Biomechanical Analysis of a 'Heavy-Load Eccentric Calf Muscle' Rehabilitation Exercise in persons with Achilles Tendinosis

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Attestation of Authorship

"I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning".

Name: …………………………………………………

Signed: …………………………………………………

Date: ………………………………………………….

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Abstract

Objective

The aim of this dissertation was firstly to determine the efficacy of heavy-load eccentric calf muscle (HLECM) training for Achilles tendinosis through a review of the current scientific literature. The second objective was to assess the biomechanics of the HLECM training technique via an experimental study of calf muscle activity in individuals with Achilles tendinosis.

Background

Achilles tendinosis is a chronic painful condition of the Achilles tendon. HLECM training has been developed as a popular form of conservative treatment for Achilles tendinosis. However, there is little research investigating the biomechanics of the HLECM training technique. A key component of the original technique is the inclusion of a straight and bent knee condition, proposed to activate the gastrocnemius and soleus muscles respectively. Despite widespread use of these specific conditions in subsequent research, there is no evidence to suggest this selective muscle activation occurs in persons with Achilles tendinosis.

Study Design

A literature review was conducted to determine the effectiveness of the HLECM training protocol for Achilles tendinosis and to also compare its efficacy against other conservative treatment methods. The biomechanical study was a repeated measures, cross-sectional design.

Methods

A critical review of 8 studies was undertaken assessing methodological quality through a Cochrane scoring system. A qualitative analysis to establish the level of evidence for the efficacy of HLECM training was also undertaken.

For the biomechanical study, participants (n=18) diagnosed with Achilles tendinosis were recruited. Gastrocnemius and soleus muscle activity during the straight and bent knee conditions of the HLECM training technique, and during a maximum voluntary contraction (MVC), were determined through use of electromyography (EMG). The data was expressed as a percentage of the MVC for each muscle in each condition. Participant data sourced from a previous study, (Potts, 2005), served as controls (n=18). A three-factor repeated measures ANOVA was performed. The within subject factors were joint position and muscle, while group (experimental or control) was the between subjects factor.

Results

The critical review demonstrated a positive response to HLECM training but also highlighted the presence of inconsistent inclusion and exclusion criteria, variable outcome measures and alterations to the original HLECM protocol methodology. These factors contributed to the difficulty in comparing the outcomes of studies and hence the efficacy of the intervention.

Participants with Achilles tendinosis demonstrated significantly higher EMG activity of both the gastrocnemius and soleus muscles in all conditions. There was a significant effect of joint position on the total group (the experimental and control group combined). The gastrocnemius muscle was significantly more active in the straight knee condition and the soleus muscle in the bent knee condition.

Conclusion

There is moderate evidence of the efficacy of HLECM training for the treatment of Achilles tendinosis. The mechanisms of pain alleviation and return to functional activity through this use of this regime remain unclear. There is evidence to suggest there is a selective activation of the gastrocnemius and soleus muscles of the calf during the straight and bent knee conditions of the HLECM training protocol as described by Alfredson et al. (1998). Furthermore, the presence of Achilles tendinosis pathology influences calf muscle activity levels during performance of this training protocol.

1   Introduction

Achilles tendinosis is a chronic, painful, degenerative condition of the Achilles tendon. Although prevalent in non-athletic individuals, it is more common in males between the ages of 35-45 years and those who have undertaken sports or recreational activities involving Achilles tendon loading, such as running and badminton (Fahlstrom, Lorentzon, & Alfredson, 2002; Kujala, Sarna, & Kaprio, 2005; Maffulli, Wong, & Almekinders, 2003). The etiology of Achilles tendinosis is multifactorial, with excessive tendon loading being the most frequently reported pathological stimulus (Rees, Wilson, & Wolman, 2006). Pathophysiological changes to tendon structure and morphology have been observed in imaging studies, however the cause of Achilles tendon pain remains unclear.

Achilles tendinosis is usually treated conservatively with interventions including stretching, bracing, electrotherapy, orthotics and exercises (Alfredson & Cook, 2007). The use of eccentric loading has been popularised by Alfredson et al. (1998) who developed a 12 week eccentric training regime termed "heavy-load eccentric calf muscle" (HLECM) training for the treatment of Achilles tendinosis. This has since been extensively utilised in subsequent research (Alfredson & Cook, 2007). The mechanisms of efficacy of HLECM training are not known, but are based on the concept of rendering the tendon more "load resistant" and reversing the pathophysiological changes seen in this condition. Prospective studies have demonstrated a reduction in tendon size and structural abnormalities, an increase in collagen synthesis and reduced ingrowth of neovessels in the Achilles tendon following HLECM training (Langberg, Rosendal, & Kjaer, 2001; Ohberg, Lorentzon, & Alfredson, 2001; Shalabi, Kristoffersen-Wiberg, Svensson, Aspelin, & Movin, 2004) A number of recent systematic reviews have been undertaken to determine the efficacy of eccentric training for tendinopathy, however, none have examined the HLECM training protocol specifically (Kingma, deKnikker, Wittink, & Takken, 2006; Satyendra & Byl, 2006; Wasielewski & Kotsko, 2007; Woodley, Newsham-West, & Baxter, 2006).

The HLECM training protocol involves the performance of a modified heel raise exercise where only an eccentric contraction of the calf musculature on the symptomatic limb is permitted. The number of repetitions is high, 180 per day were recommended in the original study. Furthermore, the exercises are often painful for the individual to complete and this, along with a gradual increase in weights, were considered to be essential criteria for success in the Alfredson et al. (1998) study. The technique is divided further into a straight and bent knee component, proposed to facilitate muscle activity in the gastrocnemius and soleus muscles of the calf respectively. Despite the widespread use of these two components in subsequent studies, no research exists to validate this statement.

Compliance to the HLECM training regime is not well recorded or reported in research, but assumed to be of importance in order to achieve a graded exposure to tendon loading. Understanding the mechanics of the exercise technique itself may assist in the formulation of a more concise protocol for patients to follow or one which is more effective in a shorter time frame. There is a paucity of research investigating the mechanics of rehabilitative exercises for tendinopathy. Previous research has demonstrated no significant difference in electromyographic (EMG) activity in the gastrocnemius and soleus muscles during performance of each HLECM training component in individuals without pathology (Potts, 2005). This result does not support the assertion made in the Alfredson et al. (1998) study and questions the necessity of inclusion of both components. However, in order to establish whether this also occurs in a patient population, it is necessary to investigate calf muscle activity in persons diagnosed with Achilles tendinosis.

1.1 Purpose

The purpose of this dissertation is firstly to examine the literature in order to assess the efficacy of the HLECM training protocol as a treatment for Achilles tendinosis. Secondly, to conduct a biomechanical study examining calf muscle activity during performance of the training protocol in persons with this condition.

2 Heavy Load Eccentric Calf Muscle Training for Achilles Tendinosis: A Critical Review

A critical review of current research implementing the HLECM training protocol as a treatment for Achilles tendinosis was undertaken. The original study by Alfredson et al. (1998) is detailed here for comparison with subsequent research. This is followed by an outline of the key findings of the review and a discussion with particular emphasis on the biomechanics of the HLECM training technique.

2.1 Introduction

The HLECM regime has been studied in both randomised and clinical trials investigating its efficacy for different populations (Fahlstrom, Jonsson, Lorentzon, & Alfredson, 2003; Sayana & Maffulli, 2007). It has been compared to other conventional therapies (Brown, Orchard, Kinchington, Hooper, & Nalder, 2006; Mafi, Lorentzon, & Alfredson, 2001; Norregaard, Larsen, Bieler, & Langberg, 2007; Petersen, Welp, & Rosenbaum, 2007; Rompe, Nafe, Furia, & Maffulli, 2007; Roos, Engstrom, Lagerquist, & Soderberg, 2004; Tol, Vos, Weir, Visser, & deWinter, 2006) and the effect of HLECM training on tendon morphology has also been widely examined (Alfredson & Lorentzon, 2003; Alfredson, Nordstrom, Pietila, & Lorentzon, 1999; Knobloch et al., 2007; Langberg et al., 2007; Ohberg & Alfredson, 2004; Ohberg, Lorentzon, & Alfredson, 2004; Shalabi et al., 2004).

2.1.1 Purpose of Review

The purpose of this critical review was to determine the effectiveness of this specific protocol on outcome measures including pain, function and tendon morphology and to also compare its efficacy for different populations and against other conservative treatment methods.

2.2　　　Selection Criteria

Inclusion criteria:　The following criteria were used in order to select relevant papers to be included within the review:

> *Type of participant:*　human participants diagnosed with either mid-portion or insertional Achilles tendinosis. A clinical or imaging diagnosis was accepted.
> *Type of study design:*　randomised and quasi-randomised trials
> *Type of intervention:*　at least one of the treatment interventions was to include the HLECM training protocol.

Exclusion criteria:　Papers written in non-English languages.

2.3　　　Search Strategy

Electronic databases were searched and the following key words were used with Boolean operators linked to these terms (Fig. 2.1).

The objective was to include randomised controlled trials (RCT's) which implemented the specific HLECM protocol as described by Alfredson et al. (1998). The RCT is generally considered to be the paradigm of intervention research and thus generates the strongest scientific proof of the efficacy of an intervention.　Due to there being only six RCT's implementing the HLECM training protocol, quasi-randomised trials (QRT's) were also included for evaluation (vanTulder, Furlan, Bombardier, & Bouter, 2003).

| **Electronic search of seven databases** |
| Medline via PubMed, Evidence Based Medicine Reviews, Cochrane Controlled Trials Register, Physiotherapy Evidence Database (PEDro), Ovid Databases, Sport Discus and Ebsco Health Databases from 1966-2007. |

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| **Key words** |
| Eccentric training intervention in Achilles tendinosis |

↓

| 29 intervention studies and critical/systematic reviews |

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| Title and abstract review of 17 papers utilising HLECM training specifically |

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| Full article review of 8 papers |

↓

| 6 randomised controlled trials and 2 quasi-randomised controlled trials; critically appraised, data extracted and scored |

Figure 2.1   Flow diagram of eccentric training search strategy.

2.4   Methodological Quality

An assessment of the quality of each publication was conducted using a criteria list recommended by the Cochrane Back Review Group (vanTulder et al., 2003) (Table 2.1). This method was selected as its use facilitates comparison across other Cochrane reviews of alternative interventions. The criteria list consists of 11 items which are rated with a yes (Y), no (N) or don't know (DK) with a yes response generating one point, thus the maximum score is 11. The criteria list contains internal validity criteria that refer to characteristics of the study that might be related to selection bias (A and B), performance bias (D, E, G and H), attrition bias (I and K) and detection bias (F and J). An operationalisation of the criteria list was used to assist with assignment of the yes/no/don't know response (Appendix A). The methodological quality scores are outlined in Table 2.2.

Table 2.1   Criteria list for the methodological quality assessment (van Tulder et al., 2003).

A. Was a method of randomization performed?

B. Was the treatment allocation concealed?

C. Were the groups similar at baseline regarding the most important prognostic indicators?

D. Was the patient blinded to the intervention?

E. Was the care provider blinded to the intervention?

F. Was the outcome assessor blinded to the intervention?

G. Were co-interventions avoided or similar?

H. Was the compliance acceptable in all groups?

I. Was the drop-out rate described and acceptable?

J. Was the timing of the outcome assessment in all groups similar?

K. Did the analysis include an intention-to-treat analysis?

Table 2.2   Methodological quality scores of reviewed studies.

No.	First Author	Study Design	A	B	C	E	G	H	D	F	I	J	K	/11
1	Brown (2006)	RCT	Y	Y	Y	Y	DK	DK	Y	Y	Y	Y	N	8/11
2	Rompe (2007)	RCT	Y	N	Y	Y	DK	N	Y	Y	Y	Y	Y	8/11
3	Tol (2006)	RCT	Y	N	Y	Y	DK	Y	N	DK	Y	Y	N	6/11
4	Roos (2006)	RCT	Y	DK	Y	DK	DK	Y	N	DK	Y	Y	Y	6/11
5	Norregaard (2007)	QRT	Y	N	Y	DK	DK	Y	N	DK	Y	Y	N	5/11
6	Knobloch (2007)	RCT	Y	N	Y	N	DK	DK	N	Y	N	Y	N	4/11
7	Petersen (2007)	RCT	Y	N	Y	DK	DK	DK	N	DK	Y	Y	N	4/11
8	Mafi (2001)	QRT	Y	N	Y	N	DK	DK	N	DK	N	Y	N	3/11

Key: Y = yes, N = no, DK = don't know, RCT = randomised controlled trial, QRT = quasi-randomised trial

2.5 Qualitative Analysis

A qualitative analysis of the selected studies was conducted by determining the level of scientific evidence (Reid & Rivett, 2005; vanTulder et al., 2003).

