3	85 ± 3 #
Uninvolved *Hamstrings* (°)	76 ± 3	83 ± 3 #	78 ± 3	85 ± 3 #
Sit-and-reach (cm)	42.0 ± 2.1	44.3 ± 1.7 #	45.5 ± 1.8	47.3 ± 1.7 #
Involved *Gastrocnemius* (°)	59 ± 2	60 ± 1	60 ± 2	61 ± 1
Uninvolved *Gastrocnemius* (°)	58 ± 2	60 ± 2	59 ± 1	59 ± 2
* Involved *Soleus* (°)	56 ± 2	59 ± 1 #	57 ± 2	56 ± 2
Uninvolved *Soleus* (°)	54 ± 2	58 ± 2 #	55 ± 2	57 ± 2

#Significantly different from baseline, $p < 0.05$
*Significantly different between EXP group and CON group, $p < 0.05$

CHAPTER EIGHT
DISCUSSION

A. INTRODUCTION

The present study examined the efficacy of backward locomotion training during a knee rehabilitation program. Rehabilitation techniques are constantly developed and adapted to aid in better and quicker recovery from injury and return to sport. Therefore, this study will not only contribute to the broad knowledge base of knee rehabilitation, but also have practical relevance regarding the usefulness of backward locomotion as a training modality during rehabilitation. The rationale for including backward locomotion in a knee rehabilitation program is threefold: (1) biomechanically, backward locomotion reduces the patellofemoral joint compressive forces; (2) backward locomotion training increases the strength and power of the *quadriceps;* and (3) backward locomotion training increases cardiorespiratory fitness. Other advantages of backward locomotion training include the improvement in coordination and balance, and facilitation of neuromuscular function.

The main findings of the study are that backward locomotion as part of a knee rehabilitation program resulted in a statistically significant increase in cardiorespiratory fitness and a practical significant increase in *quadriceps* and *hamstrings* muscle strength and power. Backward locomotion training showed similar increases in dynamic balance, and comparable changes in lower limb flexibility and circumferences compared to forward locomotion training.

B. DESCRIPTIVE CHARACTERISTICS

Knee injuries are highly prevalent in the physically active population. Clements *et al*. (1999) reported 34% of triathletes suffer knee injuries and Bradley *et al*. (2008) noted that 54% of football players had a history of sustaining a knee injury during sport. Knee injuries are the most common cause of permanent disability (Kujala *et al*., 1995). In this study the study sample was representative of individuals with knee injuries between the ages of 18 and 59 years with no other musculoskeletal injuries. All participants had either knee injury or -surgery in the previous 12 months, or had an ongoing knee problem limiting their activities of daily living. All but one participant sustained their knee injuries during sporting activities. That participant injured his knee in a car accident. The ages of the study sample were similar than previous studies (Halinen *et al*., 2006; Beynnon *et al*., 2005), which is indicative of the population who are most at risk to sustain a knee injury.

Both men and women were included in this study, although only 33% of the total group was women. There is an increased predisposition (up to eight times) of knee injuries in women, specifically ACL injuries (Kimberly *et al*., 2000; Stevenson *et al.,* 1998; Hutchinson, 1995) and patellofemoral disorders (Hutchinson, 1995; DeHaven and Lintner, 1986). Intrinsic and extrinsic risk factors have been proposed to explain this higher risk in women. Intrinsic factors are not modifiable and include physiological joint laxity, hormonal differences, lower extremity alignment, pelvis width, tibial rotation and ligament size. Extrinsic factors are potentially changeable and include baseline level of conditioning, experience, skill, strength, muscle recruitment patterns, and landing techniques (Kimberly *et al*., 2000; Hutchinson, 1995). Women also exhibit less muscular protection of the knee ligaments during external loading of the knee than their male counterparts (Wojtys *et al*., 2003). Yet, similar sports injury rates between men and women have been reported. This is due to the fact that knee injury prevalence seems to be sport-specific and that more men tend to participate in high-risk contact sports such as football (Kimberly *et al*., 2000). Conversely, Majewski *et al*. (2006) documented that 68.1% of treated knee injuries occurred in men, compared to the 31.6% in women. The gender of the remaining 0.3% was not documented.

Controversy exists regarding the risk of recurrent injury. Stevenson *et al.* (1998) reported a recurrent injury risk of 27% in women compared to 13% in men, among competitive alpine ski racers. However, Salmon *et al*. (2006) documented a 14% incidence of recurrent ACL injury in women and 19% in men in a seven year follow-up period. Corry *et al*. (1999) also reported a gender difference in outcome after ACL reconstruction. Two years after ACL reconstructions, women had greater knee laxity compared to men. Although Salmon *et al*. (2006) also reported significantly greater knee laxity in women when compared to men, the magnitude of the difference was small and the laxity results for both men and women were excellent. There were also no differences in activity level, as well as subjective or functional assessments of the men and women, either two or seven years postoperatively.

Consideration was given to the fact that an assumption was made in this study that men and women would respond similarly to the exercise interventions and that the results would not be affected by the mixed group. In fact, most studies on knee rehabilitation include both men and women (Tagesson *et al*., 2008; Heijne and Werner, 2007; Liu-Ambrose *et al*., 2003; Barber-Westin *et al*., 1999). To counter any possible bias in the results, men and women were separately and randomly divided into the EXP and CON groups. Therefore any possible differences between men and women regarding the response to the rehabilitation program, could not affect the outcome of the study. There were also no statistically significant differences in the baseline characteristics between the EXP and CON groups.

In general, the incidence of knee injuries varies depending on the type of sport. In this study, meniscus injuries (30.8%) as well as ACL injuries (17.9%) were most prevalent and were equally distributed between the two groups. Majewski *et al*. (2006) documented the type and frequency of sport injuries treated in a clinic in Switzerland over a 10 year period. 39.8 Percent of all treated injuries were related to the knee. The majority of the knee injuries occurred while engaging in soccer (35%) and skiing (26%). The most frequently occurring knee injuries were that of the ACL (20.3%), meniscus (14.5%) and MCL (7.9%).

All participants completed 24 exercise sessions. The rehabilitation program was divided into four phases of six sessions each. After each phase, adaptations were made to allow for progression. Participants were encouraged to exercise three times per week, but only a few were able to maintain this schedule. The majority of subjects completed two sessions per week. The duration of the intervention period was not set strictly at eight weeks since patients following knee injury will normally continue with rehabilitation until the prescribed rehabilitation program is completed.

The knee rehabilitation program consisted of cardiorespiratory training, strengthening exercises of the upper and lower legs, balance and joint proprioception exercises and stretches. The cardiorespiratory training lasted 20 minutes in Phase I and II, 25 minutes in Phase III and 30 minutes in Phase IV of every exercise session. The speed and incline of the treadmill, and level on the elliptical trainer was increased during subsequent exercise sessions to ensure that the cardiorespiratory training during each session was performed at an intensity of more than 60% of HR_{max}. The strengthening exercises in the rehabilitation program are typically found in phase I and II of knee rehabilitation programs. A generalized program was designed to accommodate the wide variety of knee injuries. The aims of the rehabilitation program were to restore or maintain full knee extension and flexion, achieve good *quadriceps* tone and leg control and to strengthen *quadriceps* and *hamstrings*, improve neuromuscular control, and improve cardiorespiratory fitness. This program is similar to the usual knee rehabilitation programs.

C. CHANGES IN PHYSIOLOGICAL AND PHYSICAL PARAMETERS

1. Aerobic fitness

Aerobic fitness was assessed by means of a progressive incremental exercise test to exhaustion on a cycle ergometer. Since the exercise modality during the intervention period was walking and running, a maximal exercise test on a treadmill would have been more specific. However, jogging and running is contraindicated in the early phases of several knee injuries due to the increased impact force and loading on the knee which increases the risk for a recurrent injury. A walking submaximal exercise test on a treadmill would not have been sufficient to show possible improvements in aerobic fitness since several subjects would not have been able to reach the second level of such a test due to knee constraints. Therefore, the aerobic test was performed on a cycle ergometer since cycling is considered a safe exercise modality during knee rehabilitation as there is reduced impact and loading on the knee (Olivier *et al.*, 2009).

1.1 Changes in VO_{2peak}

There were no statistically significant differences in baseline VO_{2peak} values between the backward and forward locomotion groups. After the interventions there was a slight, but not statistical significant decrease in VO_{2peak} values in the backward locomotion (1 ± 3%) and forward locomotion (2 ± 3%) groups. There were no statistical significant differences between the backward and forward locomotion and the practical difference between the groups was small. Helgerud *et al.* (2007) found that aerobic, high-intensity training at 90 – 95% of HR_{max} improved VO_{2max} statistically significantly more than aerobic training at 70% of HR_{max}, following an eight week training program. Childs *et al.* (2002) reported that they had to increase backward walking speed at week four of six weeks of training to maintain a fixed percentage of 60% of $VO_{2max.}$ They concluded that the changes in gait following backward locomotion training resulted in a decreased oxygen demand and that backward walking training resulted in greater economy of movement as an individual became more skilled at the novel activity. The participants in this study only trained at an intensity of ~60% of HR_{max} or higher, therefore the exercise intensity was not high enough to improve their VO_{2peak}. It is conceded that more deliberate efforts should have been made to adjust the exercise intensity as the program progressed, however, the researcher did not want to take undue risks with the participants. This also explains the lower submaximal VO_2 values that were reported by White *et al.* (1995) and Heath *et al.* (2001) following a backward training program. White *et al.* (1995) reported a 13% and 16% reduction in submaximal VO_2 following a six week backward walking program at 3.2 $km.h^{-1}$ and 5.12 $km.h^{-1}$, respectively, three times per week for eight minutes per session. Heath *et al.* (2001) also found a reduction in submaximal VO_2 (19%

decrease), following a four week backward walking program, three times a week for 15 minutes.

