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Changes in muscular power associated with delayed onset muscle soreness

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CHANGES IN MUSCULAR POWER ASSOCIATED WITH DELAYED ONSET MUSCLE SORENESS

By

Carmel Nottle

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USE OF THESIS

The Use of Thesis statement is not included in this version of the thesis.

ABSTRACT

The aims of the this study were to investigate the effects of delayed onset muscle soreness (DOMS) following downhill running on cycling power output and to determine the extent of any relationships between power output, strength, and DOMS. 12 active male subjects (aged 18-25 years) were randomly assigned to either a test (n=7) or control (n=5) group. The test group performed a 5 x 8 minute downhill running protocol at a grade of −7% and a speed corresponding to 80% of the subjects age predicted heart rate maximum. Measurements of isometric knee extension and flexion strength, peak and average cycling power output (Wingate Test), muscle tenderness, muscle soreness and plasma creatine kinase (CK) were taken pre-run and 30 minutes, 24, 72 and 120 hours post-run for both groups. The test group did not perform the downhill running protocol.

The control group showed no significant changes in any of the testing variables across time. For the test group, significant decreases ($p<.05$) in mean knee extensor strength were observed 30 minutes (16.7%) and 24 hours (10.9%) post-run. Significant increases ($p<.01$) in soreness and tenderness scores were also 30 minutes, 24, 72 and 120 hours post-run, and 24 and 72 hours post-run respectively. Although changes in knee flexor strength, average power, peak power (9.8, 5.3 and 3.6% respectively) and plasma CK were observed in the test group post-run, these results were not significant. Variations in correlation coefficients were seen between the variables of flexor strength, extensor strength, peak power and average power, and tenderness and soreness over the testing occasions. In particular significant correlations from baseline testing ($r^2 = 0.69$) for extensor strength and average power were reduced 120 hours post-run ($r^2 = 0.32$). No significant correlations were seen between soreness or tenderness, in relation to power output or strength, however this result may reflect a variation in testing protocols, and the use of active subjects with possible protection against damage and soreness.

Results show that peak power, average power and strength are reduced during periods of DOMS, however, a direct relationship could not be confirmed from the current study without further investigation.

DECLARATION

I certify that this thesis does not incorporate without acknowledgement any material previously submitted for a degree or diploma in any institution of higher education; and that to the best of my knowledge and belief, does not contain any defamatory information or material previously published or written by another person except where due reference is made in text.

Signed: .....  .....

Date: ....13-11-1993.....

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DEFINITION OF TERMS

$g \cdot kg \cdot BW^{-1}$	grams per kilogram of body weight
sec	second(s)
bpm	beats per minute
RPM	revolutions per minute
μL	microlitre
psi	pounds per square inch
kPa	kilopascal
SEM	standard error mean
cm	centimetres
kg	kilograms
km/hr	kilometres per hour
hr/wk	hours per week
$mmolL^{-1}$	millmole per litre
U/I	International Units

CHAPTER 1 INTRODUCTION

The ability of an individual to produce muscular power is considered an essential element of sporting performance (Beckenholdt & Meyhew, 1983). The term muscular power is defined as the product of force and the velocity at which that force is applied (Kreighbaum & Barthels, 1990, p. 106). As a result, the measurement of both mechanical power and work (work = force x displacement), has become standard for determining maximal power. Maximal power output of a muscle group is related to the capacity of anaerobic metabolism during exercise (Vanderwalle, Peres, Heller & Monod, 1985).

It has been suggested that the generation of muscular power may be reliant on either the existence of a large muscle mass or a high percentage of type IIb muscle fibres (Manning, Dooly-Manning & Perrin, 1988; Narici, Roi, Landoni, Minetti & Cerretelli, 1989). Additionally, the production of muscular force, and hence power, is closely correlated with muscle fibre length and muscle pennation (Scott & Winter, 1991). Consequently, studies relating to delayed onset muscle soreness (DOMS) have shown that disruption to the fibre structure caused by exercise, results in a significant decrease in muscular force production (Smith, et al., 1994; Eston, Finney, Baker & Baltzopoulos, 1996).

Muscular force alone, however, is not a common indicator associated with sporting performance. Rather, generation of dynamic force, or power, is generally correlated with performance in both individual events (i.e. high jump and judo) and pairs or teams events (i.e. tennis and soccer). Furthermore, the ability of an individual to sustain or

repeatedly reproduce near maximal power during an event is another key factor in performance success (Beckenholdt & Meyhew, 1983).

Since it has been shown that muscular force declines during periods of DOMS, it is reasonable to expect that maximal power production will also be negatively affected. However, little or no investigation has been carried out in this area. The purpose of the current study is to investigate whether power related performance is decreased during periods of DOMS, and identify whether a relationship exists between maximal power production, muscular strength, and muscle soreness following exercise.

1.1 Research Questions

1. Does maximal power production decrease during periods of delayed onset muscle soreness?

2. Do relationships exist between changes in maximal power production, muscle strength and delayed muscle soreness following exercise?

1.2 Hypotheses

1. The test group will display greater DOMS and levels of plasma creatine kinase than the control group.

2. Peak power output will be decreased in the test group compared to the control group.

3. Average power will be decreased in the test group compared to the control group.

4. A positive relationship will exist between the degree of DOMS and power output performance.

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CHAPTER 2 LITERATURE REVIEW

2.1 Delayed Onset Muscle Soreness

2.1.1 Definition

Delayed onset muscle soreness (DOMS) is the sensation of discomfort or pain that can occur in any skeletal muscle following unaccustomed muscular exertion, with pain generally developing 1-2 days following exercise and subsiding 5-7 days post exercise (Armstrong, 1984; Miles & Clarkson, 1994). A characteristic of the pain associated with DOMS is that it is absent at rest and experienced when active movement or contraction tenses the muscle, or when direct pressure is placed on the muscle. In addition to soreness, DOMS clinically presents as electrically silent muscle shortening, stiffness, decreased flexibility and range of movement, and a decrease in maximal force production (Gulick & Kimura, 1996).

2.1.2 Mechanisms of DOMS

Throughout the literature a number of theories have been proposed to explain the mechanisms underlying DOMS, and while no one theory has been shown to be a sole contributor, others have received limited support from following investigators. Investigating authors (Newham, Mills, Quigley & Edwards, 1983; Thomas, Londeree, Lawson, Ziogas & Cox, 1994) have largely rejected the early idea that DOMS is caused by an accumulation of lactate within the exercised muscle. Opposition to the theory results from the observation that lactate production during exercise is not correlated with resulting sensations of DOMS. That is, exercise most commonly resulting in DOMS (eccentric exercise) is physiologically more efficient and results in lower lactate production levels than concentrically based exercise. Futhermore, lactate levels in both

the blood and muscle return to resting levels before the appearance of pain (Schwane, Watrous, Johnson & Armstrong, 1983).

Similarly, the muscle spasm theory of Travell, Rinzler and Herman (1942) has received limited support because of failure to duplicate their experimental findings (Abraham, 1977). They (Travell et al., 1942) proposed that the delayed pain occurred as a result of ischemia initiated by local tonic muscular spasm representative of a positive feedback nervous cycle. While this theory has been used to explain the stiffness commonly associated with DOMS (Miles & Clarkson, 1994), it has been concluded that it is unlikely to be the mechanism responsible for the delayed pain experienced in this condition (Gulick & Kimura, 1996).

Other investigations relating to the sensation of DOMS are consistent in the reporting of two observations:

1. That the mechanism responsible for DOMS is most likely initiated by mechanical factors as opposed to metabolic factors (Hough, 1902; Stauber, Clarkson, Fritz & Evans, 1990).
2. That inflammation and enzyme efflux from muscle fibres is responsible for the activation and sensitisation of free nerve endings resulting in the sensation of DOMS (Pyne, 1994; Smith, 1991).

It has been proposed that the observed muscle damage following exercise results in the stimulation of an inflammatory response causing the development of a muscle oedema and increases in muscle osmotic pressure, thus stimulating the sensation of pain (Pyne, 1994; Smith, 1991). The delayed appearance of pain is therefore explained by the time

taken for noxious substances (such as calcium, histamine and potassium) to enter the microcirculation and extracellular space within the muscle, and for the inflammatory response to occur (Stauber et al., 1990).

2.1.3 Physiological Responses during DOMS

2.1.3.1 Creatine Kinase Response

Creatine Kinase (CK) is an enzyme controlling anaerobic adenosine triphosphate (ATP) production from the phosphagen, or ATP-PC system, and is responsible for the reversible reaction:

$$\text{Creatine Phosphate} + \text{ADP} \xrightleftharpoons{CK} \text{Creatine} + \text{ATP}$$

This system is used to replenish levels of ATP during strenuous exercise or short term, high intensity exercise (Powers & Howley, 1994, p. 34; McArdle, Katch & Katch, 1996, p. 103).

Found in the brain, skeletal and cardiac muscle (Eston, Mickleborough & Baltzopoulos, 1995, p. 90) elevated plasma CK following exercise is commonly used to indicate the existence of skeletal or cardiac muscle damage. The increase in plasma CK, however, is not directly related to the degree of muscle fibre necrosis (Kuipers, 1994; Newham, Jones & Edwards, 1983) with individual responses shown to occur (Clarkson, Nosaka & Braun, 1992). While the time course reported for increases in plasma CK following damaging exercise usually involves a steady rise to a peak 5-7 days post exercise

(Schwane, Johnson, Vandenakker & Armstrong, 1983), variations in both the time course and the degree of efflux have been demonstrated.

Following a repeated stepping exercise, Newham, Jones et al. (1983) reported both small, rapid (<24 hrs) plasma CK peaks, and greater magnitude, delayed rises (>4 days). A similar observation was reported by Clarkson et al. (1992) following maximal eccentric actions of the forearm flexors. Clarkson et al. also suggests that peak CK responses may vary according to exercise mode with peaks occurring most often 24hrs post exercise for downhill running as opposed to 4 days post exercise for high-force eccentric exercise.

2.2 Strength and Power Changes following Eccentric Exercise

Investigators of the effects of eccentric exercise on strength have demonstrated declines in maximal voluntary strength, maximal twitch and maximal tetanic tensions (Davies & White, 1981; Jones, Newham & Torgan, 1989; Talag, 1973). The strength loss is generally observed immediately post exercise with significant decreases still evident up to 4 days post exercise. Similarly, a study by Sargeant and Dolan (1987) reported decreases in both maximal voluntary strength and short term power output following eccentric exercise. Similar to strength declines, significant decreases in power output were seen immediately post exercise with an average recovery period of 4 days. Reductions in peak isokinetic torque during maximal voluntary contraction have also been observed following eccentric exercise (Eston et al., 1996) with 30, 90 and 160°/sec contractions showing peak torque declines similar to those reported for maximal isometric strength (Crenshaw, Thornell & Friden, 1994; Eston et al., 1996; MacIntyre, Reid, Lyster, Szasz & McKenzie, 1996).

The observed declines in strength and power are thought to be primarily the result of ultrastructural damage within the muscle (Brown, Child, Donnelly, Saxton & Day, 1996; Eston et al., 1995). Byrd, McCutcheon, Hodgson and Gollnick (1989) found that following high intensity exercise calcium uptake by the sarcoplasmic reticulum (SR) was reduced by up to 50%, and concluded that such a decrease was therefore a possible contributor to observed changes in muscle contractility. Similarly, Clarkson et al. (1992) reported that a delay in the restoration of calcium levels following exercise would occur if the SR had sustained damage, therefore negatively influencing muscle force production. Damage noted to the myofibrillar Z-band and disruption of sarcomere length and functioning may further contribute to observed strength declines (Clarkson et al.; Friden & Lieber, 1992)

2.3 Protection against Muscle Damage

While ultrastructural muscle damage is thought to be responsible for DOMS following unaccustomed, strenuous, or eccentric exercise (Armstrong, 1984), such damage is not only repairable, but may result in a structural adaptation, protecting the muscle against subsequent bouts of exercise for up to 6 weeks (Ebbeling & Clarkson, 1989). Investigations by Clarkson et al. (1992) found that responses in plasma CK, soreness, swelling and strength loss were reduced following a second bout of eccentric exercise compared with the first bout performed six weeks prior. Similarly, Eston et al. (1996) reported reductions in elevated plasma CK, muscle tenderness, and peak torque declines following a downhill treadmill run when preceded two weeks by repeated maximal eccentric activation of the knee extensors.

The mechanisms by which this observed protection occurs is not known, although it is thought to be partly due to strengthening of the muscle membranes and connective tissue (Ebbeling & Clarkson, 1994), and altered cellular and neurological factors (Clarkson et al., 1992).