Level 1: Strong evidence provided by generally consistent findings in multiple higher quality RCT's.

Level 2: Moderate evidence provided by generally consistent findings in one higher quality RCT and one or more lower quality RCT's.

Level 3: Limited evidence provided by generally consistent findings in one or more lower quality RCT's.

Level 4: No evidence if there were no RCT's or if the results were conflicting.

An arbitrary ranking of methodological quality was assigned to each study based on their Cochrane score (Reid & Rivett, 2005):

Cochrane score	Ranking	Number of studies
8-11	High quality	2
5-8	Moderate quality	3
1-4	Low quality	3

2.6   Results

A total of eight studies met the criteria and were selected for the critical review. These included six RCT's and two QRT's. The methodological quality of the reviewed studies is displayed in Table 2.1 and the key features of the studies in Table 2.3.

The methodological quality scores of the studies ranged from 3 to 8 out of a possible 11 points. The majority of the studies had comparable groups at baseline, had an acceptable drop-out rate and had similar timing of outcome assessments. Approximately half of the studies detailed subject and treatment provider blinding to treatment status. Few included an intention to treat analysis or described the avoidance or detail of con-interventions.

From the qualitative analysis outlined above, there is moderate evidence to suggest HLECM training is effective for treating Achilles tendinosis.

The following is an overview of the key findings of each study when comparing the efficacy of HLECM training to other conservative treatment methods and the proposed mechanisms of efficacy via its influence on tendon morphology. This is preceded by an overview of the original Alfredson et al. (1998) research.

Table 2.3: Key findings of reviewed studies.

Score	Study	Participants Mean Age Symptom Duration	Intervention	Outcome Measures	Key Findings
8/11	Brown et al. (2006)	Group 1: N = 13 46.3 yrs 8.1 mnth	Group 1: Aprotinin injection x3 over 3 weeks and HLECM training	VISA-A Tenderness assessment Pain VAS	No significant benefit of Aprotinin over Placebo in any outcome measures Significant increase in VISA-A scores following HLECM training
		Group 2: N = 13 46.3 yrs 10.9 mnth	Group 2: Placebo injection x 3 over 3 weeks and HLECM training	Single leg hops Return to sport	
8/11	Rompe et al. (2006)	Group 1: N = 25 48.1 yrs 10.9 mnth	Group 1: HLECM training + gradual increase from 1x10 reps day 1 to 3x15 reps at day 14	VISA-A Likert scale for degree of improvement	No significant difference between Shockwave therapy and Eccentric groups on all outcome measures Significantly better outcomes for Eccentric and Shockwave therapy than Wait-and-see group (p<0.001)
		Group 2: N = 25 51.2 yrs 12.5 mnth	Group 2: 3 sessions once a week over maximal area of tenderness	Pain scale Pain pressure threshold and tenderness	Significant improvement on all outcome measures except tendon diameter in Eccentric group and Shockwave therapy groups (p<0.001)
		Group 3: N = 25 46.4 yrs 9.2 mnth	Group 3: medication, stretching, training modification, ergonomic advice	US tendon diameter Success of treatment = 1 or 2 on improvement scale	

Key: RCT = randomised controlled trial, QRT = quasi-randomised trial, N = participant number, yr/s = year/s, US = ultrasound, reps = repetitions, FAOS = foot and ankle outcome scale, VISA-A = Victorian Institute of Sport Assessment – Achilles, KOOS = knee injury osteoarthritis outcome score, VAS = visual analogue scale.

Score	Study/Score	Participants Mean Age Symptom Duration	Intervention	Outcome Measures	Results
6/11	Tol et al. (2006)	Group 1: N=34 44.1 yrs 33.7 mnth Group 2: N=36 45.1 yrs 27.7 mnth	Group 1: HLECM training Group 2: HLECM training + dorsiflexion night splint 12 weeks	VISA-A Patient satisfaction rating of poor, fair, good, excellent Treatment success = good or excellent	No significant difference between Eccentric and Night splint groups in all outcome measures Significant increase in VISA-A score in Eccentric and Night Splint groups
6/11	Roos et al. (2004)	N = 44 46 yrs, 5.5 mnth Group 1: N=16 Group 2: N=13 Group 3: N=15	Group 1: HLECM training + gradual increase of reps/ straight knee Group 2: Dorsiflexion night splint 12 weeks Group 3: HLECM training + dorsiflexion splint	FAOS Likert scale for physical activity Likert scale for difficult during sport	No significant difference between groups in any outcome measures Significantly improvement on FAOS pain subscale in all groups
5/11	Norregaard et al. (2007)	N=45 Group 1: 41 yrs 26 mnth Group 2: 31 yrs 31 mnth	Group 1: HLECM protocol + gradual increase reps avoid pain, included concentric exercise Group 2: 5x 30 second calf stretch daily	KOOS questionnaire Tenderness US tendon thickness	No significant difference between Eccentric and Stretching groups in any outcome measures

Key: RCT = randomised controlled trial, QRT = quasi-randomised trial, N = participant number, yr/s = year/s, US = ultrasound, reps = repetitions, FAOS = foot and ankle outcome scale, VISA-A = Victorian Institute of Sport Assessment – Achilles, KOOS = knee injury osteoarthritis outcome score, VAS = visual analogue scale.

Score	Study/Score	Participants Mean Age Symptom Duration	Intervention	Outcome Measures	Results
4/11	Knobloch et al. (2007)	Group1: N=15 33 yrs Group 2: N=5 32 yrs	Group 1: HLECM + reps performed once daily Group 2: cryotherapy and relative rest	Capillary blood flow Tissue oxygen saturation (SO_2) Post capillary venous filling pressure (rHb) Pain VAS	No significant difference in flow, SO_2 between groups Significant rHb decrease in eccentric group only ($p<0.05$) Significant reduction of pain in eccentric group only ($p<0.05$)
4/11	Petersen et al. (2007)	Group 1: N=37 42.5 yrs 7.4 mnth Group 2: N=35 42.6 yrs 7.3 mnth Group 3: N=28 43 yrs 7.0 mnth	Group 1: HLECM training Group 2: AirHeel brace worn daily for 12 weeks Group 3: HLECM training and AirHeel brace	AOFAS hindfoot scale US tendon diameter measure Pain VAS	No significant difference between groups in any outcome measures Significant decrease in AOFAS score all groups ($p<0.0001$)
3/11	Mafi et al. (2001)	Group 1: N=22 48.1 yrs 18 mnth Group 2: N=22 48.4 yrs 23 mnth	Group 1: HLECM training Group 2: heel raises, step-ups, skipping and side jumps	Pain VAS Patient satisfaction - method unclear	Eccentric training significantly better than concentric training ($p<0.002$)

Key: RCT = randomised controlled trial, QRT = quasi-randomised trial, N = participant number, yr/s = year/s, mnth = months, US = ultrasound, reps = repetitions, FAOS = foot and ankle outcome scale, VISA-A = Victorian Institute of Sport Assessment – Achilles, KOOS = knee injury and osteoarthritis outcome score.

2.7 Heavy Load Eccentric Calf Muscle Training – The Original Study

The study by Alfredson et al. (1998) was a landmark prospective study investigating the efficacy of the unique HLECM regime for the treatment of Achilles tendinosis. A full description of this research is presented here to allow comparison with the studies selected for the critical review.

Alfredson et al. (1998) examined the effect of HLECM training on pain during activity and calf muscle strength in a group of 15 recreational athletes with an average age of 44.3 years. A control group of 15 participants selected for surgical treatment with an average age of 39.6 years was also studied. At baseline the surgical group had a much longer duration of symptoms, 33.5 months versus 18.3 months in the HLECM group, although the differences were not statistically analysed. All participants had undertaken unsuccessful conservative treatment. Inclusion in the study was based on a clinical and ultrasound diagnosis of Achilles tendinosis 2-6 cm above the tendon insertion on the calcaneus (termed mid-portion tendinopathy). All participants had morning stiffness in the Achilles tendon and pain during running. Participants were excluded if they had bilateral symptoms or restricted ankle motion due to other injuries or conditions.

The participants were instructed to perform the HLECM training protocol twice daily, seven days per week for 12 weeks. Continuation of running was permitted if it could be performed with mild discomfort or pain free. Two components were included within the HLECM protocol involving the calf muscle being eccentrically loaded with both the knee straight and the knee bent (Fig 2.1 & 2.2). The authors proposed this distinction allowed for preferential activation of the soleus muscle in the latter. Each component was performed in three sets of 15

repetitions three times per day. Participants were instructed to continue their exercises with the exception of pain that became disabling.

The loading method consisted of the participant standing on their forefoot, ankle maximally plantarflexed, on the edge of a step with all their body weight on the injured leg. From this position, the participant lowered the heel below the forefoot. The non-injured leg was used to return to the start position to ensure there was no concentric calf muscle activity occurring in the injured leg. The exercise was repeated for the set number of repetitions in a rhythmical fashion. When the participants could perform the eccentric loading exercise without pain, the load was increased by adding weight to a backpack worn during the exercise or the use of a weights machine. The surgical group underwent a post-operative training regime which involved a two week immobilisation period followed by flexibility training and both concentric and eccentric strengthening exercises for a period of up to one year (Alfredson, Pietila, Ohberg, & Lorentzon, 1998).

Calf muscle strength was assessed using a Biodex Isokinetic dynamometer and quantified by measurement of peak torque (Nm), the highest torque measurement from one repetition, and total work (joules), the average work per repetition. Peak torque was measured in the HLECM group before (week 0) and after (week 12) the eccentric training regime and at week 0 and week 24 after surgery in the surgical group. The rationale for a discrepancy in chronology of outcome measurement between the two groups is not evident. Pain during activity was measured using a visual analogue scale (VAS) and recordings were taken with the strength measures.

At baseline, the surgical group had significantly lower concentric plantarflexion strength at 90^{s-1} and 225^{s-1} (18.7% and 23.7% respectively) and lower eccentric plantarflexion strength (13.6%) than the non-injured side. The HLECM group also demonstrated significantly lower concentric plantarflexion strength at 90^{s-1} and 225^{s-1} (12.1% and 18.0% respectively) and lower eccentric plantarflexion

strength (15.7%) than the non-injured side. No side-to-side difference in work data was evident during eccentric plantarflexion contractions.

Following eccentric training there was no difference in side-to-side peak torque values at any velocity or contraction in the HLECM training group. Average work increased only during the concentric 90° $^{s-1}$ condition after eccentric training. The surgical group continued to demonstrate significantly less peak torque values at all velocities and during both eccentric and concentric contractions in the operated leg compared to the uninjured side. It is not stated whether the peak torque values increased significantly compared to pre-training peak torque values in the surgical group. Despite the strength deficit evident in the surgical group, pain levels decreased significantly in both groups following HLECM training (week 12) and surgery (week 24). All patients were satisfied with treatment and returned to their pre-injury levels within these time frames also.

From these findings, the authors concluded that HLECM training improved calf muscle strength and returned patients to their pre-injury level more rapidly and effectively than surgery.   However, in order to make a more accurate comparison it may have been valuable to compare the two groups at identical timeframes and to equalise groups in terms of symptom duration at baseline. It is also possible that the strength and functional improvements demonstrated in this study are augmented by a generally higher activity level of recreational athletes compared to the general population.

Figure 2.2:   Straight knee component of HLECM training.

Figure 2.3:   Bent knee component of HLECM training.

2.8   Key Findings

Eight studies were reviewed and their main findings are presented here. For the studies selected, this includes the effect of eccentric training on tendon morphology and comparison of the efficacy of HLECM training with other conservative treatment measures. Details of the study populations, interventions and outcomes are outlined in Table 2.3.

2.8.1   Tendon Morphology

The ingrowth of neovessels and accompanying nerve structures in the Achilles tendon has been proposed as a cause of pain in Achilles tendinosis and associated with a reduction in functionality and increased chronicity of tendinopathy (Ohberg & Alfredson, 2004; Peers, Brys, & Lysens, 2003; Snellenberg, Wiley, & Brunet, 2006). Knobloch et al. (2007) assessed changes in Achilles tendon microcirculation following HLECM training in participants with insertional or mid-portion tendinopathy. An eccentric training group carried out a modified HLECM protocol while a group undergoing cryotherapy and relative rest served as controls. The statistically significant reduction of postcapillary venous pressure and minimal change to capillary blood flow found in this study suggests that HLECM training does not appear to have a thrombotic effect on neovessels as proposed by other authors (Ohberg & Alfredson, 2004). Instead, it is thought that the mechanism of effect may be the facilitation of venous outflow and clearance of metabolic products in the tendon.