1.2 Changes in ventilatory threshold (VT)

Ventilatory threshold (VT) was defined as the point at which a non-linear increase in minute ventilation (VE, $ml.kg^{-1}.min^{-1}$) occurred in relation to oxygen consumption ($VO_{2,}$ $ml.kg^{-1}.min^{-1}$). VT was expressed as the percentage of $VO_{2peak.}$ VT was determined since it is be a better indicator of aerobic fitness than $VO_{2peak,}$ especially for sustainable submaximal aerobic endurance. There were no statistically significant differences in baseline VT values between the backward locomotion and forward locomotion groups. After the intervention, the backward locomotion group improved their VT (9 ± 5%), while the forward locomotion group remained relatively unchanged (0 ± 2%). The difference between the two interventions showed borderline statistically significance ($p = 0.06$) and the practical difference between backward and forward locomotion was moderate to strong (ES = 0.7). Londeree (1997) found that a training intensity near or below the VT is an adequate training stimulus for improving the thresholds and thus basic endurance capacity in inactive individuals. Therefore, the intensity of ~60% of HR_{max} in this study was sufficient to improve their VT following a period of inactivity due to their knee injuries. Terblanche *et al.* (2004) also found a significant improvement in cardiorespiratory fitness following a six week backward locomotion program in healthy females.

1.3 Changes in peak power output (PPO)

The peak power output (PPO) is an indication of the highest power output, measured in watts achieved during the maximal exercise test. There were no statistically significant differences in baseline PPO values between the backward locomotion and forward locomotion groups. Following the intervention, the backward locomotion group showed a statistical significant improvement in PPO (14%), while the forward locomotion group showed no statistical significant improvement (4%). The difference between the two interventions was statistically significant ($p < 0.05$) and resulted in a strong practical difference between backward and forward locomotion (ES = 0.8). The greater improvement in PPO in the backward locomotion group could result from the increased *quadriceps* strength and power which enabled them to produce a higher power output on the cycle ergometer. This finding is in agreement with Loveless *et al*. (2005) who documented a statistically significant increase in peak power output during incremental cycling following an eight week leg strengthening program.

2. Leg strength and power

2.1 Changes in leg strength

Knee flexor and extensor strength and power were assessed by a $120°.s^{-1}$ concentric/concentric knee extension-flexion isokinetic test on the Biodex System 3 isokinetic dynamometer. The $120°.s^{-1}$ test was used since it is considered safe at 12 weeks postoperatively. Ideally the isokinetic torque production at $60°.s^{-1}$ would be used to assess muscle strength, but it would be too strenuous on the injured leg and could result in recurrent injury. There were no significant differences for the baseline *quadriceps* deficit and *hamstrings* deficit between the EXP and CON groups. The deficit in *quadriceps* strength (EXP: 28.6%, CON: 25.8%) was greater than the deficit in *hamstrings* strength (EXP: 19.8%, CON: 12.7%). Mizner *et al*. (2005) documented a loss in *quadriceps* strength of 62% one month following total knee arthroplasty, compared to the preoperatively values. The impairment in *quadriceps* strength is mainly due to decreased voluntary muscle activation and it is also influenced by muscle atrophy. Failure of voluntary muscle activation causes a reduction in the maximal force output of a muscle due to an inability to recruit all of the muscle's motor units (Stevens *et al*., 2003). Halinen *et al*. (2009) reported *quadriceps* deficits of 20.5 to 30.7% one year following ACL and MCL ruptures. Liu-Ambrose *et al*. (2003) documented the deficit in *quadriceps* strength (3.3% to 31.3%) and *hamstrings* strength (12.1% to 24.9%) in patients that had ACL reconstructions and who were at least 6 months postoperative.

A deficit of more than 10 to 15% in muscle strength is indicative of the need for rehabilitation since it indicates a muscle imbalance (Davies *et al.*, 2000). The negative values obtained in the *hamstrings* deficit imply that the *hamstrings* strength of the injured leg was greater than that of the uninjured leg. A deficit in hamstring strength was not a prerequisite for inclusion in this study.

Only the *quadriceps* of the uninvolved leg of the forward locomotion group did not improve in strength after the intervention. In both groups, the improvements for the uninvolved *hamstrings* were the largest. The improvements in the *quadriceps* strength of the involved and uninvolved legs of the backward locomotion group could be as result of the higher peak activation of the rectus femoris and longer activation of the vastus lateralis. The concentric and isometric actions of the *quadriceps* during backward locomotion are also greater than during forward locomotion (van Deursen *et al.*, 1998; Devita and Stribling, 1991).

The leg strength test studied the concentric strength of the *quadriceps* and *hamstrings*. The improvements in the *hamstrings* strength of both groups could be as a result of the specific *hamstrings* strengthening exercises that were performed during each exercise session. It is a common believe that most individuals, especially women, lack *hamstrings* strength. Myer *et al.* (2009) documented that a movement pattern may be learned where decreased recruitment of *hamstrings* and *quadriceps* dominance occur. Therefore any program that focuses specifically on *hamstrings* activation would result in improvements of *hamstrings* strength.

Mackie and Dean (1984) documented a slight decrease in *quadriceps* and *hamstrings* muscle strength following a three month backward locomotion training program of individuals with knee ligament instability. However, the intensity, duration of sessions and mode of testing for this study are unknown. Therefore explanations for their findings are not apparent. Conversely, Threkeld *et al.* (1989) documented a statistical significant increase in *quadriceps* strength following eight weeks of backward running as part of a forward running program at angular velocities of 75° and 120°. The average distance run per week was 36 kilometers, of which 30% was replaced with backward running. Their explanation for the increase in *quadriceps* strength was that backward running changed muscular balance in the legs. Anderson *et al*. (1995) found borderline statistical significant improvements in the eccentric *quadriceps* strength and concentric and eccentric *hamstrings* strength in female runners following a six week backward running program. Their study involved the incorporation of backward running into the existing forward running programs, while the control group only maintained their existing forward running program. Therefore the improvements could have resulted from the additional training stimulus, and not specifically from backward running. However, Terblanche *et al*. (2004) found no statistical significant improvements in *quadriceps* or *hamstrings* muscle strength following a six week backward locomotion program. They theorized that a six week backward locomotion program could be too short to elicit significant improvements or that the program should be conducted not only on a flat surface. Therefore, the current study was conducted over a period of at least eight weeks and the cardiorespiratory training completed at different inclines on the treadmill.

Mikkelsen *et al*. (2000) found significant improvements in *quadriceps* and *hamstrings* strength following a six month knee rehabilitation program in patients with an ACL reconstruction. However, they found the use of OKC exercises combined with CKC exercises at six weeks following ACL reconstruction lead to significantly greater improvements in *quadriceps* torque than CKC exercises alone. OKC exercises induce greater levels of neuromuscular activation which stimulates muscle growth and strength more than CKC exercises. Conversely, Heijne and Werner (2007) also found significant improvements in *quadriceps* strength after a six month knee rehabilitation program, but no statistically significantly different improvements for the early introduction of OKC exercises at four weeks, compared to late introduction at 12 weeks following ACL reconstruction. However, Mikkelsen *et al*. (2000) did not perform any OKC exercises throughout their entire rehabilitation program. Furthermore, the OKC *quadriceps* exercises in their study were carried out on an isokinetic device. In the study by Heijne and Werner (2007), isotonic training was done on a leg extension machine. They concluded that the external torque during the leg extension were not constant, with lower resistance of the *quadriceps* where the muscles are stronger, resulting in less effective strength training compared with isokinetic training.

2.2 Changes in leg power

There were no statistically significant differences in baseline average strength between the two groups. Only the *quadriceps* of the uninvolved leg of the forward locomotion group did not improve in power after the intervention. In both groups, the improvements for the involved *hamstrings* were the largest. Power is a product of force and time, therefore, a lack of force (muscular strength) of the uninvolved *quadriceps* could result in the limited improvement in power. The backward locomotion group showed equal or greater improvements in average power than the forward locomotion group and could be as a result of the increased torque and power demands on the leg musculature during the backward thrust (Grasso *et al.*, 1998; Devita and Stribling, 1991). During backward locomotion the push-off from the stance phase to the swing phase occurs from the heel. Therefore the powerful ankle plantarflexors that facilitate push-off through a heel-to-toe action during forward locomotion play a secondary role in backward locomotion. Consequently, the hip and knee extensors are mainly responsible for this heel-off action. Mackie and Dean (1984) found a statistical significant improvement in *quadriceps* and *hamstrings* muscle power following a three month backward locomotion training program of individuals with knee ligament injuries. Explanations for their findings are not apparent since details of the training program are unknown.

Although the differences in change between the backward and forward locomotion training were not statistically significant, there were moderate to strong practical differences between the backward and forward locomotion training groups, indicating that backward locomotion is a better alternative during knee rehabilitation.

3. Balance

Balance was assessed by the Athlete Single Leg Balance Test on the Biodex Balance System SD. Overall stability; anterior-posterior stability and medial-lateral stability were reported on a stability index as the average position from the centre. The overall stability index (OSI) takes into account the centre of gravity displacement in the anterior-posterior and medial-lateral directions. The anterior-posterior stability index (APSI) reports the displacement in the sagital plane and represents neuromuscular control of the *quadriceps* and *hamstrings* muscles as well as the anterior/posterior compartment muscles of the lower leg. The medial-lateral stability index (MLSI) reports the displacement in the frontal plane and represents neuromuscular control of the inversion and eversion muscles of the lower leg (Biodex, 2008). No displacement would be reported as a score of zero on the scale, therefore a higher score would indicate poor neuromuscular control. At baseline there was no statistical significant difference in the OSI of the two groups for the involved as well as uninvolved legs. However, the overall stability of the involved legs was more affected than that of the uninvolved legs.