2.4 The Wingate Anaerobic Test

The Wingate anaerobic test (WAnT) was developed in the 1970's by the Israeli Wingate Institute for Physical Education and Sport, and has become a standard measure for anaerobic muscle capacity (Inbar, Bar-Or & Skinner, 1996, p. 1). The most common protocol for the WAnT involves a 30 second all out effort on a cycle ergometer with a braking force set according to body weight (Bouchard, Taylor, Simoneau & Dulac, 1991, p. 199). There are, however, variations of the protocol according to age and fitness (Inbar et al, 1996, p. 17).

The test itself is designed to determine three specific parameters of anaerobic performance (Vandewalle et al., 1985, p. 223), these being:

1. Mean power production (MP),
2. Maximal or peak power production (PP),
3. Fatigability or the fatigue index (FI).

Power readings are determined at 5 second intervals throughout the 30 second test period with MP defined as the average work output for the 30 seconds, and PP the highest work output in a 5 second period. The rate of power decrease, or the FI is calculated (Sharp & Koutedakis, 1987, p. 10) according to the formula:

$$FI = \frac{PP - \text{minimum power}}{PP} \times 100$$

Results gained for MP are generally considered to be an indication of an individuals anaerobic capacity while PP is thought to represent predominately alactic or phosphagen metabolic capacity (Inbar, et al., 1996, p. 12).

Throughout the literature two main variations in the WAnT protocol can be identified, these being;

1. Variations in braking loads,
2. Variations in pedal crank length.

2.4.1 Load Optimisation

The most commonly used resistance for the WAnT protocol is equated at 75g·kg·BW^{-1} (Bouchard et al., 1991). Dotan and Bar-Or (1983), however, suggested that the braking load set during a WAnT may influence results for PP and MP recordings, particularly in highly anaerobically trained athletes. A study by Sharp and Koutedakis (1987) involving elite gymnasts, rowers and judo competitors also suggesting that results for MP and PP may have been underestimated for the judo players and gymnasts, with a higher resistance required to simulate normal competition and training conditions. Similarly Dotan et al (1983) suggested that the optimal load for male and female physical education students is 87 g·kg·BW^{-1} and 85 g·kg·BW^{-1} respectively. The authors however concluded that small variation (± 8.5g·kg·BW^{-1}) in loading resulted in insignificant deviations from an individuals true maximum power.

2.4.2 Cycle Crank Length

Inbar et al. (1996, p. 13) state that as with braking loads, pedal crank length may influence optimisation of such variables as muscle tension, torque, and the kinetic energy of the moving leg mass, therefore influencing MP and PP recordings. The authors suggest that pedal crank length should therefore 'theoretically' be varied according to an individuals leg length to allow for accuracy in recordings.

Previous comments by Inbar, Dotan, Trousil and Dvir (1983) also indicate optimal crank length as being dependent on individual leg length. The authors concluded that a parabolic relationship exists between power output and crank length, and that variations in MP and PP consistently occur at different crank lengths. The conventional ergometer crank length of 17.5cm, however, was found to be close to that crank length (16.6cm) for optimal power. The authors therefore concluded that only when large variations from 'normal' height occurs, should crank length vary according to individual leg length.

2.5 Summary

Repeated eccentric contraction is commonly shown to cause muscle damage following exercise, with delayed onset muscle soreness (DOMS) and elevated plasma CK levels indicators of such damage. It has also been shown that during periods of DOMS maximal force production is significantly reduced. There have however been few investigations into the influence of DOMS on dynamic force, or power, which is more closely associated to sporting performance. Investigation of this relationship may therefore have significance to performance in power related sports.

CHAPTER 3 METHOD

3.1 Subjects

Twelve male subjects aged between 18 and 25 were randomly assigned to either a control or a test group. All subjects were currently active in sport, however, individuals who regularly participated in distance running or eccentrically biased exercise were excluded because of the increased possibility of protection against muscle soreness. Subjects volunteered for the study and provided written informed consent (Appendix A) prior to testing. While subjects were encouraged not to participate in physical activity during the testing period, normal training commitments could be maintained where necessary. Subjects were also asked not to begin any unaccustomed activities or training in the week prior to testing.

3.2 Equipment

Monark Ergomedic 843E cycle ergometer

Repco cycle ergometer

Cybex 6000 isokenetic dynamometer

Trackmaster TM-500 motor driven treadmill (modified)

ACCUSPORT blood lactate analyser

Reflotron analyser (Boehringer-Mannheim)

Polar PE4000 heart rate monitor

Myometer (Dobros)

Capillary pipettor (Boehringer Mannheim)

3.3 Testing Protocols

3.3.1 Testing Schedule

Testing was completed over a 12 day (Figure 1) period with testing protocols identical for both the test and control groups.

	Day											
	1	2	3	4	5	6	7	8	9	10	11	12
Test	Baseline (1)			Baseline (2)			Run	24 hours		72 hours		120 hours

Figure 1. Arrangement of testing protocol over a standard 12 day period

Results for isometric strength and power output from the two baseline testing occassions for each of the 12 subjects were used for determination of the reliability of the testing protocol. Both groups performed the same series of tests with the exception that the test group performed a run protocol on the third testing occasion in addition to the isometric leg strength and power output protocol. Each baseline testing occasion, 30 minutes, 24, 72, and 120 hours post-run occasion consisted of an isometric leg strength and power output protocol. Baseline figures used in comparisons across time were taken from each subjects highest averaged peak values for strength, and highest recording of peak power during either of the two baseline testing occasions.

3.3.2 Run protocol

Each subject in the test group completed an intermittent run protocol (as described by Eston et al., 1996) with the treadmill grade set a –7% (Figure 2). Subjects ran for 5 sets of 8 minutes with 2 minutes rest between sets during which time subjects were free to perform stretching exercises or walk around the room. Treadmill speed was adjusted at

the end of each 2 minute interval as required to maintain a heart rate equal to 80% of the subjects age predicted heart rate maximum. Water was provided *ad libitum* during the rest periods, and a fan available at request for subject comfort. Following the completion of the run protocol subjects were given a 30 minute rest before commencing the post-run isometric leg strength and power output protocols.

Figure 2. Modified treadmill positioned at -7% grade for completion of downhill run protocol

3.3.3 Isometric Leg Strength

Maximal voluntary contraction (MVC) strength of the knee extensors and flexors was determined at 60° of knee flexion using a Cybex 6000 isokenetic dynamometer. Subjects were seated upright and secured with a seat belt style strap. Hip alignment was adjusted so that the line from the hip to the knee was perpendicular to the rotating arm of the dynamometer, and the axis of rotation of the arm was level with the lateral

condyle of the tibia. Additionally, a strap was secured across the subjects thigh to prevent the leg lifting during each contraction (Figure 3).

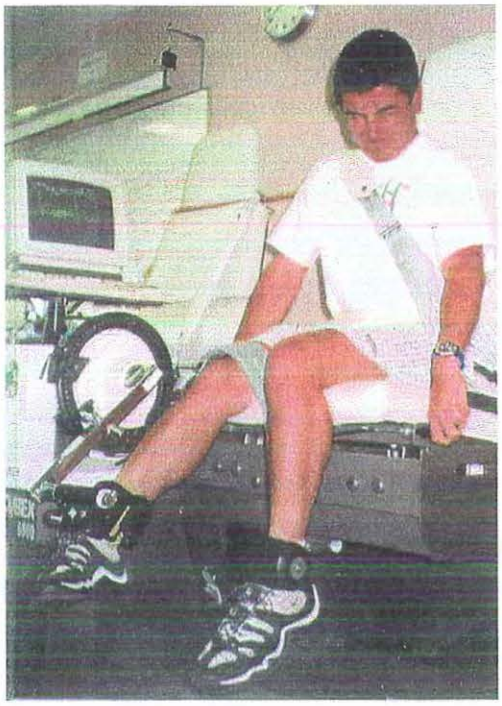

Figure 3. Subject secured in position at 60° of knee flexion during performance of a maximal voluntary contraction of the right knee extensors

Verbal encouragement was given as subjects completed 3 x 5 sec MVC's of the knee extensors and 3 x 5 sec MVC's of the knee flexors, each MVC being separated by at least 5 sec rest. A 20 sec rest period was allowed between the 3 sets of MVC's, during which time feedback on performances in the previous set was given.

3.3.4 Power Output

Maximal power and average power was assessed by performance of a Wingate Anaerobic Test (WAnT). The protocol for this test consisted of a 30 sec all out effort on a Monark Ergomedic 843E cycle ergometer (Figure 4) with the resistance set at 75 g kg^{-1} body mass as suggested by Inbar et al. (1996).

Prior to each WAnT protocol subjects completed a 5 minute warm up on a Repco cycle ergometer, performing intermittent exercise (30 sec exercise with 30 sec rest) to elicit a heart rate of approximately 150 beats per minute (bpm). This protocol was adopted as it has been suggested an intermittent warm up is the most effective for optimising performance in the WAnT (Inbar et al., 1996, p.8). A 3 minute rest was then allowed before the commencement of the WAnT.

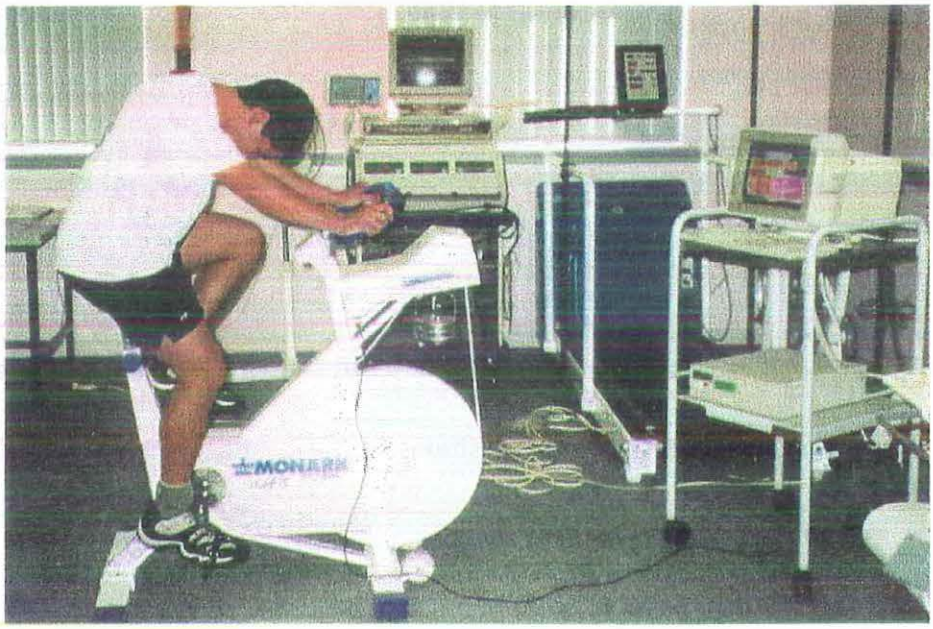

Figure 4. Example of subject positioning during performance of the Wingate Anaerobic Test

Performance of the WAnT required subjects to begin pedaling maximally with no resistance. The resistance was added when the pedaling rate reached between 180 and 200 RPM beginning the 30 sec test period. Subjects were verbally encouraged to maintain the pedal rate for the 30 sec after the load application. Once the 30 sec test period had elapsed the resistance was removed and the subjects began a 2-3 minute cool down. Seat height was adjusted for each subject and kept constant throughout the

testing period. All subjects were fitted with toe clips to allow for the exertion of force during both knee flexion and extension.

3.4 Testing Measures

3.4.1 Blood Lactate

Plasma lactate concentration was determined prior to warm-up and 30 secs post exercise for each WAnT, and immediately pre and post run for the treadmill protocol. A 30μL blood sample was collected from the fingertip using a capillary pipette and analysed using an ACCUSPORT blood lactate analyser.

3.4.2 Heart Rate Monitoring

Heart rate (HR) was monitored using a Polar PE4000, with the same monitor used for all subjects throughout the study. Recordings of HR were made immediately pre and post test for the WAnT. While HR was monitored for standardisation purposes during warm-up for the WAnT, no figures were recorded for statistical analysis. Additionally HR was recorded immediately pre-run, and at 2 minute intervals during the treadmill run protocol from which treadmill speed was adjusted.

3.4.3 Creatine Kinase (CK)

Plasma CK levels were determined immediately pre run and post run, and 24, 72, and 120 hours post run for the test group, prior to the commencement of the isometric leg strength protocol. For the control group plasma CK was determined prior to the commencement of the isometric leg strength protocol on the run day equivalent, and 24,

72, and 120 hours post-run. A 30μL blood sample collected from the fingertip using a capillary pipette was analysed immediately using a Reflotron analyser (Bohringer-Mannheim). Where lactate and CK samples were to be analysed on the same occasion the first blood sample was used for lactate analysis and the second for plasma CK.