Although the effect of HLECM training on tendon vascularity was the chief purpose of this study, the effectiveness of the eccentric training technique for the studied population could also be determined. In terms of treatment efficacy, the eccentric training group demonstrated a significant reduction in pain levels (48%) at the 12 week mark whereas the control group did not. No change in the amount of sporting participation was demonstrated in either group.

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2.8.2   Compared to Concentric Training

While it is accepted that a graduated loading of the Achilles tendon is valuable in order to treat tendinopathy, no rationale is given in the current literature for why eccentric training of the tendon may be efficacious compared to other forms of loading. Loading of the Achilles tendon may occur during exercise or through patient-generated stretching and night splinting which provide a passive stretch to the tendon and calf musculature.

Mafi et al. (2001) compared the efficacy of a concentric training programme to the HLECM training protocol in 44 participants with mid-portion tendinopathy. The concentric training regime involved predominantly concentric activities such as heel raises, step-ups, skipping and side jumps which were progressed in difficulty over the 12 week period. No previous work implementing this protocol was evident. Pain was assessed using a VAS and patient satisfaction was also obtained although the methodology of this evaluation was not outlined.

Following the 12 week intervention, 82% of participants in the HLECM group were satisfied with treatment and had resumed regular activity. In comparison, 36% of participants were satisfied with treatment and had returned to regular activity in the concentric training group.

The eccentric training achieved significantly better results than a concentric training regime in the short term in patients with mid-portion Achilles tendinopathy. The authors postulated this may have been due to increased eccentric calf muscle strength or caused by a lengthening of the muscle-tendon unit and thus an increase in its ability to bear load during activity. The inclusion of calf strength measures such as those used by Alfredson et al. (1998) or measures of dynamic passive muscle-tendon elastic properties in this study may have assisted with clarification of the different biomechanical effects of each form of training (Gadjosik, Alfred, Gabbert, & Sonsteng, 2007)

2.8.3　　Compared to Stretching

Stretching, an alternative form of loading, is often prescribed to patients with Achilles tendinopathy, however, previously the efficacy of stretching for this condition has been examined only as a component of a cluster of conservative management methods (Mayer, Hirschmuller, Muller, Schuberth, & Baur, 2006). It has been proposed the combination of specific soft tissue mobilisation and patient-generated stretches of the Achilles tendon and calf muscles would alter compliance of the tendon-muscle complex and thus reduce micro-failure of the tendon when loaded (Hunter, 2000). While there may be a physiological rationale for the use of stretching in Achilles tendinosis, no studies investigating the efficacy of patient self-stretching have been undertaken until recently.

Norregaard and colleagues (2007) compared the effectiveness of eccentric training and Achilles tendon stretching in a group of 45 patients with mixed insertional and mid-portion tendinopathy. The interventions consisted of a modified HLECM training protocol in one group and patient-generated stretches of the calf muscle-tendon complex in another. Outcomes were determined through assessment of tenderness by manual examination, ultrasonography, use of the Knee Injury and Osteoarthritis Outcome Score (KOOS) and an assessment of global improvement.

The results of the study revealed no significant difference between the stretching and eccentric training group on all measured parameters. There were statistically significant improvements on the KOOS score and a significant decrease in tendon diameter and tenderness could be seen at the one year mark in both groups. An analysis of predictors of outcome demonstrated a poorer prognosis for women, those with thinner tendons and insertional tendinopathy.

2.8.4   Compared to Night Splinting

Night splinting, with the ankle in a neutral or dorsiflexed position, functions as a form of prolonged stretching to the both the Achilles tendon and calf musculature. Use of a night splint has been investigated in other lower limb conditions, such as plantar fasciitis, with beneficial effects (Barry, Barry, & Chen, 2002). The effect of night splints on Achilles tendinopathy has only recently been examined (Roos et al., 2004; Tol et al., 2006). The rationale for the application of a prolonged stretch in tendinopathy has not been specifically outlined by these authors.

Roos et al. (2004) investigated the effect of a modified HLECM training protocol and night splinting alone, or in combination, in a group of 44 participants with a clinical diagnosis of mid-portion tendinopathy. The night splint was worn over the anterior ankle and designed to maintain a position of 90º dorsiflexion. The outcome measures implemented were the Foot and Ankle Outcome Score (FAOS), physical activity levels and difficulty during sporting activities which were recorded on Likert scales unique to the study.

Following the intervention period, all groups improved significantly, demonstrated by the decrease in pain rating on the FAOS and improvements on the Likert scales utilised. At one year, all three groups reported decreased pain levels of between 35-42%. No statistically significant differences were seen in pain scores, physical activity scores or difficulty with sport measures at any time between the three groups. There was a trend toward the HLECM training group demonstrating a greater reduction in pain than the night splint group at 12 weeks, deemed to be a clinical but not statistically significant difference. From these results, the authors concluded that HLECM training reduces pain and increases function in patients with Achilles tendinopathy up to one year. However, no added value of wearing a night splint could be observed from the results of this study. It was thought by the authors that a larger sample size would have yielded a statistically (rather than clinically) significant difference in the groups.

Tol et al. (2006) also investigated the additional value of a night splint to the HLECM protocol in 58 patients clinically diagnosed with chronic mid-portion Achilles tendinopathy. Participants were randomised into HLECM training alone or HLECM training combined with night splinting and the outcome assessments used included the Victorian Institute of Sports Assessment- Achilles Questionnaire (VISA-A) and a patient satisfaction rating scale.

Patient satisfaction with the treatment was 63% for the eccentric exercise group and 48% for the night splint group. The VISA-A scores increased significantly in both groups although again there was no significant difference observed between the groups. Based on these findings the authors also concluded there is no value of wearing a night splint in addition to performing the HLECM protocol for the treatment of Achilles tendinopathy.

2.8.5 Compared to Bracing

Petersen et al. (2007) compared the effect of an AirHeel cushioned brace, eccentric training and a combination of these therapies in 100 patients with a clinical and ultrasound diagnosis of mid-portion tendinopathy. The AirHeel is a specifically designed compressive brace for treatment of Achilles tendinopathy and was instructed to be worn by patients during the day time. The compression imparted by the brace is thought to enhance circulation and reduce swelling associated with tendinopathy. However, this theory has not been validated by research. The eccentric training regime utilised in this study was identical to the HLECM training outlined by Alfredson et al. (1998) including use of the straight and bent knee components.

This study assessed both pain and function using the Short Form-36, the American Orthopaedic Foot and Ankle Society (AOFAS) score and the VAS in addition to ultrasonography investigating tendon diameter following intervention. At completion of the intervention period the results demonstrated a significant

decrease in the AOFAS score in all groups at 12 weeks and in only the combination group at one year. Pain during everyday activities, walking and sports decreased significantly in all groups although the results were less marked than earlier studies. Tendon diameter did not alter significantly after intervention. Based on these outcomes, no significant difference in the efficacy of the three treatment interventions could be observed.

2.8.6 Compared to Shockwave Therapy

Extracorporeal shockwave therapy (ESWT) is thought to produce an initial analgesic effect in tendinopathies by altering cell membrane permeability. This means a higher stimulus is required to provoke an action potential in the sensory neuron conveying pain messages to higher centres (Chung & Wiley, 2002). In the long term, ESWT may increase blood flow and induce an inflammatory mediated response through induced damage to vascular structures. Neither of these theories have been substantiated by research.

Rompe et al., (2007) conducted a randomised controlled trial comparing the effect of a modified HLECM training regime, shock-wave therapy or a wait-and-see approach for mid-portion Achilles tendinopathy in 75 patients. Shock-wave therapy was applied by the senior author in a standardised dose for three sessions at weekly intervals. The area of maximal tenderness was treated in a circumferential pattern starting at the point of maximum pain level. Participants in the wait-and-see group visited their orthopaedic specialist once during the intervention period of 12 weeks. Alternative treatment methods including medication, stretching, training modification and ergonomic advice were discussed with the patients in this group although it is not outlined whether they were undertaken. A number of functional outcome measures were implemented including the VISA-A, a degree of improvement scale and a numeric rating scale for pain, similar to the VAS. Pain pressure threshold of the Achilles tendon was also assessed using an algometer, which is unique to this research.

Participants in the HLECM training and shock-wave therapy groups improved significantly on the VISA-A, on the Likert scale for general improvement and in the NRS for pain and for pain threshold compared to the wait-and-see group. Tenderness on the NRS improved in all groups significantly. Both the shock-wave therapy and eccentric training lead to a successful outcome in 50-60% of patients with no significant difference in any of the outcome measures between these two forms of therapy. A proportion of participants appeared to benefit from crossover to shock-wave therapy or the eccentric training regime following the initial intervention. This suggests that perhaps differing conservative treatments may be beneficial for specific subgroups of patients with Achilles tendinosis, however, the features defining such subgroups remain unknown.

2.8.7　　Compared to Aprotinin

Aprotinin is a broad-spectrum metalloprotease (MMP) inhibitor used to treat tendinopathy among a range of other conditions. MMPs have been shown to be present in excessive proportions in patellar and rotator cuff tendinopathy (Rukin & Maffulli, 2006). Aprotinin is thought to normalise the concentration of MMPs, assisting healing. Brown et al. (2006) investigated the effectiveness of aprotinin in combination with eccentric exercise in 26 patients with mid-portion Achilles tendinosis. Participants were randomised to either receiving an aprotinin injection and eccentric exercise or a placebo (saline) injection and eccentric exercise. Three aprotinin or placebo injections were administered peritendinously once a week for the first three weeks. The eccentric exercise programme was based on the Alfredson et al. (1998) HLECM model but not outlined clearly in this study. An assessment of tendon tenderness, number of hops until pain, number of single leg raises to pain, return to sport, patient satisfaction rating and VISA-A scale were utilised.

Absolute improvements in VISA-A score were greater in the aprotinin group compared to the placebo group but this was not statistically significant. Most

other evaluation measures were not statistically significantly different between groups at any follow-up point except for number of hops to pain and patient rating were better in the aprotinin group at the two week follow-up. Compared to other studies, the therapeutic effect of eccentric training at the twelve week mark was weak with only 13% of the placebo group and 31% of the aprotinin group returned to sport. At the one year follow-up point however, the overall results were markedly better with 85% in the aprotinin group and 77% in the placebo group returning to previous sporting levels. Although the results were not statistically significantly superior to placebo, the authors recommended a larger trial be conducted due to the beneficial effects seen in previous work on patellar tendinopathy.

2.9   Discussion

Alfredson et al. (1998) developed a unique eccentric training protocol that has been widely utilised in subsequent research. This research has compared the efficacy of HLECM training with many other conservative interventions for Achilles tendinosis. In addition, the influence of eccentric training on tendon structure and morphology has been examined. This critical review has evaluated both the quality and key findings of this body of research in order to determine what conclusions may be drawn currently and where future research is required.

The original study by Alfredson et al. (1998) reported 100% of participants returned to previous activity with reduced pain levels within a 12 week period. While other research has demonstrated good results using the HLECM protocol, almost none have replicated these statistics. This may be due to several factors including the following; inconsistent inclusion and exclusion criteria, different outcome measures implemented, participant compliance levels and variations in HLECM protocol methodology including training principles.

2.9.1   Inclusion and Exclusion Criteria

The diagnosis of Achilles tendinopathy may be achieved via a clinical exam, ultrasound (US), magnetic resonance imaging (MRI) or a combination of these (Cook, Khan, & Purdam, 2002). The studies reviewed demonstrated variability in the use of diagnostic measures for inclusion, with five of the eight utilising a clinical diagnosis only. It is possible a clinical diagnosis may not exclude the presence of other associated conditions such as paratendonitis, Haglund's deformity or an Achilles tendon tear. The presence of other conditions may in turn influence the efficacy of the HLECM regime in the studied population.

The criteria for inclusion within each study also varied according to age, activity levels, location and duration of symptoms. As Achilles tendinosis primarily affects individuals aged between 35 and 45 years, it is ideal for study populations to reflect this. Most studies reviewed did include participants with a mean age between 31 and 51 years. Athletic populations, such as those in the Alfredson et al. (1998) study, demonstrate excellent results with HLECM training in a 12 week period. A recent prospective study has demonstrated reduced efficacy of HLECM training for non-athletic populations (Sayana & Maffulli, 2007). The majority of studies reviewed here contained a proportion of individuals involved in recreational sport or did not detail the composition of their study populations. Two studies specified participation in recreational sport for inclusion and both demonstrated significant improvements in function and reduction in pain for the eccentric training group (Roos et al., 2004; Tol et al., 2006).

The location of symptoms in the study population was fairly standard across the studies reviewed with six of eight studies including only those with mid-portion tendinopathy. Clinical trials have demonstrated that individuals with insertional tendinopathy do not respond as positively as those with mid-portion symptoms to eccentric training (Fahlstrom et al., 2003). Norregard et al. (2007) and Knobloch et al. (2007) did not exclude those with insertional pain however the former study

did observe less of a response to HLECM training in this subgroup within their research.