Paterno *et al.* (2004) documented statistical significant improvements in overall stability (right leg: 19%; left leg: 18%) and anterior-posterior stability (right leg: 25%; left leg: 23%), but not medial-lateral stability (right leg: 5%, left leg: 0%) following three 90-minute neuromuscular training sessions per week for 6 weeks in healthy female high school athletes. Their explanation for the findings were that the training program utilized failed to properly stimulate stability improvement in the medial-lateral direction. The 3 components of the dynamic neuromuscular training protocol utilized in the study include: (1) balance training and hip/pelvis/trunk strengthening, (2) plyometrics and dynamic movement training, and (3) resistance training.

In the present study, statistical significant improvements were seen in overall stability, anterior-posterior stability and medial-lateral stability of the involved as well as uninvolved legs, except the anterior-posterior stability of the uninvolved leg of the CON group following neuromuscular training of thirty minutes or less in each exercise session. There were no statistical significant differences of the OSI, APSI and MLSI of the involved legs as well as uninvolved legs between the two groups before the intervention. Only the APSI of the uninvolved leg of the CON group did not improve after the intervention but could be explained by the huge inter-individual variability (9 ± 20%).

As stated previously, both sensory and motor systems influence balance control. Proprioceptive inputs from postural muscles, especially leg postural muscles are important (Hosseinimehr *et al.*, 2009). During backward locomotion the neuromuscular system can be exercised extensively by incorporating dynamic gait as well as static postural control on alternating legs. Therefore backward locomotion could facilitate balance and proprioception (Bates *et al.*, 1986), but there is no statistically significant or practical difference between backward and forward locomotion.

4. Leg circumference

The EXP and CON groups showed statistical significant changes in the circumferences of the involved legs at the proximal (EXP: 3 ± 1; CON: 1 ± 9%), mid-thigh (EXP: 2 ± 1; CON: 1 ± 7%) and distal (EXP: 1 ± 1; CON: 2 ± 7%) sites, and only the CON group at the calf site (1 ± 5%). In the uninvolved legs the EXP group showed a statistical significant change in circumference of the mid-thigh (2 ± 0%), whereas the CON group showed statistical significant changes in circumferences of the proximal (2 ± 7%) and distal (1 ± 7%) sites. However, the change in circumferences cannot be ascribed to an increase in muscle mass, since the fat percentage of the EXP (6 ± 1%) and CON (8 ± 3%) group increased over the intervention period. Therefore, the asymmetry between the circumferences of the involved and uninvolved legs was also assessed. Only the EXP group showed a statistical significant improvement in the deficit of the circumference of the proximal thigh. The deficit of 2 ± 0% between the legs improved to a deficit of 0 ± 1%.

Leg circumferences were measured to assess the deficits between the involved and uninvolved legs. It was expected that there would have been atrophy in the involved legs. However, it was not expected that the backward locomotion, forward locomotion or leg strengthening exercises would have resulted in hypertrophy in the muscles following only eight weeks of training. According to the literature, the early gains in muscular strength following a training program results from neural adaptations and not enlargement of the fibers (Powers and Howley, 2004: 266). Therefore, the improvements in *quadriceps* and *hamstring*s muscle strength following the rehabilitation program probably resulted from neural adaptations.

Although the circumferences were measured by the same investigator, the method of measurement could not have been sensitive enough to measure small changes. Skinfold measurements at the calf and thigh sites in addition to the circumferences would have given more specific indications regarding the type of changes in the lower limb circumferences.

5. Flexibility

Flexibility tests were conducted to measure musculotendinous components of flexibility and used to identify limitations to musculotendinous flexibility. It is commonly believed that lack of flexibility may be the cause of soft tissue injuries, but it is still not clear from the research whether insufficient or excessive flexibility are predictors of future injury (Harvey, 1998). During this study, stretching was performed at the end of each exercise session in order to improve or maintain full ROM in the knee and muscle.

There were no statistical differences in *quadriceps* flexibility between the EXP and CON group at baseline. Only the involved *quadriceps* showed a statistical significant difference in change between the EXP and CON group. The EXP group improved in 3°, whereas the CON group remained constant. The mean angles following the interventions for the involved *quadriceps* (EXP: 53°; CON: 55°) as well as uninvolved *quadriceps* (EXP: 54°; CON: 54°) are comparable to the mean angle of the *quadriceps* (52.5°) in healthy basketball players, tennis players, runners and rowers (Harvey, 1998).

There were no statistical differences in *hamstrings* flexibility between the EXP and CON group at baseline. The involved and uninvolved *hamstrings* of the EXP and CON group showed a statistical significant improvement in flexibility. However, there were no statistical significant differences between the two groups after the interventions. Therefore, the improvements are likely resultant from the *hamstrings* stretches following each exercise session. Chan *et al*. (2001) documented an improvement of 9° in hamstring flexibility following a four week stretching protocol which entailed two sets of five repetitions of a 30 second stretch. An improvement of 11° was documented following an eight week stretching protocol which involved one set of five repetitions of a 30 second stretch. The current study showed improvements in the involved *hamstrings* (EXP: 8°; CON: 6°) and uninvolved *hamstrings* (EXP: 7°; CON: 7°). However, the stretching protocol only entailed two repetitions of 30 seconds. Therefore, the stretching protocol was likely to cause the increase in *hamstrings* flexibility and not specifically the backward or forward locomotion.

The sit-and-reach test is an indicator of *hamstrings* and lower back flexibility. The EXP and CON group showed statistical significant improvements in flexibility following the interventions. However, there were no statistical significant differences between the two groups after the interventions. Therefore, the improvements could also be as a result of the *hamstrings* stretches following each exercise session of the rehabilitation program.

Restrictions of dorsiflexion may be due to *gastrocnemius-soleus* complex tightness. Individuals with a restriction of dorsiflexion often compensate by pronating the foot in weight-bearing which can cause biomechanical changes in the lower extremity and predispose individuals to overuse injuries. *Gastrocnemius* flexibility should be 60° to 70°, of which more than 70° is considered abnormal, whereas *soleus* flexibility should be 50° to 60° and more than 60° is considered abnormal (Gore, 2000: 112-113).

There were no statistical significant differences in the *gastrocnemius* flexibility between the EXP and CON groups at baseline. There were no statistically significant changes after the intervention for the two groups. The angles (29 - 31˚) for *gastrocnemius* flexibility were comparable to, or slightly better than the angles (20 - 30˚) described by Gore (2000: 112-113) as normal *gastrocnemius* flexibility.

There were no statistical significant differences in the *soleus* flexibility between the EXP and CON groups at baseline. Both the involved and uninvolved *soleus* of the EXP group improved in flexibility following the intervention. The difference in change between the interventions was statistical significant for the involved *soleus*. The statistical significant improvements in *soleus* flexibility of the backward locomotion group could be as a result of the sharp dorsiflexion that occurs at the ankle joint during backward locomotion when weight acceptance occurs. The maximum ankle dorsiflexion angle is noticeably greater in backward locomotion compared to forward locomotion (van Deursen *et al.*, 1998; Devita and Stribling, 1991; Vilensky *et al.*, 1987); therefore, additional stretching of the *soleus* could have occurred.

D. EVALUATION OF THE INTERVENTION PROGRAM

The rehabilitation program included exercises to address weaknesses that are typically prevalent in patients following knee injury and included both CKC and OKC exercises. Participants only started the knee rehabilitation program 12 weeks or later after injury or surgery and followed the program for 24 sessions. Ideally, the program should be started immediately postoperatively and continued until a return to sport is allowed (Sekir *et al.*, 2010; Risberg *et al.*, 1999). Thereby a true reflection of the efficacy of backward locomotion in a knee rehabilitation program would be obtained. The intensity of the cardiorespiratory exercises was set at ~60% of HR_{max}, however, increased intensities would have been possible which would potentially increase the VO_{2peak}.

E. CONCLUSION

Limited studies have been conducted on the effect of backward locomotion training. Only one study involving backward locomotion training was conducted on individuals with knee ligament instability. No research has been conducted on the effect of backward locomotion training as part of a knee rehabilitation program.

The primary findings of this study are that backward locomotion as well as forward locomotion contributes to the recovery of knee injuries, however backward locomotion contributes more to the improvement in cardiorespiratory fitness. The practical significance of backward locomotion on *quadriceps* and *hamstrings* muscle strength and power is greater than forward locomotion. This suggests that backward locomotion is a better alternative rehabilitation modality for athletes as this will affect a quicker return to their sport and in a better conditioned state.

F. STUDY LIMITATIONS AND FUTURE STUDIES

A limitation of this study was that the rehabilitation program and backward locomotion was not started immediately following knee injury or surgery, but only once clearance from the medical doctor was obtained. Individuals that participated in this study were at least 12 weeks post injury or surgery. Accelerated rehabilitation programs incorporate full weight-bearing as early as two weeks postoperatively. Future studies are needed to determine the effects of backward locomotion incorporated from phase I of the knee rehabilitation and the continuation of the program until return to sport in order to determine whether backward locomotion training results in a quicker return to sport.

REFERENCES

ABBOTT, B., BIGLAND, B. & RITCHIE, J. (1952). The physiological cost of negative work. *The Journal of Physiology* 117(3): 380-390.