3.4.4 Muscle Soreness and Tenderness

Muscle soreness was analysed using a self report 1 (normal) to 10 (very very sore) scale (Smith et al., 1994) whilst walking for the various sites (Figure 5) on the gluteal, hamstring, quadricep, gastrocnemius and anterior tibialis muscle groups.

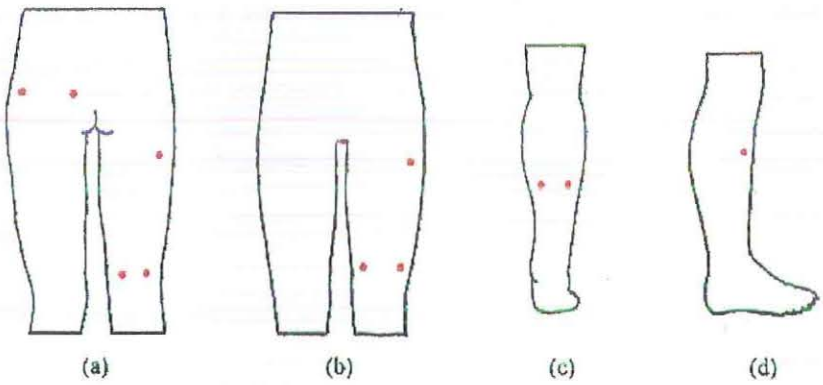

Figure 5. Standard sites used during recordings for soreness and tenderness for the (a) gluteal and hamstrings (b) quadriceps (c) gastrocnemius and (d) anterior tibialis.
Adapted from: Rogers, A. (1992). Textbook of anatomy. London : Churchill Livingstone.

Muscle tenderness measurements were taken at the same sites as muscle soreness using a Dobros myometer. Values were recorded following soreness recordings and were taken with the subject in a non-weight bearing situation. Following a similar method to that described by Eston et al. (1996), the myometer was applied at each site and the pressure increased manually, with subjects asked to report when pain was perceived. If no pain was reported with the application of a ceiling value of 14.5 psi (100kPa), it was

assumed no tenderness was present. Soreness and tenderness ratings were taken immediately pre- and post-run, and 24, 72, and 120 hours post run. Ratings were determined prior to both the strength testing protocol and the WAnT.

3.5 Statistical Analysis of Data

Reliability of testing protocols was determined by calculation of the coefficient of variation of method error between the two baseline measures of strength and power output for all 12 subjects.

Statistical analysis for muscle soreness and muscle tenderness over time was calculated using an averaged score for all sites within each muscle group. For correlation comparisons the mean of the averaged ratings was calculated to give single values for tenderness and soreness.

Each dependant variable (muscle soreness, muscle tenderness, lactate, HR, strength, power and plasma CK) was statistically analysed using a two way ANOVA with repeated measures (time) test. Where a significant p value was obtained ($p<.05$) between groups, independent sample t-test comparisons were conducted to determine those time intervals that were significantly different. Within group differences were determined using paired sample t-test.

To assess the existence of relationships between the test variables of power, muscular strength, muscle soreness and muscle tenderness, a Pearson product moment correlation coefficient was calculated. For inter-subject comparison purposes, results of strength and power are presented in terms of body weight. The reliability of isometric leg

strength and power output results was determined by calculation of the coefficient of variation of method error, for results obtained on the two baseline testing occasions. All results from testing are reported as the mean (±SEM) with individual recordings for each of the testing variables given in Appendix D.

3.6 Ethical Considerations

Ethical approval for this study was granted by the Edith Cowan University Committee for the Conduct of Ethical Research. All subjects completed a medical questionnaire (Appendix B) and under went medical screening and provided written informed consent prior to testing.

3.7 Limitations and Delimitations

3.7.1 Limitations

The current study was dependent on the appearance of muscle soreness in the test group. While the protocol adopted was based on previous studies (Eston et al., 1996; Schwane et al., 1983) where soreness was successfully induced, this did not guarantee soreness occurring in all muscle groups of the current study. It is also necessary to assume that the subjects are performing maximally during the strength and power protocol on each testing occasion. No check will be conducted throughout the testing to confirm if subjects' MVC efforts were actually maximal, with heart rate the only guide of maximal performance during the power protocol.

3.7.2 Delimitations

The subjects in the current study were not a true representation of the population for the following reasons:

1. Only male subjects were tested
2. Only subjects aged 18-25 years were tested
3. Sedentary or highly trained individuals were excluded from testing

CHAPTER 4 RESULTS

4.1 Reliability

The coefficient of variation of method error for single repeated measures of isometric strength of the leg flexors, leg extensors and power output were 2.94%, 3.72%, and 1.87% respectively. Data for the coefficient of variation for each parameter are given in Table 1. There was a good reliability for the tests in question, with each test having a coefficient of variation less than 5%.

Table 1
Coefficient of Variation of Method Error for Individual Testing Parameters

	Coefficient of Variation of Method Error (%)
Strength	
Left extension	4.04
Left flexion	3.50
Right extension	3.08
Right flexion	3.82
Power	
Peak power	1.91
Average power	2.15

4.2 Subject Characteristics

Table 2 reports mean values for age, height, weight, and activity levels for the test and control groups. No significant differences for subject characteristics were seen between the two groups with the exception of weight, with the control group significantly heavier.

Table 2
Subject Characteristics of Test and Control Group (mean ± SEM)

	Test group (n = 7)	Control group (n = 5)
Age (years)	19.1 ± 0.3	19.6 ± 0.4
Height (cm)	183.4 ± 2.4	184.0 ± 3.7
Weight (kg)	72.4 ± 1.8	83.8 ± 4.8
Activity level (hr/week)	5.7 ± 1.8	5.2 ± 0.8

Baseline values for isometric strength and power output normalised for body weight are shown in Figure 6, and demonstrate similar average strength and power output between groups.

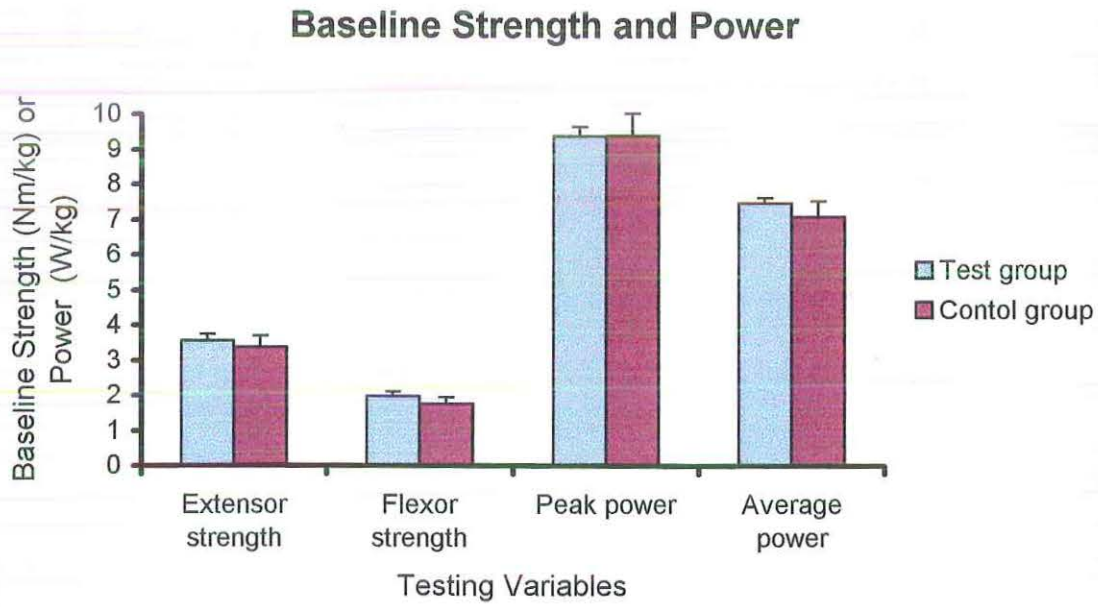

Figure 6. Baseline values (mean SEM) between test (n=7) and control (n=5) groups for extensor and flexor strength, peak power and average power

As strength of both limbs was very similar (less than 4% difference for flexors and 1% difference for extensors), results reported for strength are an average of combined limb strength for either the flexors or extensors.

4.3 Treadmill Run

For the test group, mean values for HR and running speed during the treadmill run were 159 ± 1 bpm and 12.7 ± 0.2 km/hr respectively. For each of the 8 minute periods within the run, no significant variations were recorded for either HR or running speed, with mean results shown in Figure 7.

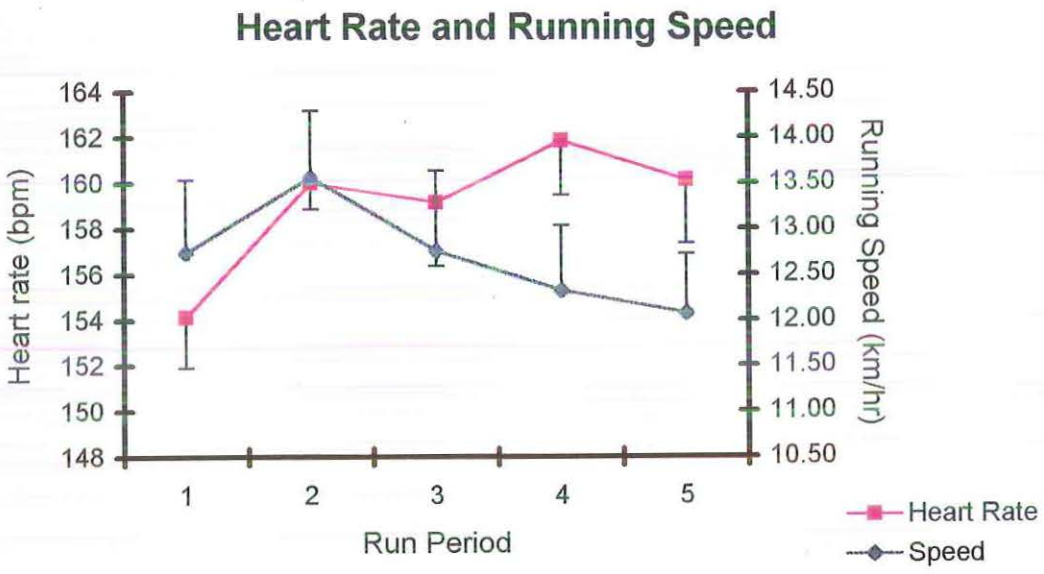

Figure 7. Heart rate and running speeds (mean ± SEM) for each 8 minute period of the treadmill run for the test group (n=7)

The variation seen in running speed over the course of the protocol resulted from increases in heart rate, with treadmill speed adjusted at the completion of each 2 minute period as required to maintain a heart rate equal to 80% maximal (age predicted) heart rate. Although mean blood lactates were slightly elevated post-run (3.8 ± 0.5 $mmolL^{-1}$) compared to pre-run (2.9 ± 0.3 $mmolL^{-1}$), the differences were not statistically significant.

4.4 Control Group Results

Recordings for peak power and average power showed a range of less than 5% over the course of five tests, with 2.0% and 1.3% respective increases seen between baseline testing and 120 hours post-run (Figure 8). A larger, range in results was seen for flexor and extensor strength across time, with a 5.9% decrease seen for the flexors and a 6.1% increase for the extensors (Figure 9), however these changes were not statistically significant.