In contrast, the duration of symptoms was considerably varied across the study populations, ranging from a mean of 5.5 to 33.7 months. With exception of Alfredson et al. (1998), all studies demonstrated similar symptom duration periods between compared groups, although many were not statistically analysed at baseline for differences. Tol et al. (2006) found patient satisfaction with outcome was influenced by symptom duration whereby participants with symptoms present less than 5.5 months rated 89% compared to 50% satisfied when the duration was greater than 5.5 months. In contrast, Norregaard et al. (2007) did not find symptom duration a significant predictor of outcome.

Exclusion criteria for participants with other medical conditions or those with bilateral symptoms were also very diverse across studies. Fundamental to the HLECM training protocol is the concept that the symptomatic tendon is subjected to only eccentric muscle contraction of the calf musculature during the exercises. The presence of bilateral symptoms means that in order to accomplish this, the return to the start position must be achieved via use of the upper limbs on an external support. The original study by Alfredson et al (1998) did not include patients with bilateral symptoms. A number of the studies reviewed did not exclude patients with bilateral symptoms, yet did not outline how a concentric component was avoided (Brown et al., 2006; Knobloch et al., 2007; Norregaard et al., 2007; Roos et al., 2004; Tol et al., 2006). Petersen et al. (2007) instructed participants to rise up on their toes and then place their weight on the uninjured leg. This would mean some component of the regime was concentric rather than a purely eccentric load as intended. It is possible that the performance of the concentric component on the affected leg in persons with bilateral symptoms may have influenced the efficacy of the HLECM training regime in these studies.

A further criteria identified in some of the reviewed studies excluded those participants who had previously performed heavy load eccentric exercises or had been unable to perform these exercises (Norregaard et al., 2007; Tol et al., 2006). It is possible this criterion would create a selection bias by excluding those participants who have not responded to HLECM training in the past. This means the remaining study population selected might demonstrate an enhanced treatment effect and thus not be representative of a typical patient population.

2.9.2   Outcome Measures

A comparison of results across studies is complex when research populations vary but also when different outcome measures are utilised. Earlier studies tended to implement only the VAS for pain and in some cases an interview method of ascertaining satisfaction and return to sport (Mafi et al., 2001). This latter method may be influenced by the therapist-patient relationship, particularly if the interviewer is also conducting the research as in the Alfredson et al. (1998) study.

More recently, studies have also used functional outcome measures including the VISA-A, the KOOS, the FAOS and unique clinical outcome scales. These measures differed in terms of being disease specific (VISA-A) and site specific (KOOS, FAOS). The VISA-A was the most consistently used in recent studies and has been shown to possess excellent test-retest reliability and construct validity (Robinson et al., 2001).

The use of unique Likert scales in research also confounds the difficulty in comparing the efficacy of interventions. All of the studies within the current review developed scales to determine a range of outcomes including tenderness, patient satisfaction, return to sport, degree of improvement and participation in physical activity. Each scale is inimitable and thus comparison of the impact of HLECM training on each population studied is difficult to ascertain. By utilising

identical outcome measures, it may be possible to determine features of either the population or intervention itself which may be more effective.

2.9.3   Methodological Variation

Variations in methodology between studies utilising the HLECM training protocol were reasonably minimal in terms of training principles such as sets, repetitions and frequency of performance. Some studies gradually introduced the HLECM regime over the first few weeks (Norregaard et al., 2007; Rompe et al., 2007; Roos et al., 2004) or reduced the frequency from twice a day (180 repetitions) to once a day only (90 repetitions) (Knobloch et al., 2007). Progressions of the HLECM training protocol were possibly more varied as the original study did not outline specifically how much weight was added to each participant's backpack, except to state that it should remain painful to complete the exercises.

The reproduction of Achilles tendon pain with exercise performance differed between studies as did the concurrent return to sporting or recreational activities. Alfredson et al. (1998) advised running may be continued if it could be performed with mild discomfort or pain free, with the majority of subsequent research adhering to this component of the protocol. Variations included an avoidance of tendon loading activities for the first four weeks (Tol et al., 2006) and the continuation of normal activity throughout (Knobloch et al., 2007). Clearly this would result in a large variation of tendon loading for each individual both within and across studies utilising this regime.

The reproduction of pain is suggested as an important component of the HLECM training protocol. Some studies attempted to reduce the pain associated with eccentric loading by altering their methodology accordingly (Norregaard et al., 2007; Rompe et al., 2007; Roos et al., 2004). This included a gradual introduction or decrease in number of repetitions. Furthermore, Norregaard et al. (2007) advised participants to avoid progressing exercises if painful contrary to

the Alfredson et al. (1998) study where patients were advised to progress exercises in order to achieve a painful state. The rationale for the modifications in the studies reviewed here was primarily to increase patient compliance with the regime.

In order for a training regime to be maximally effective, it is assumed compliance to the training principles prescribed is essential. However, most studies investigating the efficacy of HLECM training did not report participant compliance levels. Measurement of compliance, when detailed, was largely through training diaries, regular telephone calls and follow-up face-to-face visits. The definition of good compliance also varied, although was commonly classified as performance of at least 75% of the sets and repetitions prescribed (Roos et al., 2004; Tol et al., 2006). The number of repetitions and frequency of performance required in the HLECM training protocol is very high and thus it is reasonable to assume a proportion of patients would not complete the required amount each day if unsupervised. Tol et al. (2006) reported 27% of patients were completing less than 50% of the regime at the 12 week mark. This was the only study to demonstrate a relationship between a more positive outcome and increased compliance, although the results were not statistically significant.

A final methodological variation is concerned with the exercise technique itself. Alfredson et al. (1998) proposed that the two conditions of the HLECM protocol, the bent-knee and straight-knee components, target the soleus and gastrocnemius muscles respectively. It is not stated why it is necessary to target each calf muscle selectively during the eccentric training regime. The knee flexion angle required to achieve specific activity of each calf muscle has also not been outlined in the original study. In order to replicate a training protocol for research purposes, it is necessary to adhere to an identical technique. As there are currently no clear guidelines, it is possible there may have been some variation in technique execution between studies. Almost all subsequent studies reviewed here emphasised the inclusion of the two technique conditions, yet no

research has investigated whether this selective muscle activity actually occurs during HLECM training in a patient population.

2.10 Muscle Activity

Muscle activity is commonly measured by EMG which also facilitates the collection of information regarding muscle activation timing, fatigue and relative activity levels of individual muscles during selected movements (Soderberg & Knutson, 2000). Surface electrodes are usually utilised when investigating activity in the calf muscles (triceps surae) and are placed on the skin surface thereby providing a more global view of muscle activity during a contraction (DeLuca, 2006; Mademli, Arampatzis, Morey-Klapsing, & Bruggemann, 2004). In order to evaluate the relative activity levels of selected muscles, the signal must be normalised to a maximum voluntary contraction (MVC) of each muscle (Soderberg & Knutson, 2000). An isometric MVC is commonly utilised as this has been demonstrated to produce less intra-individual variability than isokinetic or dynamic methods (Burden, Trew & Baltzopoulos, 2003). Normalisation allows the average rectified values, termed the root mean square (RMS) signal for each muscle to be matched to a corresponding maximum value and muscle activity levels compared (Kennedy & Cresswell, 2001).

The gastrocnemius and soleus muscles, although sharing a similar anatomical location, differ markedly in their architecture, fiber type composition and function (Kawakami, Ichinose, & Fukunaga, 1998). Their relationship to joint angles of the ankle and knee are also specific. The EMG activity of the triceps surae at varying knee joint angles has been examined in scientific research, primarily during a maximum isometric plantarflexion contraction (Arampatzis et al., 2006; Kennedy & Cresswell, 2001; Miaki, Someya, & Tachino, 1999; Signorile, Applegate, Duque, Cole, & Zink, 2002).

As the bi-articular gastrocnemius crosses both the ankle and knee joints, it is generally accepted that the activity and torque output of this muscle is more dependent on the angle of these joints than is the mono-articular soleus (Kennedy & Cresswell, 2001). Due to the force-length relationship of skeletal muscle fibers, pronounced knee joint flexion angles cause the gastrocnemius to become actively insufficient. This is where the muscle reaches a critical shortened length where torque production cannot increase, even if the muscle is fully activated (Arampatzis et al., 2006). The research suggests this does not occur until the knee joint angle reaches at least 80º flexion (Arampatzis et al., 2006). At angles greater than this (i.e. where the knee is less flexed), there is an increasing amount of gastrocnemius activity up to a maximum with the knee fully extended, measuring 180º (Miaki et al., 1999; Signorile et al., 2002).

The angle of knee flexion required to facilitate activation of the soleus muscle during HLECM training has not been identified in the Alfredson et al. (1998) study. Electrical activity of the soleus muscle at differing knee joint angles has been investigated and the results demonstrate it to be maximal at 40º to 90º flexion (Kennedy & Cresswell, 2001; Miaki et al., 1999; Signorile et al., 2002). It is thought this may be due to a corresponding suppression of gastrocnemius activity in this position owing to the phenomenon of active insufficiency (Kennedy & Cresswell, 2001). In contrast, other research has demonstrated constant EMG activity from the soleus despite alterations in knee and ankle joint angles (Miyamoto & Oda, 2003). During the bent-knee condition of HLECM training, the knee flexion angle is greater than 90º. Given the research findings discussed, it appears that the gastrocnemius muscle would remain active in this condition and not reach a position of active insufficiency. Whether bending the knee during HLECM training preferentially targets the soleus muscle in persons with Achilles tendinosis, as purported by Alfredson et al (1998), is not known.

Potts (2005) investigated the EMG activity of the medial gastrocnemius and soleus muscles during performance of both conditions of the HLECM training

protocol in 18 participants without pathology. The EMG activity was examined during the eccentric phase of the contraction and expressed as a percentage of a value derived from an MVC of each corresponding muscle. During the straight-knee condition, the gastrocnemius activated at 61% and the soleus at 59% of their MVC values. During the bent-knee condition, the gastrocnemius activated at 47% and the soleus at 66% of their MVC values. While there was a trend for increasing relative activity of the soleus and decreasing relative activity of the gastrocnemius in the bent-knee condition, the difference between the conditions was not statistically significant. It is therefore possible that the knee flexion angle used during HLECM training is insufficient to inhibit gastrocnemius activity and preferentially target the soleus in persons without Achilles tendon pain.

2.11   Summary

Heavy-load eccentric calf muscle training as a treatment for Achilles tendinosis has been studied extensively. Although difficult to compare outcomes, a significant reduction of pain and increase in function was observed following HLECM training in all studies reviewed here. However, none of the studies have replicated the results of Alfredson et al. (1998). The efficacy of HLECM training has been demonstrated as not significantly different to shockwave therapy, stretching, bracing or night splinting. However, it has shown to be superior to concentric training. There was a trend in the studies reviewed for the groups participating in HLECM training to demonstrate enhanced functional outcomes but in all cases these were not statistically significant. Future research using larger populations may possibly yield significant differences in the efficacy of interventions for Achilles tendinosis.

A methodological variable not well detailed in the original or reviewed studies includes the use of a bent-knee and straight-knee condition, proposed to selectively activate the soleus and gastrocnemius musculature. Research has demonstrated no significance difference in activation levels of these muscles

during HLECM training in participants without pathology only (Potts, 2005). This variable has not been examined in a pathological population. The purpose of the following biomechanical study is to examine muscle activity levels of the gastrocnemius and soleus muscles in persons with Achilles tendinosis during performance of the HLECM training conditions and additionally, to compare this to activity levels demonstrated in a non-pathological population.

3. Methodology

This chapter describes the methodology of the biomechanical study and is divided into four sections comprising of the study participants and outcome measures utilised, equipment and procedures implemented and statistical methods applied.

3.1 Participants

All methods utilised in this study were approved by the Northern Regional Ethics Committee on the 29th January 2008. All participants signed a document of informed consent (Appendix B). The sample size was determined by selecting 18 participants from a larger sample of 46. Participants were matched as closely as possible for age with a group of 18 subjects without pathology from Potts (2005) study. These participants, who served as controls for the current study, were part of a previous Masters Dissertation.

Participants were recruited by information sheets located in physiotherapy and sports medicine practices in Auckland and via local media advertising between February and April 2008 (Appendix C and D). Participants were provided with an information sheet (Appendix E) from their treating medical professional.

The inclusion criteria were as follows:
- Aged over 20 years.
- Diagnosed with mid-portion Achilles tendinosis by their treating physiotherapist, sports medicine doctor or by the researcher (a practicing physiotherapist). A clinical diagnosis of Achilles tendinosis was used in this study. No imaging (i.e. ultrasound or MRI) was required to confirm the presence of the condition. The diagnostic criterion was a painful area of

the Achilles tendon 2-6cm proximal to the calcaneal insertion point on palpation. This may or may not have been associated with swelling.