AGEBERG, E., ZÄTTERSTRÖM, R., MORITZ, U. & FRIDÉN, T. (2001). Influence of supervised and nonsupervised training on postural control after an acute anterior cruciate ligament rupture: A three-year longitudinal prospective study. *The Journal of Orthopaedic and Sports Physical Therapy* 31(11): 632-644.

AGLIETTI, P., GIRON, F., BUZZI, R., BIDDAU, F. & SASSO, F. (2004). Anterior cruciate ligament reconstruction: Bone-patellar-tendon-bone compared with double semitendinosus and gracilis tendon grafts. A prospective, randomized clinical trial. *The Journal of Bone and Joint Surgery* 86(10): 2143-2155.

AKESON, W., AMIEL, D., ABEL, M., GARFIN, S. & WOO, S. (1987). Effects of immobilization on joints. *Clinical Orthopaedics and Related Research* 219: 28-37.

ANDERSEN, L.L., MAGNUSSON, S.P., NIELSEN, M., HALEEM, J., POULSEN, K. & AAGAARD, P. (2006). Neuromuscular activation in conventional therapeutic exercises and heavy resistance exercises: Implications for rehabilitation. *Physical Therapy* 86(5): 683-697.

ANDERSON, C.G., CONVERY, J.J., CRAVEN, S.D. & GREENE, J.K. (1995). The effects of retro running on quadriceps and hamstring muscle strength. Unpublished M. (Physical therapy) dissertation. Springfield College.

ARATA, A.W. (1999). Kinematic and kinetic evaluation of high speed backward running. Unpublished doctoral dissertation, University of Oregon Microform Publications.

BALLMER, P. & JAKOB, R. (1988). The non operative treatment of isolated complete tears of the medial collateral ligament of the knee. *Archives of Orthopaedic and Trauma Surgery* 107(5): 273-276.

BARBER-WESTIN, S.D., NOYES, F.R., HECKMANN, T.P. & SHAFFER, B.L. (1999). The effect of exercise and rehabilitation on anterior-posterior knee displacements after anterior cruciate ligament autograft reconstruction. *The American Journal of Sports Medicine* 27(1): 84-93.

BATES, B.T., MORRISON, E. & HAMILL, J. (1986). A comparison between forward and backward running. Human Locomotion IV, Proceedings of the Biennial Conference of the Canadian Society for Biomechanics, Montreal, Quebee, Canada: 307-308.

BATHGATE, A., BEST, J., CRAIG, G. & JAMIESON, M. (2002). A prospective study of injuries to elite australian rugby union players. *British Journal of Sports Medicine* 36(4): 265-269.

BERNSTEIN, J. (2010). In brief: Meniscal tears. *Clinical Orthopaedics and Related Research* 468(4): 1190-1192.

BESIER, T.F., FREDERICSON, M., GOLD, G.E., BEAUPRÉ, G.S. & DELP, S.L. (2009). Knee muscle forces during walking and running in patellofemoral pain patients and pain-free controls. *Journal of Biomechanics* 42(7): 898-905.

BEYNNON, B.D., UH, B.S., JOHNSON, R.J., ABATE, J.A., NICHOLS, C.E., FLEMING, B.C., POOLE, A.R. & ROOS, H. (2005). Rehabilitation after anterior cruciate ligament reconstruction. *The American Journal of Sports Medicine* 33(3): 347.

BIODEX (2008). *Biodex balance SD Software upgrade version 1.32 release notes*. New York, USA: Biodex.

BRADLEY, J., HONKAMP, N.J., JOST, P., WEST, R., NORWIG, J. & KAPLAN, L.D. (2008). Incidence and variance of knee injuries in elite college football players. *The American Journal of Orthopedics* 37(6): 310-314.

BUCKWALTER, J.A. & GRODZINSKY, A.J. (1999). Loading of healing bone, fibrous tissue, and muscle: Implications for orthopaedic practice. *Journal of the American Academy of Orthopaedic Surgeons* 7(5): 291-299.

BULGHERONI, P., BULGHERONI, M., RONGA, M. & MANELLI, A. (2007). Gait analysis of pre-and post-meniscectomy knee: A prospective study. *The Knee* 14(6): 472-477.

BURROUGHS, P. & DAHNERS, L.E. (1990). The effect of enforced exercise on the healing of ligament injuries. *The American Journal of Sports Medicine* 18(4): 376-378.

CACHUPE, W.J.C., SHIFFLETT, B., KAHANOV, L. & WUGHALTER, E.H. (2001). Reliability of biodex balance system measures. *Measurement in Physical Education and Exercise Science* 5(2): 97-108.

CARTER, N., JENKINSON, T., WILSON, D., JONES, D. & TORODE, A. (1997). Joint position sense and rehabilitation in the anterior cruciate ligament deficient knee. *British Journal of Sports Medicine* 31(3): 209-212.

CAVANAUGH, P.R. & WILLIAMS, K.R. (1982). The effect of stride length variations on oxygen uptake during distance running. *Med Sci Sports Exer* 14: 30-35.

CHALOUPKA, E.C., KANG, J., MASTRANGELO, M.A. & DONNELLY, M.S. (1997). Cardiorespiratory and metabolic responses during forward and backward walking. *The Journal of Orthopaedic and Sports Physical Therapy* 25(5): 302-306.

CHAN, S.P., HONG, Y. & ROBINSON, P.D. (2001). Flexibility and passive resistance of the hamstrings of young adults using two different static stretching protocols. *Scandinavian Journal of Medicine & Science in Sports* 11: 81–86.

CHILDS, J.D., GANTT, C., HIGGINS, D., PAPAZIS, J.A., FRANKLIN, R., METZLER, TERRI, UNDERWOOD, & FRANK, B. (2002). The effect of repeated bouts of backward walking on physiologic efficiency. *The Journal of Strength & Conditioning Research* 16(3): 451-455.

CIPRIANI, D.J., ARMSTRONG, C.W. & GAUL, S. (1995). Backward walking at three levels of treadmill inclination: An electromyographic and kinematic analysis. *The Journal of Orthopaedic and Sports Physical Therapy* 22(3): 95-102.

CLEMENTS, K., YATES, B. & CURRAN, M. (1999). The prevalence of chronic knee injury in triathletes. *British Journal of Sports Medicine* 33(3): 214-216.

COHEN, J. (1988). *Statistical power analysis for the behavioral sciences*. Erlbaum: Lawrence & Associates.

CONRAD, B., BENECKE, R., CARNEHL, J., HONE, J. & MEINCK, H.M. (1983). Pathophysiological aspects of human locomotion. In Desmedt, J.E. (Ed.),Motor Control. Mechanisms in Health and Disease. New York: Raven Press 717–726.

COOK, J., KHAN, K., HARCOURT, P., GRANT, M., YOUNG, D. & BONAR, S. (1997). A cross sectional study of 100 athletes with jumper's knee managed conservatively and surgically. *British Journal of Sports Medicine* 31(4): 332-336.

COVEY, D.C. (2001). Injuries of the posterolateral corner of the knee. *Journal of Bone and Joint Surgery* 83(1): 106-118.

CORRY, I., WEBB, J.M., CLINGELEFFER, A.J. & PINCZEWSKI, L. (1999). Arthroscopic reconstruction of the anterior cruciate ligament: a comparison of patellar tendon autograft and four-strand hamstring tendon autograft. *The American Journal of Sports Medicine* 27(3): 444-454.

CROSSLEY, K.M., THANCANAMOOTOO, K., METCALF, B.R., COOK, J.L., PURDAM, C.R. & WARDEN, S.J. (2007). Clinical features of patellar tendinopathy and their implications for rehabilitation. *Journal of Orthopaedic Research* 25(9): 1164-1175.

CREMA, M.D., ROEMER, F.W., MARRA, M.D., NIU, J., ZHU, Y., LYNCH, J., LEWIS, C.E., EL-KHOURY, G., FELSON, D.T. & GUERMAZI, A. (2008). MRI-detected bone marrow edema-like lesions are strongly associated with subchondral cysts in patients with or at risk for knee osteoarthritis: the MOST study. *Osteoarthritis and Cartilage* 16(4): S160.

DANDY, D.J. & PUSEY R.J. (1998).The long-term results of unrepaired tears of the posterior cruciate ligament. *Journal of Bone and Joint Surgery* 26: 778-784.

DAVIES, G.J., HEIDERSCHEIT, B. & BRINKS, K. (2000). Test interpretation. In Isokinetics in human performance. Ed: Brown, L.E. The United States of America: Human Kinetics.

DEHAVEN, K.E. & LINTNER, D.M. (1986). Athletic injuries: comparison by age, sport, and gender. *The American Journal of Sports Medicine* 14(3): 218-224.

DE CARLO, M. & ARMSTRONG, B. (2010). Rehabilitation of the knee following sports injury. *Clinical Sports Medicine* 29: 81-106.

DEVITA, P. & STRIBLING, J. (1991). Lower extremity joint kinetics and energetics during backward running. *Medicine & Science in Sports & Exercise* 23(5): 602-610.

DROUIN, J.M., VALOVICH-MCLEOD, T.C., SHULTZ, S.J., GANSNEDER, B.M. & PERRIN, D.H. (2004). Reliability and validity of the Biodex system

3 pro isokinetic dynamometer velocity, torque and position measurements. *European Journal of Applied Physiology* 91(1): 22-29.

DUYSENS, J., TAX, A.A.M., MURRER, L. & DIETZ, V. (1996). Backward and forward walking use different patterns of phase-dependent modulation of subcutaneous reflexes in humans. *Journal of Neurophysiology* 76(1): 301-310.