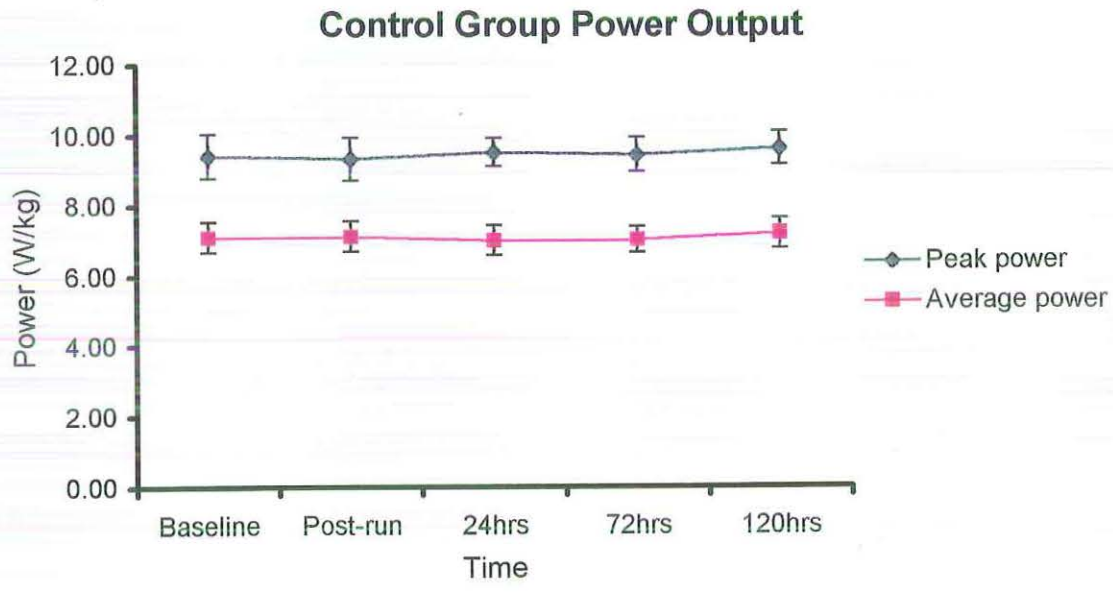

Figure 8. Peak power and average power (mean ± SEM) across time for the control group (n=5)

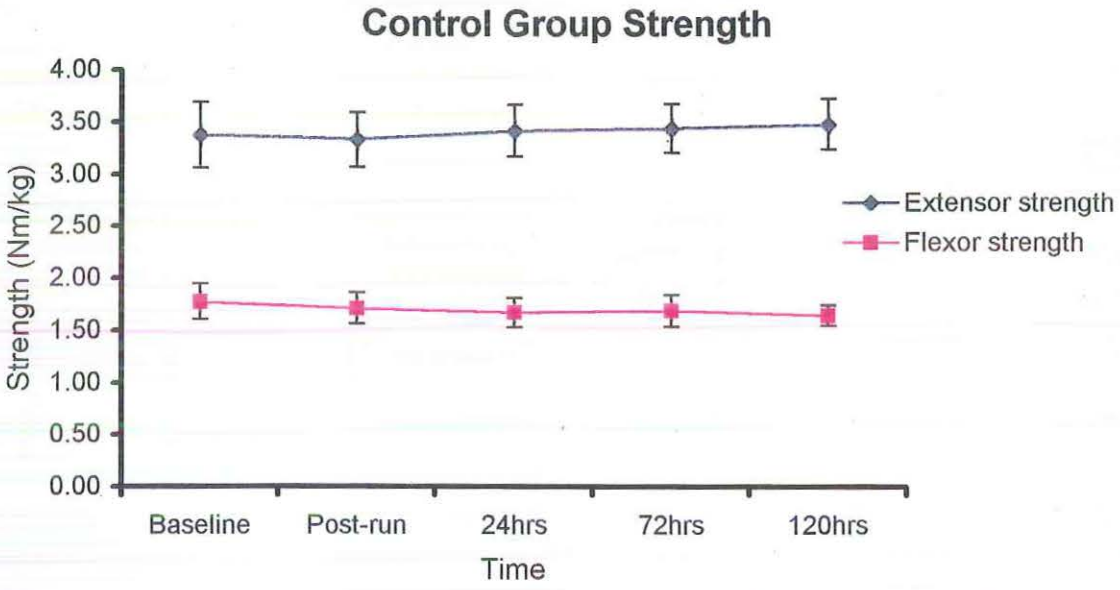

Figure 9. Extensor strength and flexor strength (mean ± SEM) across time for the control group (n=5)

Within subject recordings for plasma CK remained within the 'normal' range of 24-195 U/I (Boehringer-Mannheim, n.d.) across testing occasions, showing no significant variations. As expected, control subjects reported no evidence of increased soreness or tenderness throughout the testing period.

4.5 Test Group Results

4.5.1 Strength

Significant decreases in extensor strength were seen 24 hours post-run, with highly significant decreases seen 30 minutes post-run (Figure 10). While a similar decrease was seen in relation to flexor strength (Figure 11), results did not prove statistically significant.

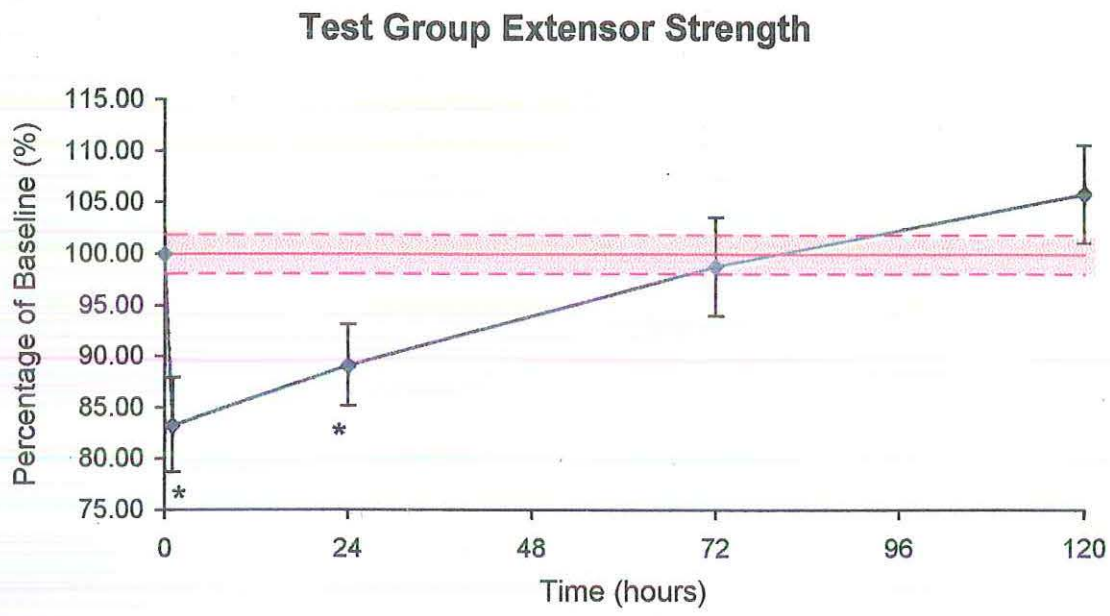

Figure 10. Extensor strength (as a percentage of baseline) across each testing occasion (mean ± SEM) for the test group (–♦–). The shaded area represents SEM of extensor strength for the control group over the testing period

* $p<.05$

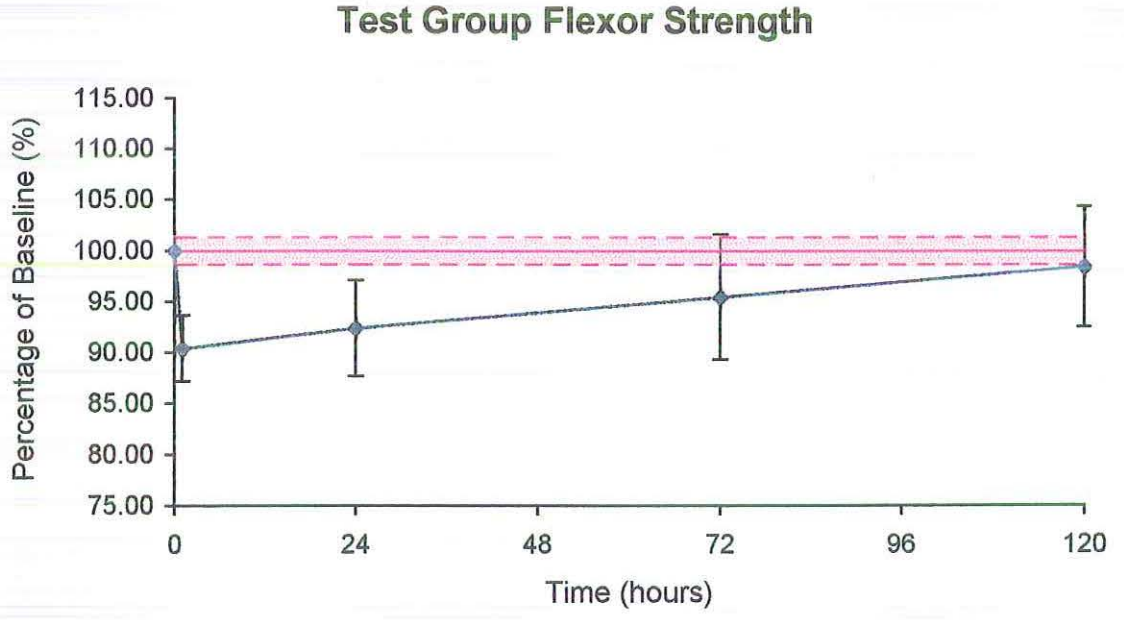

Figure 11. Flexor strength (as a percentage of baseline) across each testing occasion (mean ± SEM) for the test group (–♦–). The shaded area represents SEM of flexor strength for the control group over the testing period

Whist recovery of extensor strength above baseline recordings (5% increase) was seen for the test group, flexor strength still remained below baseline values (-1.5%) by the final testing occasion 120 hours post-run. It can also be seen that a linear trend for recovery occurred in relation to both flexors and extensors strength.

4.5.2 Power Output

Figures 12 and 13 show a mean reduction 30 minutes post-run for the test group in peak power and average power respectively. Although 3.6% and 5.3% declines in peak and average power occurred post-run, the decreases were not significant.

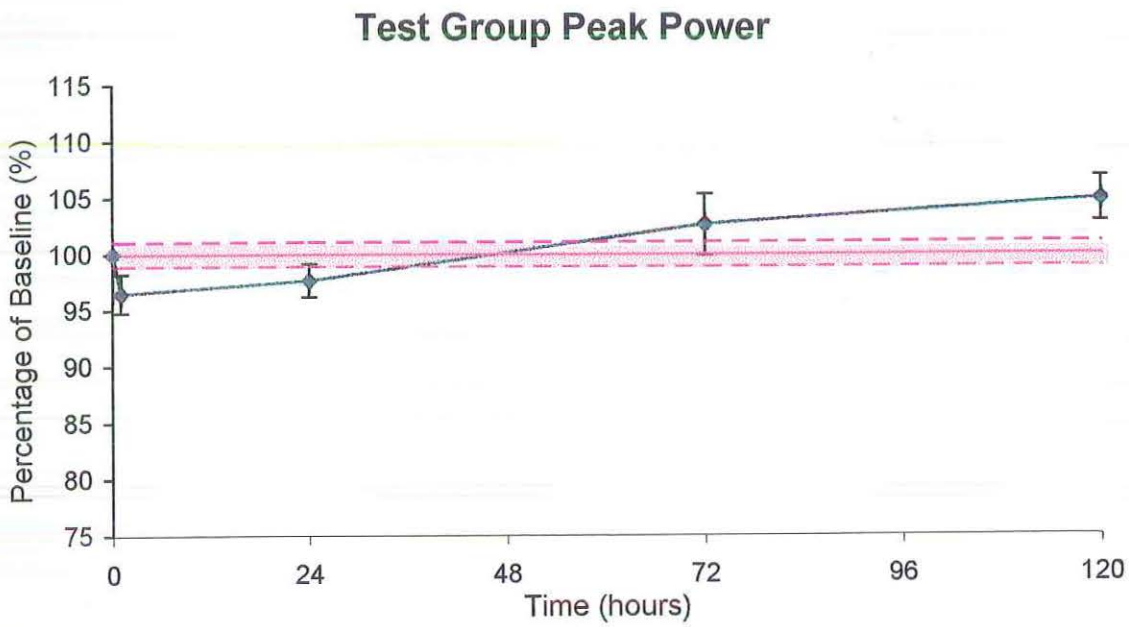

Figure 12. Peak power (as a percentage of baseline) across each testing occasion (mean ± SEM) for the test group (−♦−). The shaded area represents SEM for peak power of the control group over the testing period

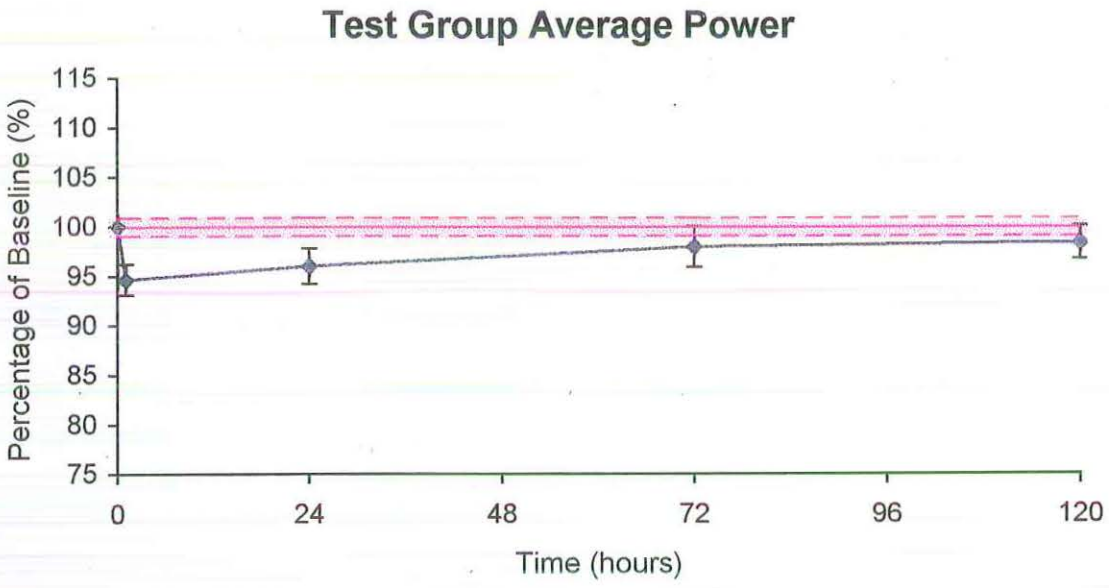

Figure 13. Average power (as a percentage of baseline) across each testing occasion (mean ± SEM) for the test group (–♦–). The shaded area represents SEM for average power of the control group across the testing period

Similar to the decreases in strength, the largest declines in peak and average power were seen 30 minutes post-run, with recovery occurring over subsequent testing occasions. As with extensor strength final recordings for peak power showed recovery above baseline values (+4%), while recovery for average power, which showed a percentage greater reduction, still remained incomplete (-1.6%) 120 hours post-run.