- Unilateral or bilateral Achilles tendinosis. The electromyographic data was collected from the lower limb deemed most symptomatic by the participant at the time of assessment.

The exclusion criteria were as follows:

- Diagnosed with insertional Achilles tendinosis. Patients with pain and/or swelling in the insertional area of the tendon, indicating insertional Achilles tendinosis, were excluded from this study. This is due to the fact that patients with insertional Achilles tendinosis have demonstrated a poorer response to eccentric training and are infrequently included within study populations examining the HLECM protocol.
- Have had a previous history of Achilles tendon repair or rupture.
- Have had a previous corticosteroid injection into either Achilles tendon
- Has the presence of neural signs or symptoms affecting their lower limbs.

The following demographic information concerning age, weight, height, gender and duration of symptoms was collected (Appendix F).

3.2 Outcome Measures

3.2.1 Victorian Institute of Sports Assessment – Achilles Questionnaire (VISA-A)

The VISA-A (Appendix G) is the only disease specific questionnaire to serve as an index of the severity of Achilles tendinopathy. It was developed by Robinson et al. (2001) who demonstrated that it has excellent test-retest reliability (r=0.93) and construct validity. The questionnaire covers the domains of pain, stiffness, function in daily living and sporting activity.

3.2.2   Lower Limb Task Questionnaire (LLTQ)

The LLTQ (Appendix H) focuses on physical tasks related to lower-limb function and is not disease specific. Instead the LLTQ scores the ability of an individual to perform tasks in two separate constructs; activities of daily living and recreational activities.   In addition, the importance of each task is also rated. The validity, reliability and responsiveness of the LLTQ have been established (McNair et al., 2007). This outcome measure was included within this study in order to examine the influence of Achilles tendinopathy on these two constructs separately. It is possible that this condition may impact an individual's ability to participate in recreational activities more than activities of daily living.

3.2.3   Visual Analogue Scale

Pain levels were rated on a VAS from 0 = no pain to 10 = maximal pain for each exercise condition and during each maximum voluntary contraction (Katz & Melzack, 1999). This was noted by the researcher on a recording sheet for each subject.

3.3   Equipment and Procedures

3.3.1   Eccentric Exercise Performance

Following preparation for EMG and range of motion testing, one of two envelopes placed on a table were randomly selected by the participant indicating which condition was to be tested first (i.e. straight knee or bent knee).   A ten minute warm-up was then performed on a stationary bike at a low to moderate intensity prior to performing the HLECM exercise.

The eccentric exercise was performed according to the HLECM training protocol outlined by Alfredson et al. (1998). Participants were given a demonstration and an opportunity to practice five repetitions in order to ensure their technique was correct for each exercise condition. The start position consisted of maximal plantarflexion in standing on the tested limb followed by an eccentric dorsiflexion to their maximal available dorsiflexion range over the edge of the step. The knee was fully extended to 180º in the straight knee condition and flexed at 150º in the bent knee condition. Three repetitions of each condition were performed in each trial with the eccentric component of the exercise timing three seconds. Three trials were recorded for each exercise condition.

3.3.2   Ankle Joint Motion

Ankle joint range of motion measurement was necessary in order to identify the eccentric phase of each exercise condition. Range of movement through plantarflexion and dorsiflexion was recorded using a dual axis electrogoniometer (model 003, Penny and Giles, Gwent, England). A line between the middle of the lateral malleolus and the lateral epicondyle of the fibula was marked with the patient in standing. A second line was marked between the lateral malleolus and head of the fifth metatarsal. The measurement arm of the electrogoniometer was adhered to the skin surface using double-sided tape (3M Healthcare, St Paul, MN) and further reinforced with strapping tape (3M) along the marked lines (Fig. 3.1a). The reliability of this method has been established by previous research (Soper, Reid, & Hume, 2004). Prior to data collection the electrogoniometer was calibrated using a 90º calibration frame. Data were sampled at 500Hz via Superscope software (GW Instruments, Washington, USA).

3.3.3   Electromyographic Activity

Electromyography (EMG) was utilised to determine levels of muscle activity during performance of the HLECM exercise. The participants tested limb was

prepared by shaving and cleaning the skin with alcohol wipes. Double-differentiated, self adhesive surface electrodes were then placed on the soleus and medial gastrocnemius muscles according to the SENIAM guidelines for electrode placement (Hermens, Freriks, Disselhorst-Klug, & Rau, 2000) (Fig 3.1b). These electrodes can decrease artifacts included in the EMG signal and reduce crosstalk from surrounding muscles (Soderberg & Knutson, 2000). A reference electrode was placed over the tibial plateau. The longitudinal axis of the electrodes was orientated in parallel with the approximate fibre direction of each muscle (DeLuca, 2006). The EMG signal was sampled at 500Hz, amplified 1000x, band pass filtered (20-450Hz) and relayed to a Superscope software package (GW Instruments, Washington, USA). The data was stored in a McIntosh computer for subsequent analyses. The analysis of this data involved a cursor routine that utilised the signals from the electrogoniometer in order to identify the eccentric phase of muscle activity. RMS values were calculated within this interval for three trials and then averaged.

Normalisation of the EMG signal from the gastrocnemius and soleus muscles was conducted using a maximal voluntary contraction (MVC) of each muscle. The gastrocnemius MVC was tested in prone with the knee extended (Fig. 3.2), and the soleus in a sitting position with the knee flexed to 90º (Fig. 3.3). The participants practiced using a ramping protocol of muscle contraction where they were asked to generate 25%, 50% and then 75% of a MVC in each position. Following a one minute rest, an MVC was performed with verbal encouragement for a period of five seconds. Three MVCs were conducted in each position with a one minute rest between trials. The EMG data was analysed using a cursor routine targeting the most stable signals within a two second epoch. The maximal RMS value across the three MVC trials was used in subsequent analysis. The RMS value for each muscle in each condition was expressed as a percentage of the RMS of the corresponding MVC.

3.5　　　Statistics

The dependent variables of interest were the RMS of EMG activity from the gastrocnemius and soleus muscles during the eccentric phase of ankle joint movement with the knee joint either flexed or extended. These data were expressed as a percentage of activity recorded from the MVC. Data were checked to identify outliers and abnormalities (kurtosis and skewness) in the distribution. A three-factor repeated measures ANOVA was performed. The repeated measures (within subjects) factors were the joint position and muscle, while group was the between subjects factor. The alpha level was set at 0.05. Levene's test for equality of variances was performed and as a repeated measures design was being utilised, Mauchly's sphericity test was implemented.
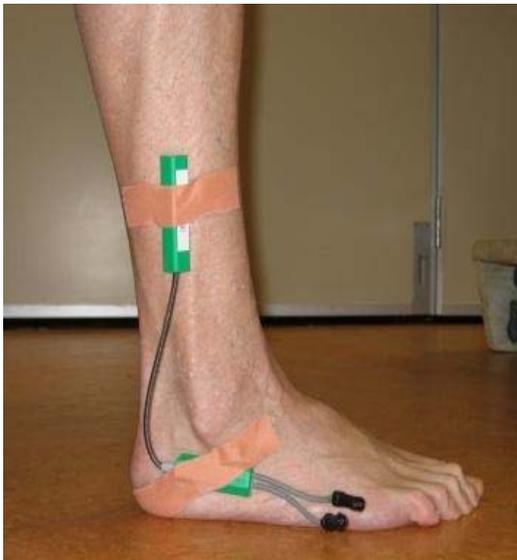

Figure 3.1a Electrogoniometer placement
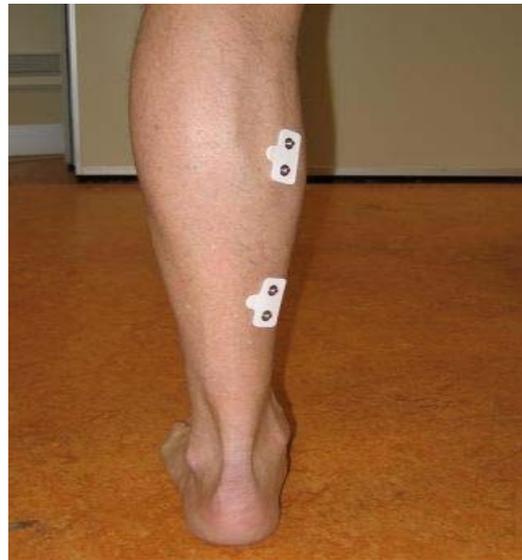
Figure 3.1b EMG electrode placement

Figure 3.2   Measurement of gastrocnemius MVC

Figure 3.3   Measurement of soleus MVC

4. Results

This chapter is divided into three sections. Firstly the participants' demographics and outcome measure scores are summarised. Secondly, muscle activity levels in participants with Achilles tendinosis are compared to controls and thirdly, the effect of knee joint position on muscle activity in the total group is reported.

4.1 Participant Demographics

Participant demographics are summarised in Table 4.1. The mean age of the experimental group was 42.6 years. The mean age of the control group was 29.7 years (Potts, 2005).

Table 4.1   Participant Demographics

Demographic	N	Mean	Standard Deviation
Age (years)	18	42.6	7.2
Height (cm)	18	173.8	7.7
Weight (kg)	18	77.6	19.6
Symptom Duration (months)	18	7.6	6.6
VISA-A	18	61	16.2
LLTQ ADL	18	34	3.8
LLTQ REC ACT	18	26	8.0

4.1.1 Outcome Measures

The mean outcome measure scores were 61 for the VISA-A, 34 for the LLTQ activities of daily living (ADL) and 26 for the LLTQ recreational activities (REC ACT) (Table 4.1). The mean VAS score (/10) for pain during the straight knee condition was 1.2, the bent knee condition 1.4, the prone MVC condition 0.2 and the seated MVC condition 0.2.

4.2   Muscle Activity and Achilles Tendinosis

The key findings related to the electromyographic data are presented in Figure 4.1 and 4.2. Levene's test results indicated that there was homogeneity in the variances across all levels of the dataset. The assumption of sphericity was not met and Greenhouse-Geisser corrections were applied to produce valid F-ratios. These showed that there was a significant main effect for group ($p < 0.05$). Irrespective of knee position and muscle, EMG activity was significantly higher (mean difference: 10%, effect size: 0.59) in those subjects with Achilles tendinosis. Mean activity levels ranged from 55% to 72% in this group depending upon joint position, while in the control subjects, they ranged from 47% to 62%.
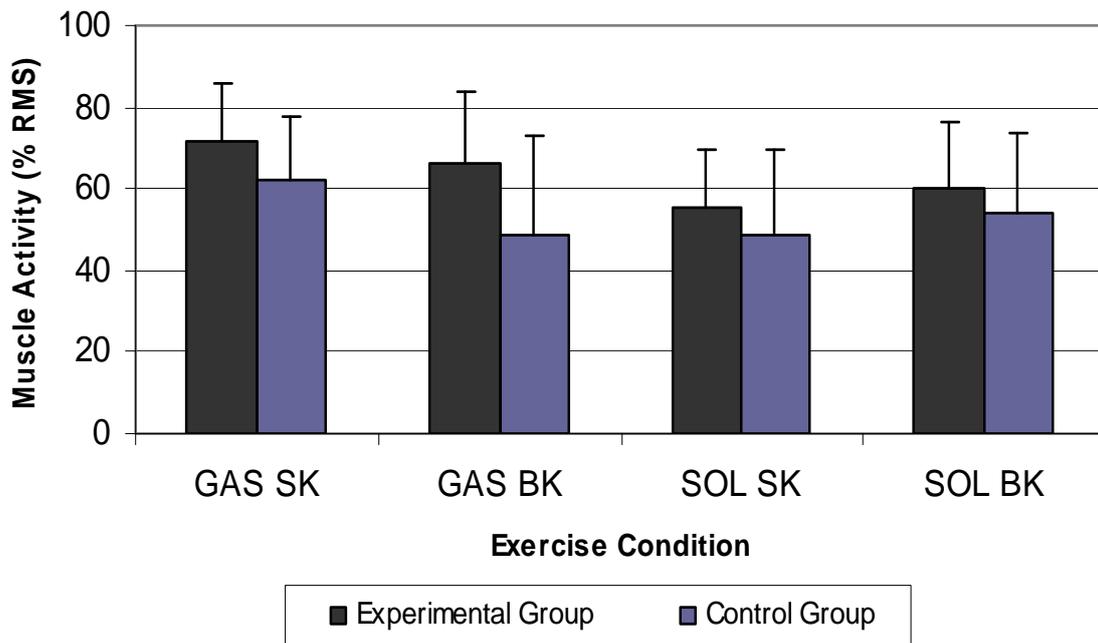

Figure 4.1   Muscle activity levels in experimental and control groups during HLECM exercise conditions. Data are mean and standard deviation.