ELLSASER, J.C., REYNOLDS, F.C. & OMOHUNDRO, J.R. (1974). The non-operative treatment of collateral ligament injuries of the knee in professional football players: An analysis of seventy-four injuries treated non-operatively and twenty-four injuries treated surgically. *Journal of Bone and Joint Surgery* 56: 1185-1190.

FLYNN, T.W., CONNERY, S.M., SMUTOK, M.A., ZEBALLOS, R.J. & WEISMAN, I.M. (1994). Comparison of cardiopulmonary responses to forward and backward walking and running. *Medicine & Science in Sports & Exercise* 26(1): 89-94.

FLYNN, T.W. & SOUTAS-LITTLE, R.W. (1993). Mechanical power and muscle action during forward and backward locomotion. *The Journal of Orthopaedic and Sports Physical Therapy* 17(2): 108-112.

FLYNN, T.W. & SOUTAS-LITTLE, R.W. (1995). Patellofemoral joint compressive forces in forward and backward running. *The Journal of Orthopaedic and Sports Physical Therapy* 21(5): 277-282.

FU, F.H., BENNETT, C.H., LATTERMANN, C. & BENJAMIN, C. (1999). Current trends in Anterior Cruciate Ligament Reconstruction. Part 1: Biology and Biomechanics of Reconstruction. *The American Journal of Sports Medicine* 27(6): 821-830.

GILLQUIST, J. & MESSENER, K. (1999). Anterior cruciate ligament reconstruction and the long-term incidence of gonarthrosis. *Sports Medicine* 27: 143-156.

GLASGOW, S.G., GABRIEL, J.P., SAPEGA, A.A., GLASGOW, M.T. & TORG, J.S. (1993). The effect of early versus late return to vigorous activities on the outcome of anterior cruciate ligament reconstruction. *The American Journal of Sports Medicine* 21(2): 243-248.

GORE, C.J. (2000). *Physiological tests for elite athletes.* Champaign, IL: Human Kinetics.

GRASSO, R., BIANCHI, L. & LACQUANITI, F. (1998). Motor patterns for human gait: Backward versus forward locomotion. *Journal of Neurophysiology* 80(4): 1868-1885.

GRIFFITHS, G.P. & SELESNICK, F.H. (1998). Operative treatment and arthroscopic findings in chronic patellar tendonitis. *Arthroscopy* 14(8): 836-839.

GRIMBY, G., GUSTAFSSON, E., PETERSON, L. & RENSTROM, P. (1980). Quadriceps function and training after knee ligament surgery. *Medicine & Science in Sports & Exercise* 12(1): 70-75.

HALINEN, J., LINDAHL, J., HIRVENSALO, E. & SANTAVIRTA, S. (2006). Operative and nonoperative treatments of medial collateral ligament rupture with early anterior cruciate ligament reconstruction. *The American Journal of Sports Medicine* 34(7): 1134-1140.

HALINEN, J., LINDAHL, J. & HIRVENSALO, E. (2009). Range of motion and quadriceps muscle power after early surgical treatment of acute combined anterior cruciate and grade-III medial collateral ligament injuries. *The Journal of Bone and Joint Surgery* 91: 1305-1312.

HARVEY, D. (1998). Assessment of the flexibility of elite athletes using the modified Thomas Test. *British Journal of Sports Medicine* 32: 68–70.

HEATH, E.M., BLACKWELL, J.R., BAKER, U.C., SMITH, D.R. & KORNATZ, K.W. (2001). Backward walking practice decreases oxygen uptake, heart rate and ratings of perceived exertion. *Physical Therapy in Sport* 2: 171-177.

HEIJNE, A. & WERNER, S. (2007). Early versus late start of open kinetic chain quadriceps exercises after ACL reconstruction with patellar tendon or hamstring grafts: a prospective randomized outcome study. *Knee Surgery, Sports Traumatology, Arthroscopy* 15(4): 472-473.

HEINZELMANN, A.D. & BARRETT, G.R. (2009). Posterior cruciate ligament reconstruction: Achilles tendon allograft, double bundle. *Clinical Sports Medicine* 28: 245-257.

HELGERUD, J., HOYDAL, K., WANG, E., KARISEN, T., BERG, P., BIERKAAS, M., HELGESEN, C., HJORTH, N., BACH, R, & HOFF, J. (2007). Aerobic high-intensity intervals improve VO_{2max} more than moderate training. *Medicine & Science in Sports & Exercise* 39(4): 665-671.

HORAK, F.B. (1991). Assumptions underlying motor control for neurological rehabilitation. In Foundation for Physical Therapy: Contemporary Management of Motor Control Problems, Proceedings of the II-STEP Conference. Alexandria, VA: Author.

HOSSEINIMEHR, S.H., NORASTEH, A.A., DANESHMANDI, H., RAHPEMAY-RAD, K & RAHIMI, R. (2009). The effect of vibration on leg muscles proprioception in static and dynamic postural control. *Journal of Medicina dello Sport* 62:35-43.

HOWELL, L.C.S.M. & TAYLOR, C.M.A. (1996). Brace-free rehabilitation, with early return to activity, for knees reconstructed with a double-looped semitendinosus and gracilis graft. *The Journal of Bone and Joint Surgery* 78(6): 814.

HRELJAC, A., IMAMURA, R., ESCAMILLA, R. F., CASEBOLT, J. & SISON, M. (2005). Preferred and energetically optimal transition speeds during backward human locomotion. *Journal of Sports Science and Medicine* 4(4): 446-454.

HURLEY, M.V. & SCOTT, D.L. (1998). Improvements in quadriceps sensorimotor function and disability of patients with knee osteoarthritis following a clinically practicable exercise regime. *British Journal of Rheumatology* 37: 1181-1187.

HUTCHINSON, M.R. (1995). Knee injuries in female athletes. *Sports Medicine* 19(4): 288-302.

INDELICATIO, P.A. (1983). Non-operative treatment of complete tears of the medial collateral ligament of the knee. *The Journal of Bone and Joint Surgery* 65: 323-329.

INSALL, J. (1979). Chrondromalacia patella: patellar malignment syndrome. *Orthopedic Clinics of North America* 10: 117-127.

JEROSCH, J. & PRYMKA, M. (1996). Knee joint proprioception in patients with posttraumatic recurrent patellar dislocation. *Knee surgery, Sports Traumatology, Arthroscopy* 4:14-18.

KARMANI, S. & EMBER, T. (2003). The anterior cruciate ligament – 1. *Current Orthopaedics* 17: 369-377.

KIMBERLY, G. & LLOYD, M. (2000). Gender differences in noncontact anterior cruciate ligament injuries. *Clinics in Sports Medicine* 19(2): 287-302.

KRAMER, J.F. & REID, D.C. (1981). Backward walking: a cinematographic and electromyographic pilot study. Physiotherapy 33(2): 77-81.

KUJALA, U.M., TAIMELA, S., ANTTI-POIKA, I., ORAVA, S., TUOMINEN, R. & MYLLYNEN, P. (1995). Acute injuries in soccer, ice hockey, volleyball, basketball, judo, and karate: analysis of national registry data. *British Medical Journal* 311: 1465-1468.

LEWEK, M.D., RUDOLPH, K.S. & SNYDER-MACKLER, L. (2004). Quadriceps femoris muscle weakness and activation failure in patients with symptomatic knee osteoarthritis. *Journal of Orthopaedic Research* 22(1): 110-115.

LIAN, O.B., ENGEBRETSEN, R. & BAHR, R. (2005). Prevalence of jumper's knee among elite athletes from different sports: a cross-sectional study. *The American Journal of Sports Medicine* 33:561-567.

LIU-AMBROSE, T., TAUNTON, J., MACINTYRE, D., MCCONKEY, P. & KHAN, K. (2003). The effects of proprioceptive or strength training on the neuromuscular function of the ACL reconstructed knee: A randomized clinical trial. *Scandinavian Journal of Medicine & Science in Sports* 13(2): 115-123.

LOGAN, M., WATTS, M., OWEN, J. & MYERS, P. (2009). Meniscal repair in the elite athlete. *The American Journal of Sports Medicine* 10(10): 1-4.

LOHMANDER, L.S., OSTENBERG, A., ENGLUND, M. & ROOS, H. (2004). High prevalence of knee osteoarthritis, pain, and functional limitations in female soccer players twelve years after anterior cruciate ligament injury. *Arthritis & Rheumatism* 50(10):3145-3152.

LOVELESS, D.J., WEBER C.L., HASELER, L.J. & SCHNEIDER, D.A. (2005). Maximal leg-strength training improves cycling economy in previously untrained men. Medicine & Science in Sports & Exercise 37(7):1231-1236.

LONDEREE, B.R. (1997). Effect of training on lactate/ventilatory thresholds: a meta-analysis. *Medicine & Science in Sports & Exercise* 29(6): 837-843.

MACKIE, J. & DEAN, T. (1984). Running backward training effects on upper leg musculature and ligamentous instability of injured knees (abstract). *Medicine & Science in Sports & Exercise* 16(2): 151.

MAJEWSKI, M., SUSANNE, H. & KLAUS, S. (2006). Epidemiology of athletic knee injuries: A 10-year study. *The Knee* 13(3): 184-188.

MCCONNELL, J. (2007). Rehabilitation and Nonoperative Treatment of Patellar Instability. *Sports Medicine & Arthroscopy Review* 15(2): 95-104.

MCDERMOTT, I.D. & AMIS, A.A. (2006). The consequences of meniscectomy. *Journal of Bone and Joint Surgery* 88(12): 1549-1556.