4.5.2.1 Pre and Post Wingate Lactate and Heart Rate (HR) Recordings

Results for the post Wingate test lactate and HR recordings showed no significant variations either between groups or within groups across time. Figure 14 and 15 show mean results for post Wingate lactate and heart rate recordings respectively.

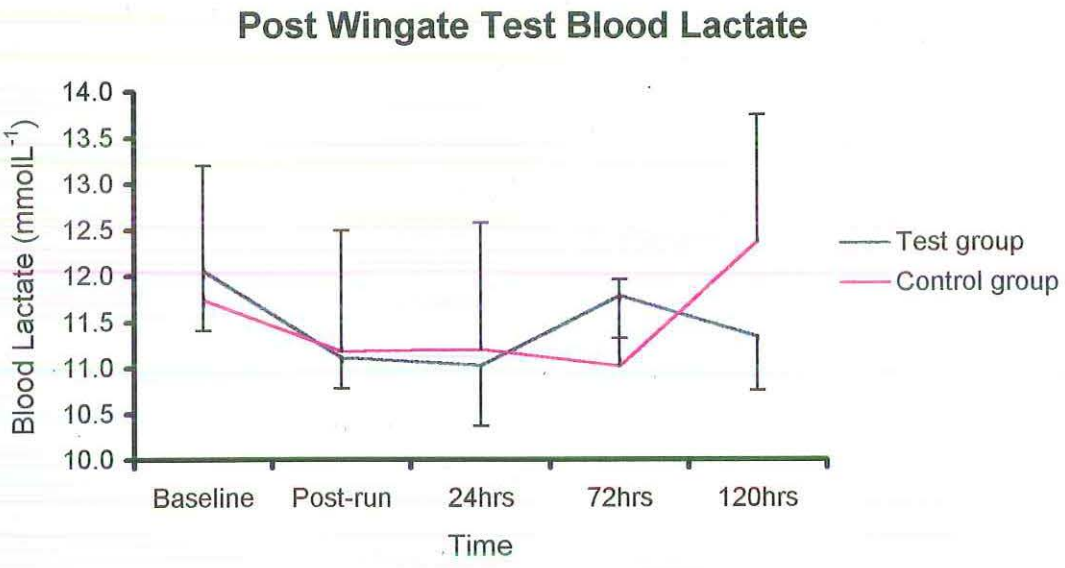

Figure 14. Post Wingate blood lactate recordings across time for the test (n=7) and control (n=5) groups (mean ± SEM)

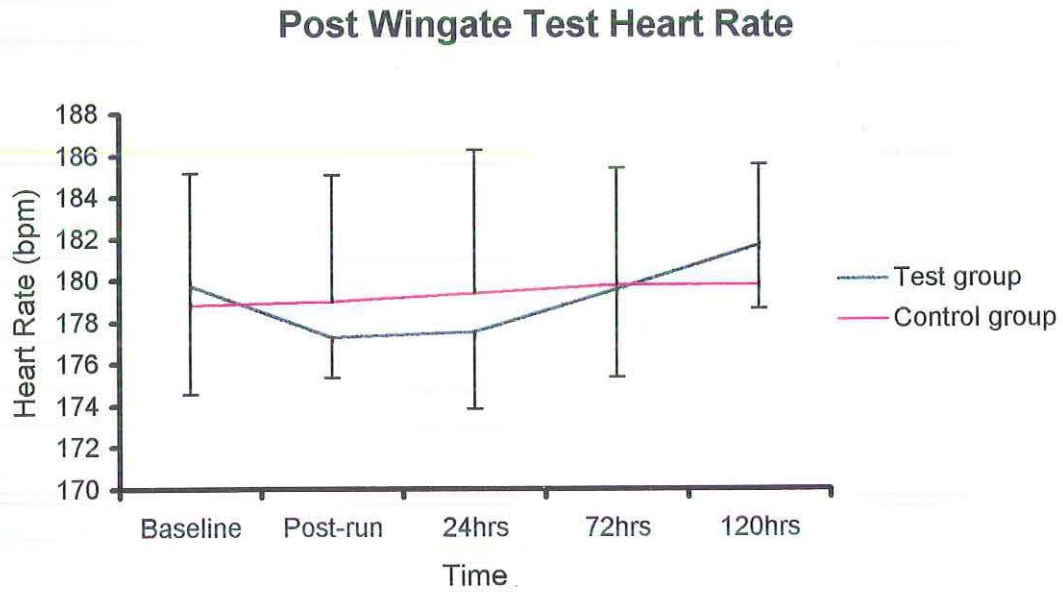

Figure 15. Post Wingate heart rate recordings across time for the test (n=7) and control (n=5) groups (mean ± SEM)

4.5.3 Plasma CK

Although a mean result above the upper limit of normal (195 U/I) was recorded for the test group on each occasion post-run, no significant differences were seen between the two groups across time. Within the test group however, plasma CK recordings were shown to be significantly increased 30 minutes, 24, 72 and 120 hours post-run. It was notable that variations in the magnitude of plasma CK efflux were also seen within the test group (Figure 16) with recordings 24 hours post-run ranging from 116 U/I to 1400 U/I.

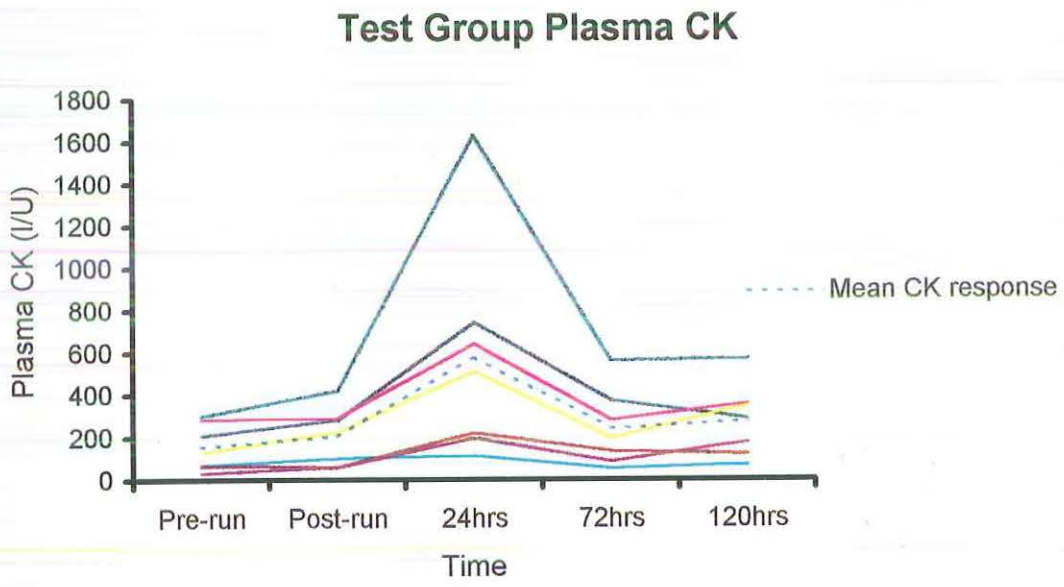

Figure 16. Plasma CK activity in the 7 test subjects, and the group mean activity, pre and post run, and 24, 72 and 120 hours post-run

4.5.4 Soreness and Tenderness

Results for mean soreness and tenderness show the greatest values recorded 24 hours post-run, and decreasing values recorded over the remaining testing occasions. Significant differences between the two groups were recorded on all testing occasions post-run for soreness (Figure 17), and 24 and 72 hours post-run for tenderness (Figure 18).

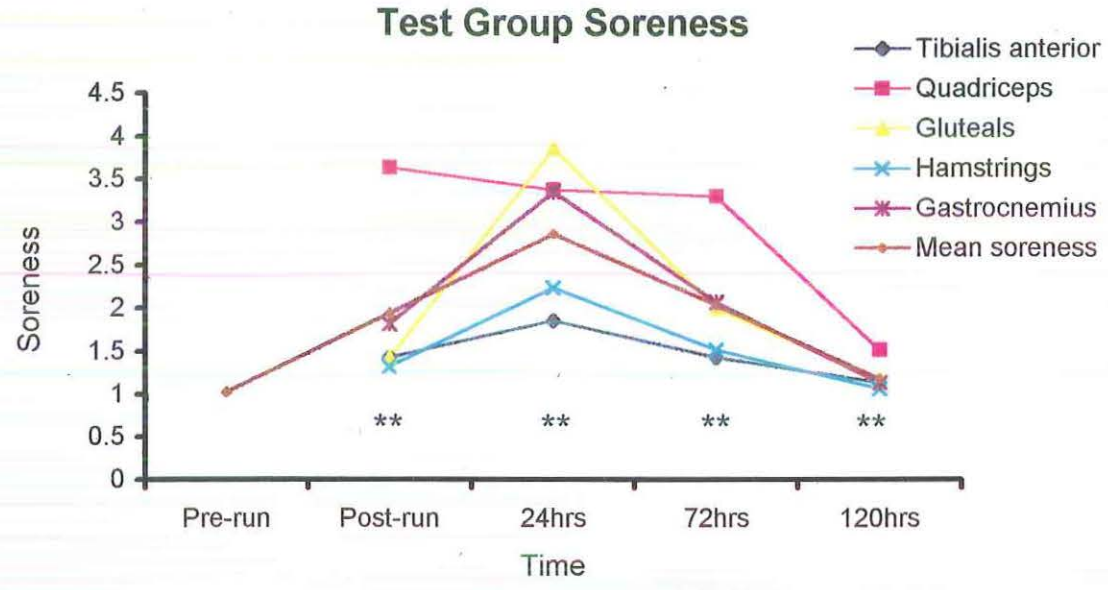

Figure 17. Mean soreness for individual muscle groups, and overall mean soreness results across time for the test group (n=7)

** p<.01

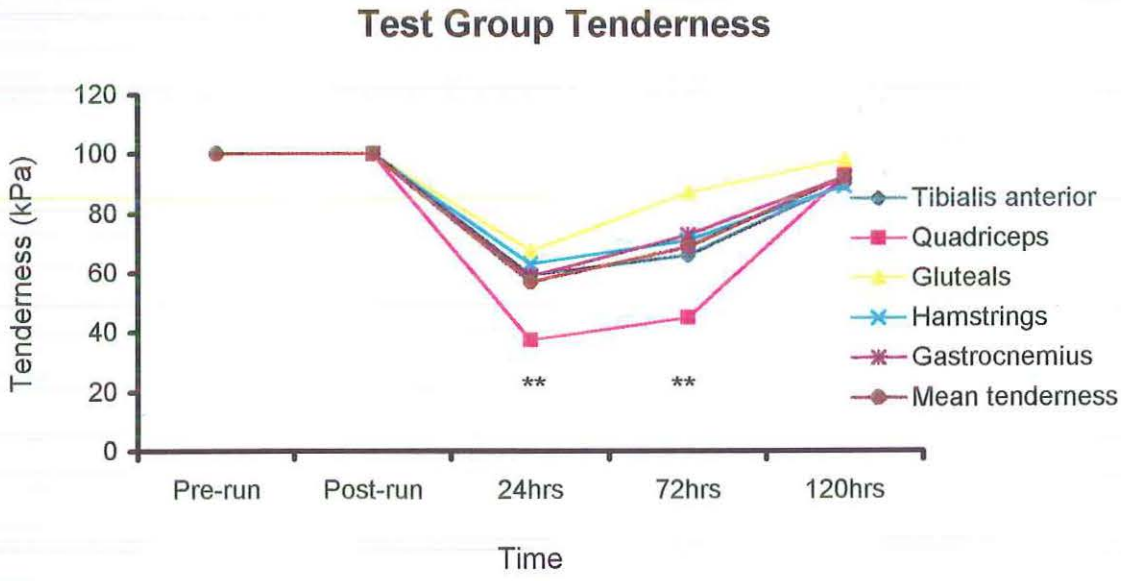

Figure 18. Mean tenderness for individual muscle groups, and overall mean tenderness results across time for the test group (n=7)

** p<.01

Similar time course results for soreness and tenderness scores were recorded for individual muscle groups, with no significant differences between muscle groups seen across testing occasions. Similarly, no significant variations in recordings were seen for individual sites within the same muscle group. High recordings for both tenderness and soreness, however, were seen for the quadriceps 24 and 72 hours post-run, relative to the other muscle groups tested.