GAS SK = gastrocnemius activity in straight knee condition

GAS BK = gastrocnemius activity in bent knee condition

SOL SK = soleus activity in straight knee condition

SOL BK = soleus activity in bent knee condition

4.3   Muscle Activity and Knee Joint Position

There was a significant interaction effect between muscle and joint position (Fig
4.2). This indicated that differences in muscle activity depended upon whether
the knee was flexed or extended. For the gastrocnemius, EMG activity was
higher when the knee was extended, whereas when the knee was flexed, EMG
levels were decreased. In contrast, soleus activity increased slightly from the
extended to the flexed knee position. There were no other significant main
effects or interactions.
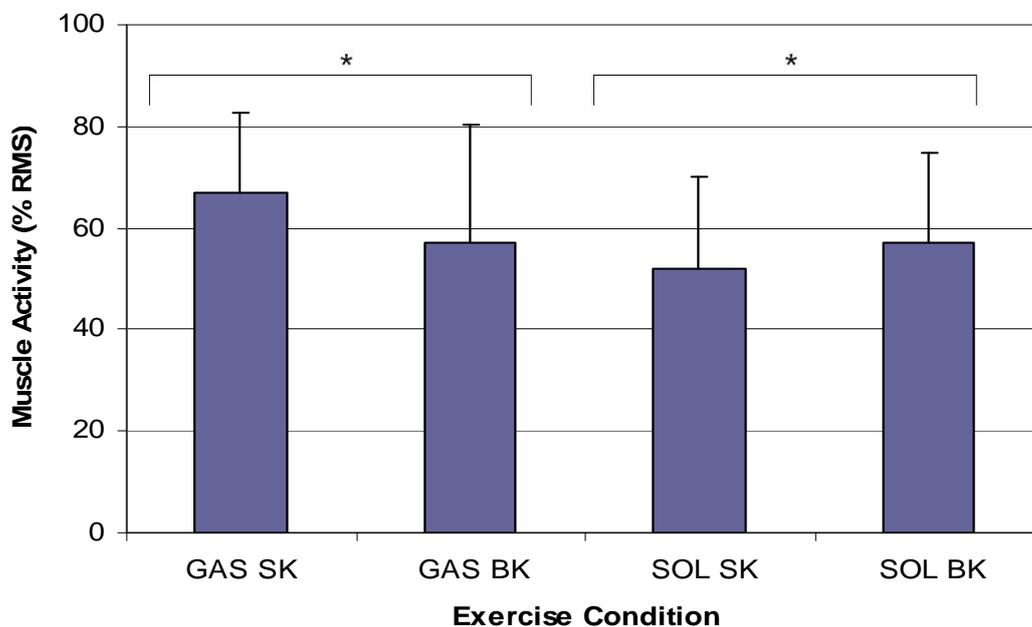
Figure 4.2   Muscle activity levels in total group during HLECM exercise conditions. Data are
                  mean and standard deviation. * = p<0.05.
                  GAS SK = gastrocnemius activity in straight knee condition
                  GAS BK = gastrocnemius activity in bent knee condition
                  SOL SK = soleus activity in straight knee condition
                  SOL BK = soleus activity in bent knee condition

5.   Discussion

This chapter is divided into five sections. Firstly, muscle activity levels with respect to the presence of pathology will be discussed. Secondly, the effect of knee joint angle on selective calf muscle activity during performance of the HLECM training protocol will be outlined. This will be followed by a discussion of the limitations and clinical implications of the present study and finally areas for future research will be identified.

5.1   Muscle Activity in Achilles Tendinosis

The main findings of the experimental study indicate that the muscle activity levels of both the gastrocnemius and soleus muscles during each condition of the HLECM protocol were significantly higher in persons with Achilles tendinosis compared to controls. Muscle activity patterns provide information about neural control strategies of movements (Lay, Hass, Nichols, & Gregor, 2007). A higher muscle activity level corresponds to a greater proportion of motor units activated within each muscle and/or an increase in firing rate (DeLuca, 2006). In this study, it appears the presence of pathology influenced the neural control strategy employed during an eccentric plantarflexor contraction, manifested by an increase in muscle activity levels. It is possible alterations in neural control and EMG activity in this study may be related to other factors that correspond with pathological conditions such as tendinopathy, including pain, muscle atrophy and reduced strength (Don et al., 2007; Valderrabano et al., 2006).

5.1.1   Pain and Muscle Activity

The mean VAS scores for pain during the HLECM protocol exercises were low in this study (0.2/10 to 1.4/10), probably limiting the effect of this variable on muscle activity levels. However, during performance of the full HLECM protocol in a

clinical and research setting, the maintenance of a painful state is considered an essential principle (Alfredson et al. 1998). The participants in this study were required to perform 12 repetitions of each condition, considerably less than the 180 required during the treatment protocol. It is probable that the presence of tendon and/or muscle pain with a greater number of repetitions influences the neural control strategies utilised by the triceps surae and associated synergists in persons with tendinopathy.

To date there is no research investigating the effect of lower limb tendon pathology on EMG activity of associated muscles. Maximal and sub-maximal muscle activity has been examined in patients with rotator cuff tendinosis (Brox, Roe, Saugen, & Vollestad, 1997). These authors demonstrated an increase in muscle activity of the rotator cuff during a maximal voluntary contraction following a pain relieving injection. However, muscle activity also increased during a sub-maximal fatiguing contraction, despite pain levels increasing threefold in this time. These authors concluded pain inhibits the central motor drive of agonist muscles during maximal contractions only. In contrast, other research has demonstrated muscle pain inhibits muscle activation during sub-maximal contractions and increases the effects of fatigue (Ciubotariu, Arendt-Nielsen, & Graven-Nielsen, 2007). Furthermore, EMG activity of synergistic muscles has been shown to increase where pain has been induced in the corresponding agonist, perhaps as a compensatory mechanism (Ciubotariu, Arendt-Nielsen, & Graven-Nielsen, 2004; Schutle et al., 2004). Recent research has also demonstrated an increase in superficial and decrease in deep cervical muscle EMG activity in the presence of neck pain disorders (Falla, 2008). This altered motor strategy causes a redistribution of load among synergistic muscles and may represent reduced neuromuscular efficiency of those muscles where EMG activity has increased. The ability to extrapolate the findings of these EMG studies to the current one may be limited however, as they investigated only isometric contractions and pain was induced locally into muscle, rather than tendon tissue.

5.1.2   Biomechanical Properties and Muscle Activity

While there is a reasonable amount of research examining the pathophysiological changes that occur with tendinosis, research has not yet investigated the biomechanical effects of Achilles tendinopathy on the triceps surae or tendon itself. However, alteration of biomechanical properties of the calf musculature, including strength changes, have been observed for up to two years following surgery for Achilles tendon rupture (Don et al., 2007). Of note is the finding that EMG activity of the soleus returned to normal levels at the six month mark despite an ongoing loss of eccentric strength of up to 30% for a period of two years. Concentric strength however, was restored at six months postoperatively. While this clinical situation differs to that of tendinopathy, previous research has also demonstrated a reduction in both eccentric and concentric strength in the calf muscles of the tendinopathic limb prior to eccentric training (Alfredson et al. 1998, Alfredson et al., 1999). It is possible the participants in the current study also possessed a reduction of eccentric strength, given the chronicity of their condition. However, muscle activity levels may in fact be independent of eccentric strength changes in this population as for those individuals post Achilles tendon surgery.

The reason for an increase in muscle activity in the presence of pathology in this study remains unknown. It may represent an increase in the proportionate number of motor units activated within the plantarflexors in an attempt to perform the task at a defined velocity with a body weight load. Many participants found it difficult to control the eccentric descent into ankle dorsiflexion at the set three second velocity and increased their speed. This, combined with the task being novel for some, may have influenced their neural strategy and hence the degree of muscle activity from the triceps surae compared to those without pathology.

5.2 Muscle Activity and Knee Joint Position

The results of this study demonstrate a significant effect of knee joint position on muscle activity levels in the total group. The gastrocnemius muscle activated at higher levels with the knee straight and the soleus with the knee bent. The outcome of this research is thus in agreement with the assertion made in the original HLECM training study; that inclusion of the bent knee component of the technique is necessary to preferentially activate the soleus muscle and this is the first study to demonstrate this experimentally.

5.2.1 Electromyographic Studies

The results from the current study reflect a similar trend to that generated in previous research where soleus activity increases as the knee flexion angle decreases (Kennedy & Cresswell, 2001; Signorile et al., 2002). However, in these studies, the maximum soleus activation occurred at angles between 40º and 90 º flexion, not at the angle of flexion maintained during the HLECM technique, which may be estimated at approximately 150 º. At this angle, this preceding research has demonstrated gastrocnemius to be reaching almost maximum levels of activation and this is the rationale for use of the 180º position in MVC testing of this muscle. Furthermore, research suggests is not until the knee is flexed to 90º that the gastrocnemius is believed to reach a point of active insufficiency where the soleus muscle must activate to compensate for a loss of corresponding force (Arampatzis et al., 2006). This current study also does not support the concept of maintenance of a constant activity of the soleus despite changes in knee angle, as demonstrated by Miyamoto and Oda (2003).

The discrepancy in results between studies investigating muscle activity and the current one may lie primarily with differences in methodology; this study measured a sub-maximal eccentric contraction while previous research has measured an isometric maximum contraction. The bent knee technique of

HLECM training involves maintaining a static knee angle of approximately 150º, while the ankle is gradually dorsiflexed to beyond neutral. Although both the soleus and gastrocnemius muscles are lengthening, their individual length-tension relationship will be different at the same knee and ankle joint angles due to their anatomical position (Arampatzis et al., 2006). Perhaps the bent knee position of the HLECM training technique, combined with an increasingly dorsiflexed ankle places the soleus at a more optimal length to generate activity than the gastrocnemius.

An alternative reason for the variation in results from the above EMG studies may be the different test positions utilised, such as four-point kneeling, sitting and standing. It has been demonstrated isometric force and muscle activity are highest in a functional standing position but testing in prone is more reliable for research purposes (Carlsson, Lind, Moller, Karlsson, & Svantesson, 2001). These authors investigated only the gastrocnemius muscle, thus it is possible the soleus behaves differently in these various positions.

5.2.2 Rationale for Selective Muscle Activation

Alfredson et al. (1998) emphasised the inclusion of the bent knee technique in order to activate the soleus, but did not outline why it is necessary to selectively recruit the triceps surae. The following section is a discussion of the possible rationale for the inclusion of both components within HLECM training based on the concept of training specificity. This is where the exercise regime of an individual closely matches their functional activities in order to produce the greatest performance gains (Morrissey, Harman, & Johnson, 1995). Specificity of training incorporates variables such as technique execution, including specific joint angles and positions, and training velocity.

The gastrocnemius and soleus muscles differ in their fiber type composition, anatomical position and architecture (Kawakami et al., 1998). The

gastrocnemius muscle is comprised of a larger proportion of type II fast-twitch fibers while soleus has an additional postural function and contains more fatigue-resistant, type I slow-twitch fibers. During an eccentric triceps surae contraction, the velocity of contraction has been demonstrated as a critical influence on the relative recruitment of the gastrocnemius and soleus due to their differing fiber type composition   The more rapid the deceleration of force by the triceps surae, the more activation of gastrocnemius and suppression of soleus is observed (Nardone, Romano, & Schieppati, 1989). During a concentric-eccentric heel raise protocol, it has also been demonstrated the triceps surae respond differently to fatigue, with the soleus fatiguing less during the eccentric phase but also displaying a reduction in muscle activation (Svantesson, Osterberg, Thomee, & Grimby, 1998).

In the quadriceps musculature, fast-twitch fibers have exhibited greater atrophy than slow-twitch fibers in the presence of knee joint pathology (Fink et al., 2007). The authors proposed this may reflect pain related immobilisation of the affected limb. Although fiber type changes have not been examined with lower limb tendon pathology to date, it is possible similar changes may occur in the triceps surae in the presence of Achilles tendinopathy. Due to their specific fibre type makeup, the gastrocnemius and soleus muscles may respond differently to a decrease in tendon load through reduced participation in daily or sporting activities. This means they may therefore benefit from selective recruitment during rehabilitation exercises.

The concept of velocity specificity is supported by the training literature, where strength gains are consistently greater at the trained velocity with some carryover to slower speeds (Morrissey et al., 1995). Within the original study no details are provided regarding the tempo of the exercise. However, the velocity of calf muscle contraction in HLECM training is generally slower than that of activities such as running or walking which typically provoke tendinopathic symptoms.