MESSNER, K. & MALETIUS W. (1999). Eighteen- to twenty-five-year follow-up after acute partial anterior cruciate ligament rupture. *American Journal of Sports Medicine* 27(4): 455-459.

MIKKELSEN, C., WERNER, S. & ERIKSSON, E. (2000). Closed kinetic chain alone compared to combined open and closed kinetic chain exercises for quadriceps strengthening after anterior cruciate ligament reconstruction with respect to return to sports: A prospective matched follow-up study. *Knee Surgery, Sports Traumatology, Arthroscopy* 8(6): 337-342.

MINETTI, A.E. & ARDIGÒ, L.P. (2001). The transmission efficiency of backward walking at different gradients. *European Journal of Physiology* 442(4): 542-546.

MIYASAKA, K.C., DANIEL, D.M. & STONE, M.L. (1991). The incidence of knee ligament injuries in the general population. American Journal of Knee Surgery 4: 3–8.

MIZNER, R.L. STEVENS, J.E. & SNYDER-MACKLER, L. (2003). Voluntary activation and decreased force production of the quadriceps femoris muscle after total knee arthroplasty. *Physical Therapy* 83(4): 359-365.

MIZNER, R.L., PETTERSON, S.C., STEVENS, J.E., VANDENBORNE, K. & SNYDER-MACKLER, L. (2005). Early quadriceps strength loss after total knee arthroplasty. *The Journal of Bone and Joint Surgery* 87A(5): 1047-1053.

MYATT, G., BAXTER, R., DOUGHERTY, R., WILLIAMS, G., HALLE, J., STETTS, D. & UNDERWOOD, F. (1995). The cardiopulmonary cost of backward walking at selected speeds. *Journal of Orthopaedic & Sports Physical Therapy* (3):132-8.

MYER, G.D., FORD, K.R., BARBER FOSS, K.D., LIU, C.L., NICK, T.G. & HEWETT, T.E. (2009). The relationship of hamstrings and quadriceps strength to anterior cruciate ligament injury in female athletes. *Clinical Journal of Sport Medicine* 19(1): 3-8.

NOYES, F.R. (1977). Functional properties of knee ligaments, alterations induced by immobilization. A correlative biomechanical, histological study in primates. *Clinical Orthopaedics* 123: 210-242.

O'DONOGHUE D.H. (1950). Surgical treatment of fresh injuries to the major ligaments of the knee. *Journal of Bone and Joint Surgery* 32A(4): 721-738.

OLIVIER, N., WEISSLAND, T., BERTHOIN, S., LEGRAND, R., ROGEZ, J., THEVENON, A. & PRIEUR, F. (2006). Following ACL surgery, a 6 week single leg cycling rehabilitation program significantly improved endurance performance and cardiorespiratory parameters in soccer players. *American Journal of Physical Medicine & Rehabilitation* 88(5): 362-368.

O'REILLY, S.C., JONES, A., MUIR, K.R. & DOHERTY, M. (1998). Quadriceps weakness in knee osteoarthritis: the effect on pain and disability. *Annual Rheumatoid Disorder* 57(10): 588-594.

OUTERBRIDGE, R.E. (1961). The etiology of chondromalacia patellae. *Journal of Bone and Joint Surgery* 43B: 752-757.

PALMER, I. (1938). On the injuries to the ligaments of the knee joint: a clinical study. *Clinical Orthopaedics and Related Research* 454: 17-22.

PALMIERI-SMITH, R.M., KREINBRINK, J., ASHTON-MILLER, J.A. & WOJTYS, E.M. (2007). Quadriceps inhibition induced by an experimental knee joint effusion affects knee joint mechanics during a single-legged drop landing. *The American Journal of Sports Medicine* 35(8):1269-1275.

PATERNO, M.V., MYER, G.D., FORD, K.R. & HEWETT, T.E. (2004). Neuromuscular training improves single-limb stability in young female athletes. *Journal of Orthopaedic and Sports Physical Therapy* 34(6):305-16.

PETERSEN, W. & LAPRELL, H. (1999). Combined injuries of the medial collateral ligament and the anterior cruciate ligament. Early ACL reconstruction versus late ACL reconstruction. *Archives of Orthopaedic and Trauma Surgery* 119(5-6): 258-62.

POWERS, S.K. & HOWLEY, E.T. (2009). *Exercise Physiology: Theory and application to fitness and performance.* New York: McGraw-Hill.

PRENTICE, W.E. (2006). *Arnheim's Principles of athletic training: A competency-based approach*. New York: McGraw-Hill.

PROSKE, U. (2006). Kinesthesia: The role of muscle receptors. *Muscle Nerve* 34: 545–558.

RAVIRAJ, A., ANAND, A., KODIKAL, G., CHANDRASHEKAR, M. & PAI, I (2010). A comparison of early and delayed arthroscopically-assisted reconstruction of the anterior cruciate ligament using hamstring autograft. *Journal of Bone and Joint Surgery* 92B(4): 521-526.

RISBERG, M.A., BEYNNON, B.D., PEURA, G.D. & UH, B.S. (1999). Proprioception after anterior cruciate ligament reconstruction with and without bracing. *Knee Surgery, Sports Traumatology, Arthroscopy* 7(5): 303-309.

RISKOWSKI, J.L., MIKESKY, A.E., BAHAMONDE, R.E., ALVEY, T.V. & BURR, D.B. (2005). Proprioception, gait kinematics, and rate of loading during walking: Are they related? *Journal of Musculoskeletal Neuromucular Interaction* 5(4): 379-387.

SALMON, L.J., REFSHAUGE, K.M., RUSSELL, V.J., ROE, J.P., LINKLATER, J & PINCZEWSKI, L.A. (2006). Gender differences in outcome after anterior cruciate ligament reconstruction with hamstring tendon autograft. *American Journal of Sports Medicine* 34: 621-629.

SANDBERG, R., BALKFORS, B., NILSSON, B & WESTLIN, N. (1987). Operative versus non-operative treatment of recent injuries to the ligaments of the knee. A prospective randomized study. *Journal of Bone and Joint Surgery* 69(8): 1120-1126.

SEKIR, U., GUR, H. & ALOVA, B. (2010). Early versus late start of isokinetic hamstring-strengthening exercise after anterior cruciate ligament reconstruction with patellar tendon graft. *American Journal of Sports Medicine* 38(3): 492-500.

SHAKESPEARE, D.T. & RIGBY, H.S. (1983). The bucket-handle tear of the meniscus. A clinical and arthrographic study. *Journal of Bone and Joint Surgery* 65(4): 383-387.

SHAW, T., WILLIAMS, M.T. & CHIPCHASE, L.S. (2005). Do early quadriceps exercises affect the outcome of ACL reconstruction? A randomised controlled trial. *Australian Journal of Physiotherapy* 51(1): 9-17.

SHELBOURNE, K.D. & KLOTZ, C. (2006). What I have learned about the ACL: Utilizing a progressive rehabilitation scheme to achieve total knee symmetry after anterior cruciate ligament reconstruction. *Journal of Orthopaedic Science* 11(3): 318-325.

STANNARD, J.P., BROWN, S.L., ROBINSON, J.T., MCGWIN, G & VOLGAS, D.A. (2005). Reconstruction of the posterolateral corner of the knee. *Arthroscopy* 21(9): 1051-1059.

STEVENS, J.E., MIZNER, R.L. & SNYDER-MACKLER, L. (2003). Quadriceps strength and volitional activation before and after total knee arthroplasty for osteoarthritis. *Journal of Orthopaedic Research* 21: 775-779.

STEVENSON, H., WEBSTER, J., JOHNSON, R. & BEYNNON, B. (1998). Gender differences in knee epidemiology among competitive alphine ski racers. *Iowa Orthopaedic Journal* 18: 64-66.

TAGESSON, S., OBERG, B., GOOD, L. & KVIST, J. (2008). A comprehensive rehabilitation program with quadriceps strengthening in closed versus open kinetic chain exercise in patients with anterior cruciate ligament deficiency: A randomized clinical trial evaluating dynamic tibial translation and muscle function. *The American Journal of Sports Medicine* 36(2): 298-307.

TERBLANCHE, E., CLOETE, W.A., DU PLESSIS, P.A.L., SADIE, J.N., STRAUSS, A. & UNGER, M. (2003). The metabolic transition speed between backward walking and running. *European Journal of Applied Physiology* 90: 520-525.

TERBLANCHE, E., PAGE, C., KROFF, J. & VENTER, R. (2004). The effect of backward locomotion training on the body composition and cardiorespiratory fitness of young women. *International Journal of Sports Medicine* 25: 1-6.

THREKELD, A.J., HORN, T.S., WOJTOWICZ, G.M., ROONEY, J.G. & SHAPIRO, R. (1989). Kinematics, ground reaction force, and muscle balance produced by backward running. *Journal of Orthopaedic and Sports Physical Therapy* 11(2): 56-63.

THOMOPOULOS, S., ZAMPIAKIS, R.D., SILVA, M.J. & GELBERMAN, R.H. (2008). The effect of muscle loading on flexor tendon-to-bone healing in a canine model. *Journal of Orthopaedic Research* 12: 1611-1617.

THORNSTENSSON, A. (1986). How is the normal locomotor program modified to produce backward walking? *Experimental Brain Research* 61(3): 664-668.

VAN DEURSEN, R.W.M., FLYNN, T.W., McCRORY, J.L. & MORAG, E. (1998). Does a single control mechanism exist for both forward and backward walking? *Gait and Posture* 7: 214-244.