4.6 Relationship between Testing Variables

Performance results for flexor and extensor strength showed significant correlations on all testing occasions post-run, with the exception of 24 hours post-run, where correlations were not significant. Figure 19 shows correlations of extensor strength and flexor strength for baseline recordings, and for recordings 24 hours post-run, where the reduced relationship was observed.

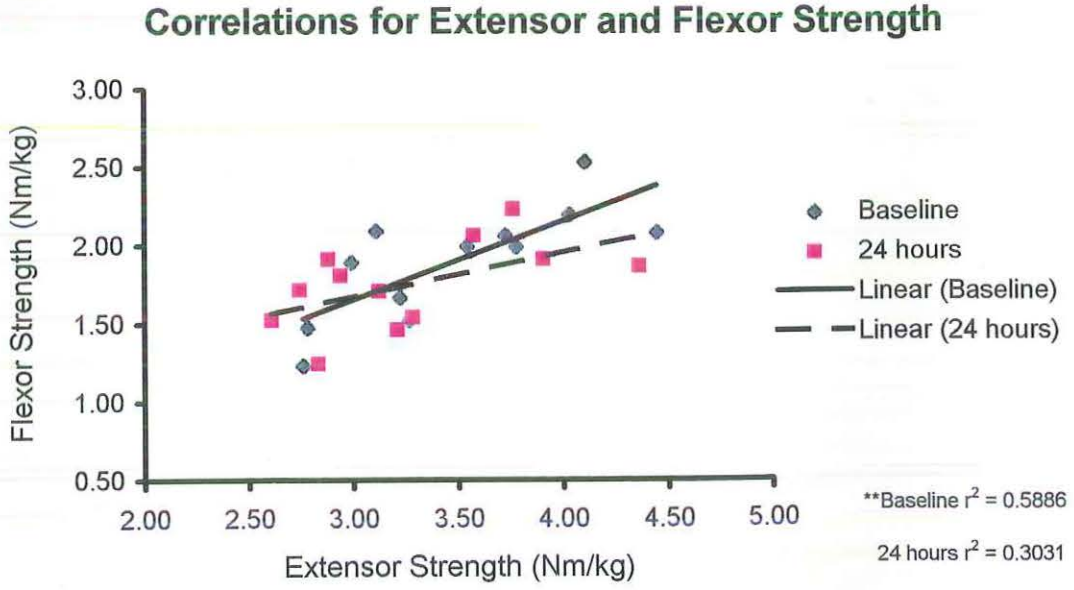

Figure 19. Changing relationship between extensor and flexor strength as evident by a changing correlation result for baseline, and 24 hours post-run testing results

** correlation significant at 0.01 level-

Correlations for extensor strength and average power, flexor strength and average power, and extensor strength and peak power, all demonstrated similar interactions for testing variables across time. Significant correlations were seen on all occasions for flexor strength and average power with the exception of 120 hours post-run, while significant results for extensor strength and average power, and extensor strength and peak power, were seen on all testing occasions with the exception of 72 and 120 hours post-run. Figure 20 shows correlations for extensor strength and average power for baseline testing and 120 hours post-run.

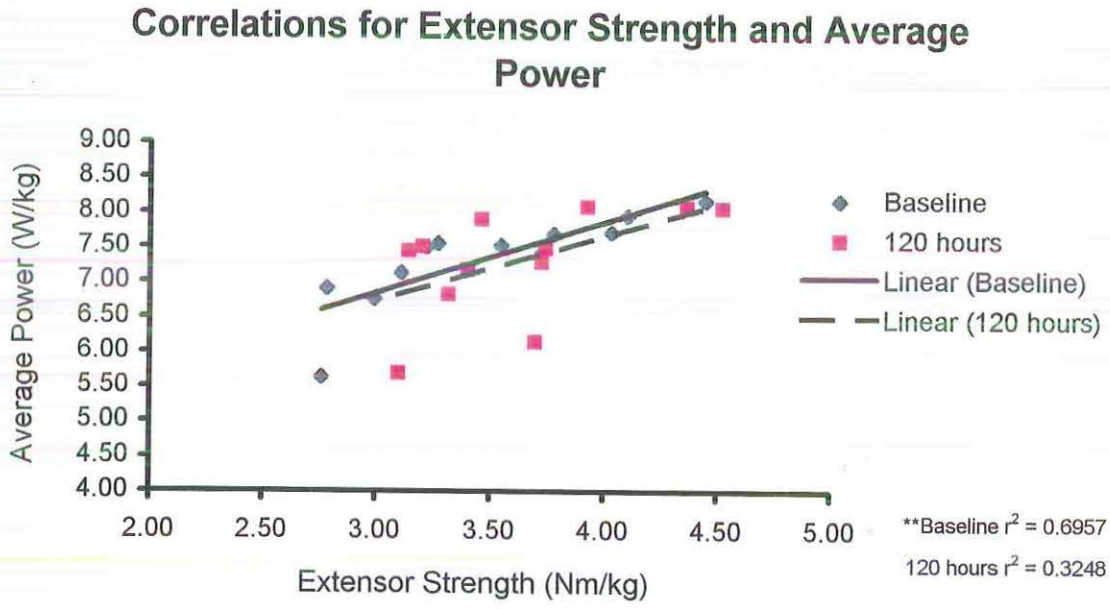

Figure 20. Changing relationship between extensor strength and average power as evident by a changing correlation for baseline and 120 hours post-run testing results
** correlation significant at 0.01 level

There were no significant correlations between soreness or tenderness and the variables of flexor strength, extensor strength, peak power, or average power. Correlations between the two variables however, showed significant negative correlations 24 hours ($r^2 = .86$) and 72 hours ($r^2 = .44$) post-run.

CHAPTER 5 DISCUSSION

5.1 Effect of DOMS on Power Output

The main focus of the current study was to assess the influence of DOMS on power output. As hypothesised, the test group showed a decrease in both average and peak power, and reported greater sensations of DOMS following the treadmill run. While previous investigations (Sargeant & Dolan, 1987) have reported a mean decrease in short term anaerobic power output of 33% 24 hours following a downhill walking exercise to fatigue, the contribution of DOMS to these observed decreases were not considered. Similar to the findings of Sargeant and Dolan (1987), results from the current study showed that both average power and peak power were reduced in the test group following a downhill run, although declines were greatest 30 minutes following the run, rather than 24 hours post-exercise. While Sargeant and Dolan reached no definite conclusions as to the cause of the decreased power, they suggested that it may result from an inability of the contracting muscles to maintain calcium homeostasis. It is suggested that following damaging exercise, calcium release from the sarcoplasmic reticulum (SR) is impaired, and restoration of calcium via the calcium pump following contraction is reduced (Sargeant & Dolan, 1987). A delay or fault in the excitation coupling of the muscle would therefore reduce the action potential created across the muscle fibre sarcolemma, and diminish the contractility of the muscle (Brown et al., 1996). Investigations by Byrd et al. (1989) also suggest that substrate accumulation or depletion (including PCr and glycogen) following damaging exercise may influence the activity of the calcium - ATPase pump, resulting in further depression of SR functioning and muscle contractility.

It has also been suggested (Talag, 1973) that decreases in performance seen following eccentric exercise are the direct result of pain preventing the subject from exercising maximally. Evidence from the current study and previous investigations (Newham, Mills et al., 1983) however suggests otherwise since there were no significant correlations. between soreness, and either peak power or average power. Furthermore, the greatest declines of both strength and power were seen 30 minutes post-run, while both muscle soreness and tenderness peaked 24 hours post-run.

Muscular strength has also been shown to decline following eccentric exercise when force production was measured during electrical stimulation of the exercised muscle (Davies & White, 1981). By performing such experiments investigators are able to compare directly force production during a constant stimulus and essentially remove to subjects perceptions and participation during the contraction. Additionally, if soreness or pain in the current study had caused the subjects not to perform with maximal effort, it would seem reasonable to assume that a decrease in post exercise heart rates and lactate results would be recorded. This, however, did not occur. It is therefore suggested that the observed power decrements, particularly that of average power, were not the result of decreased effort due to soreness, but to some other factor.

While from the current results it is not possible to comment on the suggestions that muscular performance declines occur as a result of altered calcium function, they do suggest the need for further investigation. Of particular interest is the possibility of a role of calcium in power declines as proposed by (Sargeant & Dolan, 1987) and the appearance of calcium as a noxious substance resulting in DOMS (Stauber et al., 1990).

While performance decrements and DOMS are often studied together, it has still not been firmly established if the two are actually related.

5.2 Relationship between Power Production, Muscle Strength and DOMS

A secondary focus of the current study was to assess the degree to which relationships exist between the variables of maximal power production, muscle strength and DOMS following exercise. During baseline testing, those subjects with the greatest isometric strength (for either the flexors or extensors) generally displayed the higher recordings for peak power, evident from the baseline correlation results. Therefore, it could be considered that a positive relationship between peak power and strength does exist. However, following the eccentrically biased run protocol, these correlations decreased, suggesting little or no relationship between the variables. A similar observation also occurred in relation to correlations between flexor and extensor strengths alone. One possible explanation for these results is a difference in muscle group activation during the downhill run, isometric leg strength, and power output protocols.

It has been suggested that the muscles subjected to the most damage, and therefore liable to show the greater performance decrements, are those that perform the greater amounts of eccentric work during exercise (Ebbeling & Clarkson, 1989, Friden & Lieber, 1992). Results of the current study for strength and power following the downhill run would therefore, be dependent on the degree to which muscles in which damage was induced during the run, were then involved during the subsequent strength and power protocols.

5.2.1 Biomechanics of Downhill Running, Knee Extension and Flexion, and Cycling

Kinematic studies of downhill running have shown that the extensors of the knee, gastrocnemius, tibialis anterior, extensor hallucis longus, and extensor digitorum longus are all activated eccentrically, with DOMS usually noted in the gluteals, quadriceps, and the anterior and posterior tibial muscles (Eston et al., 1995).

The strength testing protocol adopted involved the principle knee extensors and flexor muscle groups, these being rectus femoris, vastus lateralis, vastus intermedius, and vastus medialis for extension, and biceps femoris, semitendinosus, and semimebranosus for flexion. Additionally, extension is assisted by the synergist muscle tensor fasciae latae, and flexion by gracilis, sartorius, poplitues, gastrocnemius and plantaris (Rogers, 1992, p. 299-230; Williams, Warwick, Dyson & Bannister, 1989, p. 533).

In contrast to both of these protocols, a greater range of muscle group activation occurs during a cycling action with recruitment of the flexors and extensors of the hip and ankle occurring (Gregor, Komi & Jarvinen, 1987; Hull & Hawkins, 1990). In addition to the muscles involved in knee flexion and extension, tibialis anterior, soleus, iliacas, psoas and gluteus maximus have also been shown to contribute to movement at different phases of the pedalling cycle (Hamill & Knutzen, 1995). In particular, gluteus maximus contributes to approximately 20% of the mechanical energy produced by the muscles during 1 cycle action, occurring predominately in the downstroke phase (Raasch, Zajac, Ma & Levine, 1997).

5.2.2 Biomechanical Relationship between Adopted Testing Protocol

From the biomechanics of the testing protocol, it can be seen that differences exist between the muscle activation patterns for each of the three protocols. In particular, the quadriceps and the gastrocnemius are the only major contributors to mechanical work during the three different protocols. The quadriceps and the hamstring muscle groups being the only common contributors during the strength and power protocols. This may explain why a significant decrease between the two groups was seen in extensor strength only, post-run, and not flexor strength. The large contribution by the activity of smaller muscles (including tibialis anterior and soleus) in the power output of a cycling action, relative to downhill running may explain the smaller reductions seen in peak power and average power post-run.

One of the features of this study was the large variability seen in the responses to downhill running, despite a standardised protocol being used for each of the test subjects. This however, may be due to various factors that could contribute to a variation in the degree of damage, and therefore soreness. These include differences in running style, and varying levels of protection against the development of muscle damage and soreness.