Despite this discrepancy, many individuals return to these activities with minimal difficulty following the three month training period.

In the current study, it was observed some participants struggled to maintain the three second velocity of eccentric contraction required for EMG analysis possibly due to eccentric weakness of the calf muscles. Therefore, it is possible velocity is a particularly variable component of the technique both between individuals and between studies, particularly when participants are unsupervised in a home environment. Results of the outcome measures utilised in the current study indicate a reduction in full participation in both daily (34/40) and recreational activities (26/40) in the LLTQ, although the latter is more affected by the presence of Achilles tendinosis. Given the differing fiber type composition and possible variation in response to disuse, it is likely the tempo of the eccentric phase of the HLECM technique plays a critical role in determining selective muscle recruitment in addition to other training factors such as joint angle.

The inclusion of both components in HLECM training may also function to reproduce joint angles similar to those generated during a gait cycle. The triceps surae activate eccentrically during the stance phase from a straight knee position to that of a bent knee position while the ankle is being relatively dorsiflexed (Komi, Fukashiro, & Jarvinen, 1992). There is evidence to suggest that range of motion specificity exists during resistance training (Morrissey et al., 1995). This is where the greatest strength gains are made at exercised joint angles. Open and closed kinetic chain strength training following anterior cruciate ligament reconstruction has been demonstrated to increase strength maximally at the angle trained with some carryover to other similar joint angles (Hooper, Hill, Drechsler, & Morrissey, 2002).

Use of both the bent and straight knee position in HLECM training may provide a wider range of strength gains, particularly from 180º to 150º knee flexion, than if training with only the knee extended for example. Achilles tendinopathy

commonly affects individuals who participate in competitive or recreational walking or running where the triceps surae is active at similar knee and ankle joint angles to those adopted in the HLECM training technique (Kujala et al., 2005). Although some EMG studies suggest the soleus may be preferentially activated with the knee flexed to 90º, this position does not simulate those found in symptom provoking activities. The efficacy of HLECM training may be not only due to the eccentric loading per se but also the specificity of velocity and range of movement resistance training and the relationship of these to functional activities.

5.3   Limitations of the Study

The diagnosis for inclusion was made by clinical exam only, without the use of imaging, and thus the presence of mid-portion tendinopathy could not be differentiated from other possible tendon pathologies. Differing pathologies may render varying biomechanical effects, however, as the tissue tested in this case is not the tendon but the adjacent musculature, it is presumed the effect on EMG activity may not be notably different.

The performance of the exercise technique was difficult for a number of participants in the experimental group both in terms of a lack of strength to be able to slowly descend into a dorsiflexed position and also due to the novelty of the task. It should be noted the bent knee position technique was much more difficult for participants to perform correctly, even with an opportunity to practice. All participants experienced no difficulty with the straight knee position. It may be the bent knee position represents a more challenging movement pattern than the straight knee position, possibly influencing the neural strategy utilised.

Measurement of the eccentric phase was taken over three cycles of movement for three trials in each position. It may have been advantageous to teach the technique on one day with the participant given an opportunity to practice in their own time before testing muscle activity levels on another day. Alternatively,

muscle activity levels could have been tested over a greater number of trials such as the 180 used in the Alfredson et al. (1998) study. However, this may have caused muscle fatigue, which in turn may influence muscle activity.

Normalisation of the EMG data was carried out using an isometric maximum voluntary contraction. There is some debate in the literature regarding the reliability of this measure, although isometric contractions are preferential to isotonic measures (Burden, Trew, & Baltzopoulos, 2003). Maximum voluntary contractions are influenced by factors including familiarity with the task, verbal encouragement and previous resistance training (Shield & Zhou, 2004). There is good evidence to demonstrate the presence of knee joint injury reduces voluntary muscle activation levels of the quadriceps muscles (Urbach & Awiszus, 2002). Although not examined in persons with tendon pathology, it is possible the participants in the experimental group were not able to maximally activate their triceps surae. Additionally, although there was opportunity to practice, the task was unfamiliar, which also may reduce voluntary activation levels (Shield & Zhou, 2004). The twitch interpolation technique involves a supramaximal stimulus applied to the nerve trunk of a muscle during a voluntary contraction and provides a more accurate assessment of the completeness of muscle activation (Shield & Zhou, 2004). This technique may have been useful in this study to ensure a more accurate MVC and hence RMS value was generated.

Finally, the data obtained was age matched to that from previous work by Potts(2005) to assist in comparison of results. There was a lack of other demographic information (i.e. gender, height and weight) available from the Potts (2005) study to compare populations further

5.4 Clinical Implications

Almost all of the participants in the experimental group had consulted a physiotherapist and been prescribed some form of eccentric calf muscle loading

exercise. This suggests the use of HLECM training is frequent in clinical practice. Accordingly, gaining knowledge regarding the biomechanics of the technique itself is advantageous for a number of health practitioners and patients. As discussed, there exists limited research investigating the biomechanics of rehabilitation exercises used for the treatment of tendinopathy. Assessing factors such as muscle activity provides information that may be used to explain differences in rehabilitation effects in addition to allowing design of more effective rehabilitation programmes. Compliance to the regime has been demonstrated to be a problem in the research utilising HLECM training and anecdotally for the participants of this study. Assessing the biomechanics of the HLECM training protocol may lead to a more concise programme which in turn may improve compliance levels and possibly efficacy.

The results of this study suggest it is useful to include both components of the HLECM training regime as they selectively activate the gastrocnemius and soleus muscles. Given the findings related to the specificity theory of training discussed above, it may also be useful to include varying velocities within the regime or trial the effect of a more flexed bent knee position in order to achieve wider range of motion training specificity.

5.5 Future Research

In order to design improved rehabilitation programmes for those with Achilles tendinopathy it would be useful to investigate the influence of other biomechanical variables such as eccentric strength, muscle atrophy and muscle-tendon stiffness on the efficacy of the regime. This would also provide an improved description of the relationship between pathology and biomechanical changes in this particular population. By stratifying studied populations into subgroups based on these biomechanical factors or others, such as symptom duration and severity, an explanation of the variation in efficacy seen in the current literature may be attained. The use of standardised inclusion and

exclusion criteria, functional outcome measures and clarification of the HLECM training methodology means comparison between future studies will be enhanced.

It may be argued that it is not specific muscle activation that is required but the overall loading of the Achilles tendon through HLECM training that achieves an efficacious result. How the tendon converts mechanical signals into a healing response is currently not known (Wang, 2006). To assist with clarifying which aspects of HLECM training may influence efficacy, modification of particular variables such as repetition numbers, use of one component only (i.e. straight knee position) and velocity of contraction, with use of appropriate control groups, would also be valuable.

Given the finding that those individuals with Achilles tendinosis demonstrate elevated levels of muscle activity of the triceps surae during the HLECM exercises, it would also be useful to investigate whether this variable normalises following implementation of the HLECM 12 week protocol.

5.6   Conclusion

Heavy load eccentric calf muscle training was developed by Alfredson et al. (1998) as an intervention for Achilles tendinopathy. Results of the literature review demonstrate there is moderate evidence for the efficacy of HLECM training although the mechanisms of pain alleviation and return to functional activity through the use of this regime remain unclear. This experimental study has demonstrated the straight and bent-knee components of the HLECM training regime selectively activate the gastrocnemius and soleus muscles respectively in a population diagnosed with Achilles tendinosis. Additionally, individuals with Achilles tendinosis exhibit higher muscle activation levels of the triceps surae during the eccentric phase of this technique than controls. The reasons for this increase in muscle activity in a pathological population are not currently known.

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Appendix A

Operationalisation of the Criteria List

A   A random (unpredictable) assignment sequence. Examples of adequate methods are computer generated random number tables and use of sealed opaque envelopes. Methods of allocation using date of birth, date of admission, hospital numbers or alternation should not be regarded as appropriate.

B   Assignment generated by an independent person not responsible for determining the eligibility of the patients. This person has no information about the persons included in the trial and has no influence on the assignment sequence or on the decision about eligibility of the patient.

C   In order to receive a "yes", groups have to be similar at baseline regarding demographic factors, duration and severity of complaints, percentage of patients with neurologic symptoms and the value of the main outcome measure(s).

D   The reviewer determines if enough information about the blinding is given in order to score a "yes"

E   The reviewer determines if enough information about the blinding is given in order to score a "yes"

F   The reviewer determines if enough information about the blinding is given in order to score a "yes"

G   Cointerventions should either be avoided in the trial design or similar between control and index groups

H   The reviewer determines if the compliance to the interventions is acceptable, based on the reported intensity, duration, number and frequency of sessions for both the control and index interventions(s).

I   The number of participants who were included in the study but did not complete the observation period or were not included in the analysis must be described and reasons given. If the percentage of withdrawals and drop-outs does not exceed 20% for short-term follow-up and 30% for long-term follow-up and does not lead to a substantial bias a "yes" is scored (N.B. these percentages are arbitrary and not supported by literature).

J   Timing of outcome assessment should be identical for all interventional groups and for all important outcome assessments.

K   All randomised patients are reported/analysed in the group they were allocated to by randomisation for the most important moments of effect measurement (minus missing values) irrespective of non-compliance and cointerventions.

Appendix B

# Consent Form	**AUT** UNIVERSITY TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

Project title: **Investigation of calf muscle activity during a rehabilitation exercise in patients with Achilles tendinosis**

Project Supervisor: **Duncan Reid**

Researcher: **Shelley Johnson**

○ I wish to have an interpreter (please circle) Yes No

○ I have read and understood the information sheet dated 26th September 2007 for volunteers taking part in this study designed to investigate the activity of the calf muscles during exercise.

○ I have had an opportunity to discuss this study. I am satisfied with the answers I have been given.

○ I understand that taking part in this study is voluntary (my choice) and I may withdraw from the study at any time and this will in no way affect my future health or continuing health care.

○ I understand that participation in this study is confidential and that no material which could identify me will be used in any reports on this study.

○ I understand that the investigation will be stopped if it should appear harmful to me.

○ I have had time to consider whether to take part and I know who to contact if I have any side effects from the study or questions about the study.

○ I wish to receive a copy of the report from the research (please tick one):
Yes ○ No ○

I _____ (full name) hereby consent to take part in this study.

Participant's Signature:

....…………………………….……………………………………

Date:

This study has received ethical approval from the Northern Regional Ethics Committee on 29 January 2008.

Appendix C
Physiotherapist Information Form

Project Title:

Biomechanical analysis of a "heavy load eccentric calf muscle" rehabilitation exercise in patients with Achilles tendinosis; a pilot study.

Thank you for your assistance with this study. Attached is an information sheet, outlining what the study involves, for patients and their treating physiotherapist to read.

Inclusion and Exclusion Criteria

The inclusion criteria for this study are:
- Aged over 20 years.
- Diagnosed with unilateral Achilles tendinosis by their treating physiotherapist (refer note below for diagnosis criteria)

The exclusion criteria for this study are:
- Diagnosed with insertional Achilles tendinosis (refer note below for diagnosis criteria)
- Have had a previous history of Achilles tendon repair or rupture.
- Have had a previous corticosteroid injection into either Achilles tendon
- Has Achilles tendinosis bilaterally.
- Has the presence of neural signs or symptoms affecting their lower limbs.

Diagnosis of Achilles Tendinosis

The diagnosis used for this study is a clinical one; no imaging (i.e. ultrasound) is required to confirm the presence of the condition. The diagnostic criterion is a painful area of the Achilles tendon 2-6cm from the tendon insertion into the calcaneus. This may or may not be associated with a thickened, swollen area. Patients with pain and/or swelling in the insertion area of the tendon, indicating insertional Achilles tendinosis are excluded from this study. This is due to the fact that patients with insertional Achilles tendinosis have demonstrated a poorer response to eccentric training programmes using the exercises described.

Process of Referring a Patient to this Study

If you have a patient who fits the inclusion and exclusion criteria, please provide them with a patient information sheet and ask them to consider their participation in the timeframe until their next physiotherapy treatment. They are welcome to take longer if necessary. They are also able to contact the principal researcher, Shelley Johnson, if they have any questions regarding the study.

Once the patient has decided to take part, they need to contact either:

Shelley Johnson
Principal Researcher
(07) 8701033 or 021332814
shelljohnson@mailcity.com

or,

Duncan Reid
Primary Supervisor
(09) 9219999 ext 7806
duncan.reid@aut.ac.nz

They are welcome to leave a message with contact details and they will be telephoned or emailed and a time arranged to attend the Health and Rehabilitation Research Centre, Auckland University of Technology, Akoranga Drive, Northcote, Auckland. A $20 petrol voucher will be provided to assist with travel costs. Appointment times may be outside working hours if necessary.