VILENSKY, J.A., GANKIEWICZ, E. & GEHLSEN, G. (1987). A kinematic comparison of backward and forward walking in humans. *Journal of Human Movement Studies* 13: 29-50.

WILLIFORD, H.N., OLSON, M.S., GAUGER, S., DUEY, W.J. & BLESSING, D.L. (1998). Cardiovascular and metabolic costs of forward, backward, and lateral motion. *Medicine & Science in Sports & Exercise* 30(9): 1419-1423.

WINTER, D.A., PLUCK, N. & YANG, J.F. (1989). Backward walking: A simple reversal of forward walking? *Journal of Motor Behavior* 21(3): 291-305.

WOJTYS, E.M., HUSTON, L.J., SCHOCK, H.J., BOYLAN, J.P. & ASHTON-MILLER, J.A. (2003). Gender differences in muscular protection of the knee in torsion in size-matched athletes. *The Journal of Bone and Joint Surgery* 85: 782-789.

WOO, S.L.Y., DEBSKI, R.E., WITHROW, J.D. & JANAUSHEK, M.A. (1999). Biomechanics of knee ligaments. *The American Journal of Sports Medicine* 27(4): 533-543.

APPENDIX A

STELLENBOSCH UNIVERSITY
CONSENT TO PARTICIPATE IN RESEARCH

The effects of backward locomotion as part of a rehabilitation program on upper leg strength of patients following knee injuries

You are asked to participate in a research study conducted by Marisa Brink, BHons Sport Science (Biokinetics) from the Department of Sport Science at Stellenbosch University. The results obtained from the research will contribute to a thesis in fulfillment of the requirements for the Degree Master of Science in Sport Science. You were selected as a possible participant in this study because you have knee injury that is limiting your performance.

1. PURPOSE OF THE STUDY

The primary aim of the study is to establish the efficacy of backward locomotion training during a knee rehabilitation program by determining if backward walk / run training causes greater increases in aerobic fitness, *quadriceps* and *hamstrings* muscles strength, dynamic balance, flexibility of the lower limb, and circumferences of the lower limb than forward walk / run training as part of a knee rehabilitation program.

2. PROCEDURES

If you volunteer to participate in this study, we would ask you to do the following:

2.1 Perform a battery of tests

The results of the tests will be used as baseline measurements to compare to the results obtained from the same tests conducted after the intervention. The tests will include anthropometric measurements and tests for flexibility, balance, submaximal cardiovascular capacity and upper leg strength. All the tests will be performed at the Stellenbosch Biokinetic Centre and the Sport Physiology Laboratory.

2.1.1 Anthropometric measurements and body impedance analysis (BIA)

Your stature (height), body mass and leg circumferences will be taken. You will be asked to wear light clothing and to be barefoot during the procedures.

2.1.2 Flexibility tests

Quadriceps, hamstring, soleus and *gastrocnemius* flexibility will be measured with a goniometer. None of the tests will cause any discomfort other than a light stretch.

2.1.3 Balance test

Your balance will be tested during a one leg stance on an instable platform. You will have to balance yourself for 20 seconds on the platform and repeat it three times. Hand railings are on the sides of the platform to prevent you from falling if you loose your balance.

2.1.4 VO_{2peak} (Maximal aerobic capacity)

You have to perform a fitness test on a cycle ergometer (stationary bike). You will have to cycle at a set speed of 80 - 100 repetitions per minute. Every three minutes the resistance will increase until you cannot maintain the set speed. At that point we will stop the test. You may stop at any time you feel that you can not continue the activity.

2.1.5 Upper leg strength

Your upper leg strength and power will be measured by means of knee flexor and extensor strength test on the Biodex System 3 isokinetic dynamometer. The test will consist of 10 repetitions of flexion and extension at an angular speed of 120 °/s. During the test you will be asked to give your maximal effort to obtain a true measurement of your strength and power.

2.2 Attend 24 knee rehabilitation sessions

You will be randomly divided into either the experimental group or control group. Both groups will have to attend 24 rehabilitations sessions (preferably three times a week for eight weeks). The duration of each session will be an hour. The sessions will focus on knee rehabilitation and will include 20 to 30 minutes of cardiorespiratory exercise on a treadmill and elliptical trainer. The experimental group will perform the cardiorespiratory exercises backward, whereas the control group will perform the same exercises forward.

2.3 Perform the same battery of tests as pre-intervention

The same battery of tests will be performed in the same order, after the intervention period. The results obtained will be used to compare to the results obtained pre-intervention.

3. POTENTIAL RISKS AND DISCOMFORTS

The researcher will do all within her power to reduce possible risks. There is a foreseeable risk of falling during the single leg balance test on the Biodex Balance System SD. Hand railings are on the sides of the platform to prevent one from falling. Another risk of falling is on the treadmill when walking either forward or backward. The treadmill has hand railings to prevent one from falling. Participants in the experimental group will be familiarized with backwards walking on a treadmill while wearing a harness to prevent them from falling.

Delayed onset of muscle soreness (DOMS), may be experienced after the pre-test and the initial rehabilitation sessions. This discomfort will only be experienced for a couple of days after which it will clear by itself.

During the cardiorespiratory test you may experience one or more of the following symptoms: light-headedness, dizziness, fainting, chest, jaw, neck or back pain or pressure, severe shortness of breath, wheezing, coughing or difficulty breathing, nausea, cramps or severe pain or muscle ache. If you experience any of these adverse symptoms, you can stop the exercise test. Health and safety procedures are in place to deal with emergencies that may arise during the test.

4. POTENTIAL BENEFITS TO PARTICIPANTS AND OR TO SOCIETY

Potential benefits to the participants include increased upper leg strength, flexibility, balance and aerobic capacity. Both the experimental and control group will experience the beneficial effects of a rehabilitation program developed for patients following knee injuries.

If backward locomotion shows to be more efficient than forward locomotion, it could be included in the rehabilitation programs for patients following knee injuries to accelerate the recovery process.

5. PAYMENT FOR PARTICIPATION

As a participant you will receive no remuneration for participation in the study and there is no cost involved in participation in the study.

6. CONFIDENTIALITY

Any information obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission or as required by law. All data sheets will be numerically coded and no names will be included in the data collection or analysis. This means that results will be reported as means of groups and not include any names.

Recorded data will be securely retained for a period of six years at the Sport Science Department. No one except the researcher and project supervisor will be able to access these raw data. Please take note that overall data will be published in a master's thesis and scientific journal.

7. PARTICIPATION AND WITHDRAWAL

The researcher's intent is to only include subjects that freely choose to participate in this study. Thus participation is voluntary and you are free to withdraw consent at any time without consequences of any kind. You may also refuse to answer any questions you do not want to answer and still remain in the study. The investigator may withdraw you from this research if circumstances arise which warrant doing so. Participation will be terminated if you partake in other rehabilitation programs or physical activities during the intervention period. Your consent to participate in this research will be indicated by your signing and dating of the consent form. Signing the consent form indicates that you have freely given your consent to participate, and there has been no coercion to participate.

8. IDENTIFICATION OF INVESTIGATORS

If you have any questions or concerns about the research, please feel free to contact the principle researcher Marisa Brink **(084 517 6310 or 13401520@sun.ac.za)** or the project supervisor, Prof E. Terblanche **(021 808 27 42 or et2@sun.ac.za)** at any time if you feel a topic has not been explain to your complete satisfaction.

9. RIGHTS OF RESEARCH SUBJECTS

You may withdraw your consent at any time and discontinue participation without penalty. You are not waiving any legal claims, rights or remedies because of your participation in this research study. If you have questions regarding your rights as a research subject, contact **Ms. Maryke Hunter-Husselmann (contact number: (021) 808 4623 or mh3@sun.ac.za)** the Unit for Research Development.

SIGNATURE OF RESEARCH PARTICIPANT OR LEGAL REPRESENTATIVE

The information above was described to me by Marisa Brink in Afrikaans and / or English and I am in command of this language. I was given the opportunity to ask questions and these questions were answered to my satisfaction.

I hereby consent voluntarily to participate in this study. I have been given a copy of this form.

____

Name of Participant

____ ______________

Signature of Participant or Legal Representative **Date**

SIGNATURE OF INVESTIGATOR

I declare that I explained the information given in this document to ____________________ .

He/she was encouraged and given ample time to ask me any questions. This conversation was conducted in Afrikaans and / or English.