5.2.2.1 Variations in Running Styles

When comparing the running action of downhill and level running, the main differences involve the angle of the knee and ankle joints between the foot strike and peak flexion angle. As a result, the period of negative or eccentric work for the knee and ankle as a percentage of total stance time is significantly greater during downhill running (Eston et al., 1995). The more eccentric work performed, the more damage and therefore

soreness that can be expected. Additionally, a large portion of injuries caused during running can be linked to gait irregularities, particularly when joint problems result in increased tensions and stresses on the muscles (Millar, 1994). The sites and severity of these injuries dependent on the nature and severity of the irregularity.

Variation in stride length may alter the total period of eccentric work performed during downhill running, while variations in running gait could influence the injury patterning and the susceptibility to damage. Based on this, it would then seem reasonable that variations between test subjects in terms of both stride length and gait have the potential to influence the severity and pattern of damage, and therefore soreness, seen following the treadmill run. These concepts would also explain the variations in strength and power loss between subjects. Further investigation of running style (including stride length and time in the support phase) and the patterning of soreness and damage however, are required to fully assess the degree to which the two interact.

5.2.2.2 Susceptibility to Exercise-Induced Muscle Damage

Numerous studies (Ebbeling & Clarkson, 1989; Smith et al, 1994) have been conducted focusing on muscle adaptation to repeated bouts of exercise, and the reductions in the normal responses seen post exercise. The results generally show that plasma CK responses are substantially reduced, as is the reporting of muscle soreness following subsequent exercise bouts (Eston et al., 1996; Schwane, Williams & Sloan, 1987). With regard to strength decrements, there is little evidence that prior exercise provides protection against strength loss, but rather, the time taken for strength to recover is reduced (Newham, Jones & Clarkson, 1987; Smith et al.).

During the current study, strength declines reached near full recovery (<2% decline) by 72 hours post-run, a shorter recovery than those reported previously (MacIntyre et al., 1996; Smith et al., 1994) for similar strength decline observations. Additionally, relatively low plasma CK responses were evident in 3 of the 7 test subjects, and low mean (<4) scores for soreness were reported for all testing occasions. Given that the subjects in the current study were active in different modes of sports, and for varying lengths of time per week, different levels of past exposure the damaging exercise, and thus protection could be expected. For this reason, it is possible that the run protocol used in the current study was not of a sufficient duration and/or grade, to induce substantial damage in all of the subjects.

5.3 Muscle Soreness and Tenderness

In the present study subjects were asked to rate their soreness whilst walking for various sites on the gluteal, hamstring, gastrocnemius and anterior tibialis muscle. A tenderness score was also determined using a myometer where force is applied to the muscle and subjects asked to report the moment pain is perceived. As hypothesised, and consistent with the findings of previous investigators (Eston et al., 1995; Schwane, Johnson et al., 1983), the test group reported greater DOMS following the downhill run protocol. Additionally, muscle tenderness was also noted for the same sites as muscle soreness, although the degree of soreness and tenderness were not always related.

Throughout the literature, two different methods of determining muscle soreness are generally used. The first involves the method adopted in the current study where subjects are asked to rate soreness using a linear scale, 1 representing no soreness and

10 very, very sore muscles (Smith et al., 1994). The second method involves subjects rating soreness during self-palpation of the muscle where 0 = a complete absence of soreness; 1= light pain felt only on palpation; 2 = moderate pain, some stiffness, and/or weakness, especially during movement; 3 = severe pain that limits the range of motion (Abraham, 1977; Schwane, Johnson et al., 1983). However, as one of the clinical symptoms associated with DOMS is the presence of palpation tenderness (Gulick & Kimura, 1996), the second method described for soreness assessment could be considered a combination of a soreness scale and a tenderness scale.

While muscle tenderness evaluation has been reported by various authors (Edwards, Mills & Newham, 1981; Eston et al., 1996) in relation to eccentric exercise and muscle damage, most neglect to distinguish between soreness and tenderness. Throughout the literature, soreness is generally referred to as pain occuring in the muscle during movement (Armstrong, 1984; Miles & Clarkson, 1994) Tenderness however is pain felt only when direct pressure is placed on the muscle (Eston et al). In addition, most studies to date evaluate either soreness or tenderness, and not both together.

Previous studies (Franklin, Currier & Franklin, 1991; MacIntyre et al., 1996) investigating DOMS have generally shown muscle soreness to be greatest 2 days post exercise and subsiding 5-7 days post exercise. While subjects in the current study were not tested 2 days post-run, muscle soreness was shown to be greatest 24 or 72 hours post-run when compared to 30 minutes and 120 hours post-run, indicating a similar soreness pattern to those which have been reported. Consistent with the findings of Gleeson, Blannin, Zhu, Brooks and Cave (1995) soreness was reported in all four of the muscle groups, although greater (but not significant) soreness was generally reported in

the gastrocnemius, gluteal, and quadriceps muscle groups. Muscle tenderness was also reported in the test group post-run, although not immediately as with soreness, with peak tenderness recordings occurring 24 hours post-run similar to the findings of Jones, Newham and Torgan (1981).

Results of the current study indicated tenderness to be both delayed in its appearance, and to have a similar recovery period as DOMS. Also, soreness and tenderness were shown to be highly correlated 24 hours post-run, while correlations 72 and 120 hours post-run were not as highly correlated. It has been suggested (Edwards et al., 1981; Newham, Mills et al., 1983) that tenderness associated with DOMS occurs most commonly in the musculotendinous junction, as opposed to being reported equally throughout the deeper tissue of the muscle as in DOMS. This however was not seen in the current study, with no significant differences seen for tenderness values at any site across the various muscle groups examined. Based on the literature relating to the mechanisms of DOMS, the sensation of soreness is most likely a result of type IV fibre stimulation, or that stimulation resulting in longer lasting, dull sensations of pain. In contrast, the short, sharp pain usually reported during tenderness evaluations may represent a type III fibre stimulation (Carlsson & Pellettieri, 1982; Terenios, 1987; Wall, 1987).

As a significant correlation between soreness and tenderness was only observed 24 and 72 hours post-run it would suggest the possibility that one sensation may exist without the other. Additionally, maximum tenderness values were frequently reported for a site within a muscle that was reported as being only mildly sore (score of 5 or 6 out of 10). Due to the relative absence of literature directly comparing soreness and tenderness,

further investigation would be required before suggestions of a link between the two sensations could be made, or alternately, before the two sensations could be appropriately separated.

5.4 CK Responses

It was hypothesised that the test group would display higher levels of plasma CK than the control group. The results, although demonstrating raised plasma CK for each of the post-run time periods in the test group, did not prove statistically significant. This is most likely the result of an insufficient sample size, given the variability of plasma CK responses seen in the test group. There was however an increase in plasma CK seen across time within the test group, with significant increases seen immediately, 24, 72, and 120 hours post-run.

In support of Clarkson et al. (1992), a peak plasma CK response occurred most often 24 hours post-run with levels returning to normal range by 72 hours post-run. Clarkson et al. also suggested, that those individuals who could be classified as low plasma CK responders, also demonstrated lower strength declines and lower ratings of soreness. These observations however, were not supported by the results of the current study, with no significant correlations observed between the change in plasma CK and changes in soreness, strength or peak power.

5.5 Lactate Responses

Results from the current study showed no changes in the post Wingate test lactate levels for the test group following the downhill run. Previous studies (Gleeson et al., 1995;

Gleeson, Blannin, Walsh, Field & Pritchard, 1998) focusing on lactate production during submaximal exercise following an eccentric bout of exercise, have shown post damage exercise lactate levels to increase. It is unclear why a similar increase in lactate was not seen during the current study.

As previously discussed in relation to strength and power declines, it is possible that the lack of any observable change in lactate production was a consequence of the subjects being protected against muscle damage. It is suggested that the damage seen following eccentric exercise occurs predominantly in the type II fibres (Lieber & Friden, 1988), and more specifically in the type IIb fibre sub-group, which is considered to be the fibre responsible for high levels of lactate production during exercise (McArdle et al., 1996, p. 124; Fox, Bowers & Foss, 1993, p. 107). Investigations of lactate production following eccentric and concentric exercise bouts have shown significant increases in submaximal exercise lactate levels 48 hours following the eccentric bout of exercise only (Gleeson et al., 1995 & 1998). These increases were suggested as being the result of one or more of the following mechanisms:

1. An increased rate of efflux of lactate from the working muscle due to increased muscle membrane permeability.
2. A greater metabolic strain on the undamaged muscle fibres or.
3. An altered recruitment pattern with greater reliance on type II fibres.

It is however not thought to be the result of impaired oxygen extraction within the muscle as oxygen efficiency following damaging exercise remains unchanged (Gleeson et al., 1995 & 1998). In support of this, a study by Essen-Gustavsson and Thornell (1994) showed significantly higher plasma lactate concentrations during submaximal exercise in racehorses that had been identified as having myofibrillar and cytoskeletal

alterations of the type IIb fibres. It is possible that subjects in the current study did not experience sufficient muscle fibre injury to cause altered lactate production during the subsequent Wingate tests. Further investigation would be required to determine if energy production and efficiency are altered during supramaximal exercise following eccentric work.

Using oxygen consumption analysis during exercise following a prior bout of eccentric exercise, various authors (Kavanagh & Jacobs, 1988; Serresse, Lortie, Bouchard & Boulay; Smith & Hill, 1991) have investigated the relative contributions of the three energy systems to energy production during maximal and supramaximal work. Using the same technique it would therefore be possible determine if any changes in the percentage contribution of each system occurred following an eccentric bout of exercise, rather than only comparing post exercise lactate concentrations.

CHAPTER 6 SUMMARY AND CONCLUSIONS

It is acknowledged that while the results for changes in flexor strength, average power, peak power and plasma CK between groups following the downhill run were not significant, this probably reflects the small sample size used in the study. It is also understood that a major factor responsible for the variation in responses, and to an extent, the low level of significant findings, is related to the use of active subjects who were likely to have developed protection against muscle damage and soreness.

A notable observation from the current study is the need to closely consider the protocol adopted for inducing muscle soreness when testing subsequent performance declines. Results from the current study were greatly influenced by the biomechanical differences between the running protocol used to induce soreness, and the cycling protocol adopted for power output determination. It is likely that more significant results would be seen if (1) power output was determined via a running protocol, or (2) muscle soreness was induced using a cycling protocol.

From the results, however, it would appear that power output is decreased during periods of DOMS, although it is inconclusive as the whether power output declines more than strength, and to what extent the variables of strength, power and soreness are related. Based on the findings it is suggested, that the eccentrically biased treadmill run performed by the test group was responsible for the observed changes in flexor strength, extensor strength, average power, peak power, soreness, tenderness, and plasma CK.

The results of the current study also suggest the need for further investigation into several aspects of DOMS and muscle damage following eccentric exercise. In particular:

1. Investigation of the possibility of a direct correlation between soreness and tenderness, and performance declines.
2. The distinction between sensations of soreness and tenderness following damaging exercise.
3. Closer consideration of the involvement of calcium as a mechanism in the sensation of DOMS, and decreases in strength and power.
4. Further investigation of the patterning of damage and soreness following eccentric exercise, with particular focus on the influence of biomechanical variations between individuals.
5. More thorough investigation of lactate production, energy system contributions, and oxygen efficiency during supramaximal exercise, following damaging exercise.
6. Further investigation into the time course and nature of protection against muscle damage.

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APPENDIX A INFORMED CONSENT FORM

INFORMED CONSENT FORM

An investigation of changes in muscular power associated with delayed onset muscle soreness (DOMS)

The aim of this research is to determine whether power related performance is decreased during periods of DOMS, and if relationships exist between maximal power production, muscular strength and DOMS following exercise.

The study will be conducted over a 2 week period at the Joondalup campus of Edith Cowan University, and as a subject you will be randomly assigned to one of two groups. Testing will consist of a total of six visits to the laboratory for both groups.

As a test group subject you will be asked to complete 3 different testing protocol, involving 1 treadmill run (5 x 8 min with 2 min rest intervals), 6 Wingate anaerobic tests, and 6 maximal isometric strength tests. The treadmill protocol will involve running at -7% grade, at a pace equivalent to 80% of your age predicted heart rate maximum. Each Wingate test will involve a 30 second all out maximal effort cycle with a resistance set according to your body weight. Each isometric strength test will involve 6 maximal contractions at 60° of knee flexion. As a control group subject you will be asked to complete only the 6 Wingate anaerobic tests and 6 maximal isometric strength tests. As a subject in either group you will also be required to undergo medical screening prior to participation.

Blood for lactate and creatine kinase levels will be taken a maximum of 16 occasions and will involve 30 microlitre whole blood samples from a finger prick.