Physiotherapist Enquiries Regarding this Study

If you require clarification of any of the above information, please contact Shelley Johnson or Duncan Reid (contact details provided above).

Appendix D

Media Recruitment Advertisement

Appendix E

Participant
Information Sheet

AUT
UNIVERSITY
TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

26 September 2007

Project Title

Investigation of calf muscle activity during a rehabilitation exercise in patients with Achilles tendinosis: a pilot study.

An Invitation

Thank you for enquiring about participation in this study which will contribute to a Master of Health Science qualification in Physiotherapy. The following is an outline of what the study involves. Your participation is entirely voluntary (your choice). You do not have to take part in this study and if you choose not to take part you will receive the usual treatment from your physiotherapist.

What is the purpose of this research?

The purpose of this research is to investigate the activity of the calf muscles while you are performing a heel raise and lowering exercise. This exercise is commonly prescribed by physiotherapists to patients with Achilles tendon pain (also known as tendonitis or tendinosis) to help reduce the pain associated with this condition and improve function. The results of this research will be presented in a dissertation document and published in national and international rehabilitation journals.

How was I chosen for this invitation?

You have been selected by your physiotherapist as an ideal candidate as you have been diagnosed by them, or another medical professional, with Achilles tendinosis and also fit the following criteria:

- have no history of Achilles tendon surgery or rupture
- have no history of previous corticosteroid injection into the Achilles tendon area
- have Achilles tendon pain on one side only (i.e. left or right)
- have no current referral of pain or neural symptoms (i.e. pins and needles) in your legs

What will happen in this research?

Prior to collecting the information from the exercises you will be required to fill in three forms. The first one collects general information about your age, height, weight and duration of symptoms. The second form, the VISA –A , collects information about the pain in Achilles tendon with various activities and the third one, the Lower Limb Task Questionnaire, collects information on how the condition affects you during functional and daily activities.

Participating in this research involves performing a light warm-up on a stationary bike then randomly selecting a form which will allocate the order of the exercise (bent or straight leg first). A small area on the calf of your affected leg will be shaved and cleaned for the application of three self adhesive electrodes that will measure the electrical activity of the muscles. A device that measures your ankle range of movement will also be adhered to the outer side of your ankle.

The exercise starts with standing on the edge of a step on your toes as a far as comfortable and you are able to touch the wall lightly in front of you for balance. One foot is removed from the step and you are then required to lower your body weight to bring your heel below the level of the step as far as is comfortable. The removed foot is then replaced on the step to raise you back up onto your toes. The sequence of lowering your body weight on one leg is repeated for two sets of 10-12 times in each set. After this you will be positioned on a table lying on your front and instructed to push as hard as possible with your calf muscle against a stationary board to measure its maximum muscle activity.

What are the discomforts and risks?

It is possible you may experience some mild delayed muscle soreness in the calf muscle for up to 48 hours following performing the exercises if you are not used to them. This soreness resolves naturally and is not a sign of injury. There is also a risk of Achilles tendon rupture with performing any activities that involve loading your calf muscle. However, this is extremely rare and has not happened in any other studies involving these exercises.

How will these discomforts and risks be alleviated?

Using the stationary bike before you perform the exercise has shown to reduce the intensity of this delayed muscle soreness. You will have full access to medical advice or treatment if the discomfort does not resolve within a couple of days or if there are any other issues relating to your lower leg symptoms. In the case of a medical emergency the researcher will refer you immediately to the appropriate medical facilities.

What are the benefits?

The data gained from this research will contribute towards designing better exercise programmes for people with Achilles tendinosis. This might mean that exercise programmes are effective more rapidly or that they are less arduous.

What compensation is available for injury or negligence?

In the unlikely event of a physical injury as a result of your participation in this study, you may be covered by ACC under the Injury Prevention, Rehabilitation and Compensation Act. ACC cover is not automatic and your case will need to be assessed by ACC according to the provisions of the 2002 Injury Prevention, Rehabilitation and Compensation Act. If your claim is accepted by ACC, you still might not get any compensation. This depends on a number of factors such as whether you are an earner or non-earner. ACC usually provides only partial reimbursement of costs and expenses and there may be no lump sum compensation payable. There is no cover for mental injury unless it is a result of physical injury. If you have ACC cover, generally this will affect your right to sue the investigators.

If you have any questions about ACC, contact your nearest ACC office or the investigator.

How will my privacy be protected?

Privacy is of extreme importance and you will be identified only by a number. Access to the experimental data will be kept in a locked cupboard and available only to the researcher and supervisor. No material which could personally identify you will be used in any reports on this study.

What are the costs of participating in this research?

Participation in this research will involve approximately one hour of your time at the Auckland University of Technology Health and Rehabilitation Research Centre. A small amount will be provided to assist with travel costs.

What opportunity do I have to consider this invitation?

Once you have received this information you have until your next physiotherapy treatment to consider whether you would like to take part. This usually ranges from 24 hours to 1 week, however may be longer if your next treatment is outside this time frame.

How do I agree to participate in this research?

You will need to sign a consent form which will be provided by the researcher at the Health and Rehabilitation Research Centre.

Will I receive feedback on the results of this research?

You will be able to receive a written summary of the findings on request to the researcher.

What do I do if I have concerns about this research?

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor (contact details below).

Concerns regarding the conduct of the research should be notified to the Executive Secretary, AUTEC, Madeline Banda, *madeline.banda@aut.ac.nz* , 921 9999 ext 8044.

Who do I contact for further information about this research?

Researcher Contact Details:

Shelley Johnson

(07) 838 3798 (W)

(021) 332814 (M)

shelljohnson@mailcity.com

Project Supervisor Contact Details:

Duncan Reid

Division of Rehabilitation and Occupation Studies
Auckland University of Technology

(09) 921 9999 ext 7806 (W)

duncan.reid@aut.ac.nz

This study has received ethical approval from the Northern Y Regional Ethics Committee on the 29th January 2008.

Patient Demographic Form

Date of Testing:

Patient Identification Number:

Age:

Gender: M   F

Height (cm):

Weight (kg):

Duration of Symptoms:

Appendix G

VISA-A

The VISA-A questionnaire: An index of the severity of Achilles tendinopathy

IN THIS QUESTIONNAIRE, THE TERM PAIN REFERS SPECIFICALLY TO PAIN IN THE ACHILLES

TENDON REGION

1. For how many minutes do you have stiffness in the Achilles region on first getting up?

100 mins ▭▭▭▭▭▭▭▭▭▭ 0 mins

0 1 2 3 4 5 6 7 8 9 10

POINTS

▢

2. Once you are warmed up for the day, do you have pain when stretching the Achilles

tendon fully over the edge of a step? (keeping knee straight)

strong severe pain ▭▭▭▭▭▭▭▭▭▭ no pain

0 1 2 3 4 5 6 7 8 9 10

POINTS

▢

3. After walking on flat ground for 30 minutes, do you have pain within the next 2 hours?

(If unable to walk on flat ground for 30 minutes because of pain, score 0 for this

question).

strong severe pain ▭▭▭▭▭▭▭▭▭▭ no pain

0 1 2 3 4 5 6 7 8 9 10

POINTS

▢

4.   Do you have pain walking downstairs with a normal gait cycle?

strong
severe
pain

| | | | | | | | | | | | no pain
0   1   2   3   4   5   6   7   8   9   10

POINTS

☐

5. Do you have pain during or immediately after doing 10 (single leg) heel raises from a

flat surface?

strong
severe
pain

| | | | | | | | | | | | no pain
0   1   2   3   4   5   6   7   8   9   10

POINTS

☐

6. How many single leg hops can you do without pain?

strong severe
pain/unable

| | | | | | | | | | | | no
pain
0   1   2   3   4   5   6   7   8   9   10

POINTS

☐

7. Are you currently undertaking sport or other physical activity?

0   r   Not at all

4   r   Modified training ± modified competition

7   r   Full training ± competition but not at same level as when symptoms began

10   r   Competing at the same or higher level as when symptoms began

POINTS

☐

8. Please complete **EITHER A, B or C** in this question.

- If you have **no pain while undertaking Achilles tendon loading sports** please complete **Q8a only**.
- If you have **pain while undertaking Achilles tendon loading sports but it does not stop you from completing the activity**, please complete **Q8b only**.
- If you have **pain which stops you from completing Achilles tendon loading sports**, please complete **Q8c only**.

A.   If you have **no pain** while undertaking **Achilles tendon loading sports**, for how long can you train/practise?

					POINTS
NIL	1-10 mins	11-20 mins	21-30mins	>30 mins	
r	r	r	r		
0	7	14	21	30	☐

OR

B.   If you have some pain while undertaking **Achilles tendon loading sport**, but it does not stop you from completing your training/practice for how long can you train/practise?

					POINTS
NIL	1-10 mins	11-20 mins	21-30mins	>30 mins	
r	r	r	r		
0	4	10	14	20	☐

OR

C.   If you have **pain that stops you** from completing your training/practice in **Achilles tendon loading sport**, for how long can you train/practise?

					POINTS
NIL	1-10 mins	11-20 mins	21-30mins	>30 mins	
r	r	r	r	r	
0	2	5	7	10	☐

TOTAL SCORE (/100)   ☐

%

Appendix H

Physical Rehabilitation Research Centre
Auckland University of Technology
New Zealand

LOWER LIMB TASKS QUESTIONNAIRE
ACTIVITIES OF DAILY LIVING SECTION

Patient: _____
           Date: _____

INSTRUCTIONS
Please rate your ability to do the following activities in the **past 24 hours** by circling the number below the appropriate response.

If you did not have the opportunity to perform an activity in the **past 24 hours**, please make your *best estimate* on which response would be the most accurate.

Please also rate how important each task is to you in your daily life according to the following scale:
1. = Not important
      2. = Mildly important
      3. = Moderately important
      4. = Very important

Please answer all questions.

TASK		NO	MILD	MODERATE	SEVERE	IMPORTANCE DIFFICULTY	DIFFICULTY	DIFFICULTY	DIFFICULTY	UNABLE OF
1.	Walk for 10 minutes	4	3	2	1	0	1 2 3 4			
2.	Walk up or down 10 steps (1 flight)	4	3	2	1	0	1 2 3 4			
3.	Stand for 10 minutes	4	3	2	1	0	1 2 3 4			
4.	Stand for a typical work day	4	3	2	1	0	1 2 3 4			
5.	Get on and off a bus	4	3	2	1	0	1 2 3 4			
6.	Get up from a lounge chair	4	3	2	1	0	1 2 3 4			
7.	Push or pull a heavy trolley	4	3	2	1	0	1 2 3 4			
8.	Get in and out of a car	4	3	2	1	0	1 2 3 4			
9.	Get out of bed in the morning	4	3	2	1	0	1 2 3 4			
10.	Walk across a slope	4	3	2	1	0	1 2 3 4			

TOTAL (/40) :_____

Enquiries concerning this questionnaire: Peter J. McNair PhD, Physical Rehabilitation Research Centre, Auckland University of Technology, Private Bag 92006, Auckland; New Zealand. email: peter.mcnair@aut.ac.nz Phone: 921-9999 Ext 7143

Appendix H

Physical Rehabilitation Research Centre
Auckland University of Technology
New Zealand

LOWER LIMB TASKS QUESTIONNAIRE
RECREATIONAL ACTIVITIES SECTION

Patient: _____

       Date:_____

INSTRUCTIONS

Please rate your ability to do the following activities in the **past 24 hours** by circling the number below the appropriate response.

If you did not have the opportunity to perform an activity in the **past 24 hours**, please make your *best estimate* on which response would be the most accurate.

Please also rate how important each task is to you in your daily life according to the following scale:

        1. = Not important
        2. = Mildly important
        3. = Moderately important
        4. = Very important

Please answer all questions.

		NO DIFFICULTY	MILD DIFFICULTY	MODERATE DIFFICULTY	SEVERE DIFFICULTY	UNABLE	IMPORTANCE OF TASK			
1.	Jog of 10 minutes	4	3	2	1	0	1	2	3	4
2.	Pivot or twist quickly while walking	4	3	2	1	0	1	2	3	4
3.	Jump for distance	4	3	2	1	0	1	2	3	4
4.	Run fast/sprint	4	3	2	1	0	1	2	3	4
5.	Stop and start moving quickly	4	3	2	1	0	1	2	3	4
6.	Jump upwards and land	4	3	2	1	0	1	2	3	4
7.	Kick a ball hard	4	3	2	1	0	1	2	3	4
8.	Pivot or twist quickly while running	4	3	2	1	0	1	2	3	4
9.	Kneel on both knees for 5 minutes	4	3	2	1	0	1	2	3	4
10.	Squat to the ground/floor	4	3	2	1	0	1	2	3	4

TOTAL (/40) :_____

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