____ ______________

Signature of Investigator **Date**

____ ______________

Signature of Witness **Date**

APPENDIX B

HEALTH SCREENING FORM

Algemene inligting / *General information*

Naam & Van / *Name & Surname*: ______________________________

Geboorte datum / *Date of birth*: ______________ ID nr: ______________

Titel / *Title:* ________ Beroep / *Occupation*: ______________________

Code: ____

Tel: (h) ______________(w) ________________(cell) __________

Epos / *Email*: ____

Mediese inligting / *Medical information*

Knieprobeem / *Knee problem*: ______________________________

____

____

Datum van besering / *Date of injury*: ________________________

Datum van prosedure / *Date of procedure*: ____________________

Verwysende dokter / *Referring doctor*: ______________________

Tel: ____

Aantal sessies by 'n fisioterapeut / *Number of physiotherapist sessions*: ________

Aantal sessies by 'n biokinetikus / *Number of Biokinetics sessions:* __________

Mediese geskiedenis / *Medical history*

1. Het u 'n geskiedenis van enige van die volgende? / *Do you have a history of any of the following?*

- ☐ Koronêre hartsiekte / *Coronary heart disease*
- ☐ Hartaanval / *Heart attack*
- ☐ Koronêre trombose / *Coronary thrombosis*
- ☐ Vernoude are / *Narrowing arteries*
- ☐ Hoë cholesterol / *High cholesterol*
- ☐ Hoë bloeddruk / *High blood pressure*
- ☐ Rumatiek koors / *Rheumatic fever*
- ☐ Beroerte / *Stroke*

☐ Angina (Borspyne) / *Chest pains*
☐ Lekkende hartklep / *Leaking heart valve*

2. Het u ‘n familiegeskiedenis van enige van die volgende? / *Do you have a family history of any of the following?*

☐ Hartaanval / *Heart attack*
☐ Koronêre hartsiekte < 60 jaar / *Coronary heart disease < 60 years*
☐ Hoë cholesterol / *High cholesterol*
☐ Hoë bloeddruk / *High blood pressure*
☐ Diabetes
☐ Oorgewig / *Overweight*
☐ Beroerte / *Stroke*

3. Beskryf asb u rookgeskiedenis / *Please describe your history of smoking*:

____

4. Het u ‘n geskiedenis van enige gewrigs- of spierbeserings behalwe die kniebesering / *Do you have a history of any joint or muscle injury other than the knee*?______________________________________
Indien ja, verduidelik / *If yes, explain*: ________________________

____

5. Gebruik u gereelde medikasie / *Are you on regular medication?* ________
Indien ja, wat is die naam, dosis en gebruik daarvan / *If yes, what are the name, dosage and use thereof?* ___________________________

____

6. Het u dokter voorheen aangedui dat u enige kondisie het waarvan ons moet kennis neem / *Have your doctor previously indicated any other conditions that we should be aware of?* ___________________________

____

Physical Activity Readiness Questionnaire (PAR-Q) and You

Yes	No	
☐	☐	1. Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?
☐	☐	2. Do you feel pain in your chest when you do physical activity?
☐	☐	3. In the past month, have you had chest pain when you were not doing physical activity?
☐	☐	4. Do you lose your balance because of dizziness or do you ever lose consciousness?
☐	☐	5. Do you have a bone or joint problem that could be made worse by a change in your physical activity?
☐	☐	6. Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?
☐	☐	7. Do you know of any other reason why you should not do physical activity?

(Adapted from ACSM's Health/Fitness Facility Standards and Guidelines, 1997)

APPENDIX C

ETHICAL CLEARANCE

Researcher:	Ms Marisa Brink
Research Project:	The effects of backward running on upper leg strength of patients following anterior cruciate ligament reconstruction
Nature of the Research Project:	M degree, Department of Sport Science, SU
Reference number:	155 / 2009
Date:	20 March 2009 (electronically)

The research proposal and associated documentation was tabled and considered electronically via e-mail by the members of the Ethics Committee (as prescribed by Council on 18 September 1996 and laid down in the SU policy framework) on 20 March 2009; the purpose being to ascertain whether there are any ethical risks associated with the proposed research project of which the researcher has to be aware of or, alternatively, whether the ethical risks are of such a nature that the research cannot continue. The submission was considered in accordance with the procedure for urgent applications for ethical clearance. In terms of the procedure for urgent applications for ethical clearance the Chair of the Ethics Committee (or a member delegated by him) prepares a provisional report that is ratified at the next formal meeting of the Ethics Committee. If approved in the provisional report, the research may proceed. If any changes would be made to the report during the process of ratification the researcher will be notified immediately.

DISCUSSION

The Ethics Committee received the following documentation:

- A completed and signed ethical clearance application form;
- A copy of the research proposal; and
- A copy of the informed consent form (both in English and in Afrikaans).

The researcher will conduct experimental research in the Stellenbosch Biokinetics Centre, the main object of which is to determine whether backward walk/run training brings significant improvement in upper-leg strength in patients who have undergone anterior cruciate ligament reconstruction. Personal and social information will be collected directly from the participants, in addition to the physical training they will undergo. All patients will be over the age of 18, will be identified at the practices of local doctors and physiotherapists, and will be asked to volunteer. All reasonable measures will be taken to ensure that participants will not be exposed to physical injury and the steps taken to ensure protection of rights to privacy are adequate.

RECOMMENDATION

It is recommended, in view of the information at the disposal of the committee, that the proposed research project continues provided that:

a. The researcher remains within the procedures and protocols indicated in the proposal, particularly in terms of any undertakings made and guarantees given.

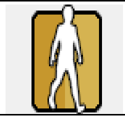
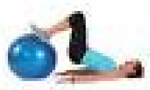
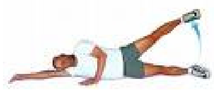
b. The researcher notes that her research may have to be submitted again for ethical clearance if there is substantial departure from the existing proposal.

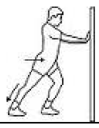
c. The researcher remains within the parameters of any applicable national legislation, institutional guidelines and scientific standards relevant to the specific field of research.

Johan Hattingh, Callie Theron, Elmarie Terblanche, Clint le Bruyns, Ian van der Waag [For the Ethics Committee: electronically 20 March 2009]

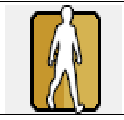
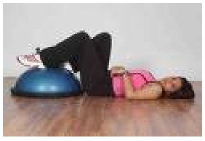
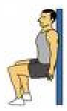
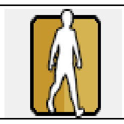
APPENDIX D

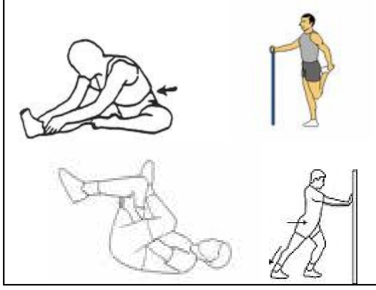
PROGRAM 1

PICTURE	DESCRIPTION	SETS/REPS
 	Cardiorespiratory training	10 min
	*Quadriceps* activation Isometric contraction (3 seconds)	1 x 10
	Knee extension on ball	1 x 12
	Knee flexion Heel slide Slide foot to body	1 x 12
	Straight leg raises Feet turned out, feet in, feet straight	1 x 10 (in each position)
 	Hamstring curls on ball Lift hips, roll ball in and out	2 x 12
	Hip lifts on one leg Other leg is lifted	1 x 12
	Sidelying leg lift Up and down x10 Hold 10 sec Small pulses x10 Pull knee to chest x10 Tap in front and behind knee x10	1 x 10
 	Walls squats Feet shoulder-width apart Lower slowly to 90°	2 x 12
	Calf raises Feet out, feet in, feet straight	1 x 10 (in each position)

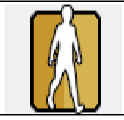
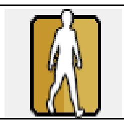
	Balance on unstable surface Stand on one leg	2 x 30 sec (each leg)
 	Cardiorespiratory training	10 min
   	<u>Stretches:</u> Hamstrings Quadriceps Gluteus muscles Calves	2 x 15 sec

PROGRAM 2

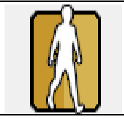
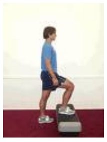
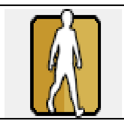
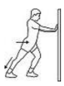
PICTURE	DESCRIPTION	SETS/REPS
 	Cardiorespiratory training	10 min
	Straight leg raises Feet turned out, feet in, feet straight	2 x 12
	Leg press with elastic	2 x 12
	Hip lifts: one foot on bosu Other leg is lifted	1 x 12 Each leg
	Hamstring curls Feet on ball, lift hips Roll ball slowly in and out	2 x 15
	Side lying leg lift x15 Hold 15 sec Small pulses x15 Pull knee to chest x15 Tap in front and behind knee x15	1 x 15 Each leg
	Single leg calf raises o Feet out, feet in, feet straight	1 x 15 Each leg
	Single leg squats Bending leg slightly	2 x 10 Each leg
	Wall sits Feet shoulder-width apart Knees not bending more than 90°	3 x 30 sec
 	Cardiorespiratory training	10 min

	<u>Stretches:</u> Hamstrings Quadriceps Gluteus muscles Calves	2 x 15 sec

PROGRAM 3

PICTURE	DESCRIPTION	SETS/REPS
 	Cardiorespiratory training	15 min
	Leg press Feet straight, feet turned in and out	1 x 10 each
	Hamstring curls on machine	1 x 12
 	Hamstring curls on ball x 15 Hold 15 sec Lift hips up and down x 15	1 x 15
	Donkey kicks On all fours Kick leg straight back	1 x 12
	Standing bent knee leg abduction Knees in line, leg to side of body	1 x 20
	Hurdle swing Lift knee to chest Turn leg in and out, keeping leg lifted	1 x 12
	Single leg squat Same hand, same leg Hand reaching to inner of foot	2 x 10
	Calf raises on bosu Feet straight, feet turned in and out	1 x 15 each
 	Cardiorespiratory training	10 min
   	Stretches: Hamstrings Quadriceps Gluteus muscles Calves	2 x 15 sec

PROGRAM 4

PICTURE	DESCRIPTION	SETS/REPS
 	Cardiorespiratory training	15 min
	Leg press: Single leg Feet straight	2 x 10 Each leg
	Hamstring curls on machine Single leg	1 x 12 Each leg
	Step ups Slowly up and down	1 x 10 Each leg
	Balance on single leg Lean forward	1 x 10 Each leg
	Single leg calf raises on bosu Feet straight, feet turned in and out	1 x 12 each
 	Cardiorespiratory training	10 min
   	Stretches: Hamstrings Quadriceps Gluteus muscles Calves	2 x 15 sec