You may experience some degree of muscle soreness and muscle stiffness in the days following the treadmill run, however this should subside within 5-7 days post run.

All of your personal information and tests results are confidential and will not be used for any other purpose other than the current study. All information will be kept under lock and key, with each subject being assigned a numbered code known only to the researchers. Additionally, no data analysis will include any name or information that may identify you specifically as a subject.

It is asked that you do not make any major changes to diet or exercise during the test period as this may influence results. Participation in the study is completely voluntary and you may withdraw at any time, for any reason.

Any questions concerning the current study can be directed to:

Carmel Nottle [redacted] (Postgraduate Student)
Dr. Paul Sacco [redacted] Research Supervisor)

I (the participant) have read the informed consent above, and any questions have been answered to my satisfaction. I have obtained medical clearance specific to participation in this study and I agree to participate realising that I may withdraw at any time.

I agree that the research data obtained from this study may be published, provided I am not identifiable.

Participant _____ Date _____

Investigator _____ Date _____

APPENDIX B SUBJECT MEDICAL QUESTIONNAIRE

Medical Questionnaire

The following questionnaire is designed to establish a background of your medical history, and identify any injury or illness that may influence your testing or performance.
Please answer all questions as accurately as possible and if you are unsure about any thing please ask.
All information provided is strictly confidential.

Personal Details

Name: _____

DOB: _____ Sex: _____

Height: _____ Weight: _____

Medical History

Have you ever had, or do you currently have any of the following?

			If you answered YES please give details
High or abnormal blood pressure	Y	N	_____
High cholesterol	Y	N	_____
Rheumatic fever	Y	N	_____
Heart abnormalities	Y	N	_____
Asthma	Y	N	_____
Diabetes	Y	N	_____
Epilepsy	Y	N	_____
Back pain	Y	N	_____
Neck pain	Y	N	_____
Severe allergies	Y	N	_____
Any infectious diseases	Y	N	_____

If you answered YES please give details

Are you currently on any medications? Y N _____

_____

_____

Have you had the flu in the last two weeks? Y N _____

Have you recently had any injuries or accidents? _____

Do you have any recurring muscle or joint injuries? Y N _____

Is there any other condition not previously mentioned which may affect your exercise performance? Y N _____

Family History

Are any of the following known to exist in your family?

			If you answered YES please give details
Cardiac disease	Y	N	_____
Pulmonary disease	Y	N	_____
Stroke	Y	N	_____

Lifestyle Habits

Do you exercise regularly? Y N
If YES how many hours per week? _____

Do you smoke tobacco or any other nicotine products Y N
If YES please how much per day? _____

Do you consume alcohol? Y N
If YES how many standard drinks per week? _____

Do you consume tea and or coffee? Y N
If YES how many cups per day? _____

Do you take any recreational drugs? Y N
If YES how much or how often per week? _____

Declaration

I acknowledge that the information provided on this form, is to the best of my knowledge, a true and accurate indication of my current state of health.

Name: _____ Date: _____

Signature: _____

APPENDIX C DATA COLLECTION FORM

Name: _____ Group: _____ ID: _____

Age: _____ Height: _____ Weight: _____

Pre-run Period

Trial 1

Date: _____ Time: _____

Strength

	Extensors		Flexors	
	Left	Right	Left	Right
Rep 1	_____	_____	_____	_____
Rep 2	_____	_____	_____	_____
Rep 3	_____	_____	_____	_____
Max. Force	_____	_____	_____	_____

Wingate

Pre test La: _____ HR: _____

RPM at start : _____

Time	5	10	15	20	25	30
RPM	_____	_____	_____	_____	_____	_____
Power	_____	_____	_____	_____	_____	_____

Peak power (W)	_____	Peak power/kg (W/kg)	_____
Minimum power (W)	_____	Minimum power/kg (W/kg)	_____
Average power (W)	_____	Average power/kg (W/kg)	_____
Power drop (W/s)	_____	Power drop/kg (W/s/kg)	_____

Post test La: _____ HR: _____

Trial 2

Date: _____ Time: _____

Strength

	Extensors		Flexors	
	Left	Right	Left	Right
Rep 1	_____	_____	_____	_____
Rep 2	_____	_____	_____	_____
Rep 3	_____	_____	_____	_____
Max. Force	_____	_____	_____	_____

Wingate

Pre test La: _____ HR: _____

RPM at start : _____

Time	5	10	15	20	25	30
RPM	_____	_____	_____	_____	_____	_____
Power	_____	_____	_____	_____	_____	_____

Peak power (W)	_____	Peak power/kg (W/kg)	_____
Minimum power (W)	_____	Minimum power/kg (W/kg)	_____
Average power (W)	_____	Average power/kg (W/kg)	_____
Power drop (W/s)	_____	Power drop/kg (W/s/kg)	_____

Post test La: _____ HR: _____

Name: _____ Group: _____ ID: _____

Run Period

Creatine Kinase

Pre-run _____ Post-run _____

Lactate

Pre-run _____ Post-run _____

Muscle Soreness

	Pre-run					Post-run				
Soreness	Gluteals	Quad	Hamstring	Calf	A. Tib	Gluteals	Quad	Hamstring	Calf	A. Tib
Left										
Right										
Tenderness										
Left										
Right										

Run – HR and Speed

		Minute			
Set	**Measure**	**2**	**4**	**6**	**8**
1	**HR**				
	Speed				
Rest	*HR*				
2	**HR**				
	Speed				
Rest	*HR*				
3	**HR**				
	Speed				
Rest	*HR*				
4	**HR**				
	Speed				
Rest	*HR*				
5	**HR**				
	Speed				
End	*HR*				

Post-run Wingate

Pre test La: _____ HR: _____

RPM at start : _____

Time	5	10	15	20	25	30
RPM						
Power						

Peak power (W) _____ Peak power/kg (W/kg) _____

Minimum power (W) _____ Minimum power/kg (W/kg) _____

Average power (W) _____ Average power/kg (W/kg) _____

Power drop (W/s) _____ Power drop/kg (W/s/kg) _____

Post test La: _____ HR: _____

Post-run Strength

	Extensors		Flexors	
	Left	Right	Left	Right
Rep 1				
Rep 2				
Rep 3				
Max. Force				

Name: _____ Group: _____ ID: _____

Post-run Period

Day 1
Date: _____ Time: _____

Creatine Kinase _____

Muscle Soreness

Soreness	Gluteals	Quad	Hamstring	Calf	A. Tib
Left					
Right					
Tenderness					
Left					
Right					

Strength

	Extensors		Flexors	
	Left	Right	Left	Right
Rep 1	_____	_____	_____	_____
Rep 2	_____	_____	_____	_____
Rep 3	_____	_____	_____	_____
Max. Force	_____	_____	_____	_____

Wingate
Pre test La: _____ HR: _____

RPM at start : _____

Time	5	10	15	20	25	30
RPM	_____	_____	_____	_____	_____	_____
Power	_____	_____	_____	_____	_____	_____

Peak power (W) _____ Peak power/kg (W/kg) _____
Minimum power (W) _____ Minimum power/kg (W/kg) _____
Average power (W) _____ Average power/kg (W/kg) _____
Power drop (W/s) _____ Power drop/kg (W/s/kg) _____

Post test La: _____ HR: _____

Name: _____ Group: _____ ID: _____

Day 3
Date: _____ Time: _____

Creatine Kinase _____

Muscle Soreness

Soreness	Gluteals	Quad	Hamstring	Calf	A. Tib
Left					
Right					
Tenderness					
Left					
Right					

Strength

	Extensors		Flexors	
	Left	Right	Left	Right
Rep 1	_____	_____	_____	_____
Rep 2	_____	_____	_____	_____
Rep 3	_____	_____	_____	_____
Max. Force	_____	_____	_____	_____

Wingate
Pre test La: _____ HR: _____

RPM at start : _____

Time	5	10	15	20	25	30
RPM	_____	_____	_____	_____	_____	_____
Power	_____	_____	_____	_____	_____	_____

Peak power (W) _____ Peak power/kg (W/kg) _____
Minimum power (W) _____ Minimum power/kg (W/kg) _____
Average power (W) _____ Average power/kg (W/kg) _____
Power drop (W/s) _____ Power drop/kg (W/s/kg) _____

Post test La: _____ HR: _____

Name: _____ Group: _____ ID: _____

Day 5
Date: _____ Time: _____

Creatine Kinase _____

Muscle Soreness

Soreness	Gluteals	Quad	Hamstring	Calf	A. Tib
Left					
Right					
Tenderness					
Left					
Right					

Strength

	Extensors		Flexors	
	Left	Right	Left	Right
Rep 1	_____	_____	_____	_____
Rep 2	_____	_____	_____	_____
Rep 3	_____	_____	_____	_____
Max. Force	_____	_____	_____	_____

Wingate
Pre test La: _____ HR: _____

RPM at start : _____

Time	5	10	15	20	25	30
RPM	_____	_____	_____	_____	_____	_____
Power	_____	_____	_____	_____	_____	_____

Peak power (W) _____ Peak power/kg (W/kg) _____
Minimum power (W) _____ Minimum power/kg (W/kg) _____
Average power (W) _____ Average power/kg (W/kg) _____
Power drop (W/s) _____ Power drop/kg (W/s/kg) _____

Post test La: _____ HR: _____

APPENDIX D INDIVIDUAL SUBJECT DATA

Subject Charateristics of Age, Height, Weight and Activity Levels for the Test Group

Test group				
Subject Number	Age (years)	Height (cm)	Weight (kg)	Activity (hrs/week)
1	20	180	70	15
2	19	195	80	5
3	20	174.5	78.5	4
4	19	183	69	1
5	18	185	70	5
6	18	186	70	8
7	20	180	69	2

Subject Characteristics of Age, Height, Weight and Activity Levels for the Control Group

Control group				
Subject Number	Age (years)	Height (cm)	Weight (kg)	Activity (hrs/week)
1	19	187	78	6
2	20	185	97	5
3	21	186	85	8
4	19	192	90	3
5	19	170	69	4

Results of Left Limb Strength Measurements from Baseline Testing for the Combined Sample

		Strength (Nm)			
		Left Limb			
		Extensors		Flexors	
Group	Subject	Test 1	Test 2	Test 1	Test 2
test	1	199.47	206.27	102.00	108.80
test	2	348.07	343.87	158.67	167.73
test	3	285.60	299.20	163.20	149.60
test	4	204.00	208.53	122.40	140.53
test	5	222.13	222.13	95.20	104.27
test	6	256.13	231.20	133.73	131.47
test	7	321.53	308.27	172.27	167.73
control	1	219.87	235.73	136.00	154.13
control	2	249.30	249.30	149.60	142.80
control	3	394.40	388.67	179.07	160.93
control	4	251.60	249.30	111.07	108.80
control	5	244.80	190.40	129.20	126.93

Results of Right Limb Strength Measurements for Baseline Testing for the Combined Sample

		Strength (Nm)			
		Right Limb			
		Extensors		Flexors	
Group	Subject	Test 1	Test 2	Test 1	Test 2
test	1	235.73	244.80	86.30	124.67
test	2	296.93	285.60	183.60	156.40
test	3	278.80	285.60	160.93	158.70
test	4	190.40	204.00	117.87	120.13
test	5	235.73	210.80	108.80	108.80
test	6	240.27	213.07	145.07	133.73
test	7	244.80	242.53	170.00	176.80
control	1	217.60	249.33	165.47	172.27
control	2	290.13	281.07	136.00	133.73
control	3	361.67	357.13	174.53	167.73
control	4	240.27	244.80	111.07	108.80
control	5	276.53	244.80	145.07	126.93

Results of Power Output from Baseline Testing for the Combined Sample Group

		Power Output (W)			
		Peak power		Average Power	
Group	Subject	Test 1	Test 2	Test 1	Test 2
test	1	633.52	632.77	525.17	507.33
test	2	698.41	808.59	573.25	617.65
test	3	666.09	799.91	553.63	579.36
test	4	614.28	632.76	442.99	466.62
test	5	592.20	605.10	538.86	528.22
test	6	610.59	603.63	526.85	498.51
test	7	657.81	680.55	558.43	549.56
control	1	670.39	704.54	576.04	548.64
control	2	756.60	761.98	664.45	670.67
control	3	859.96	950.78	688.92	695.37
control	4	733.63	750.03	524.61	507.31
control	5	641.42	724.99	488.05	530.68

Heart Rate Recordings for each 8 Minute Period During the Treadmill Run for the Test Group

	Heart rate (bpm)				
	Run Period				
Subject	1	2	3	4	5
1	152	161	162	162	161
2	143	163	164	166	171
3	156	160	164	169	165
4	158	160	145	150	155
5	160	163	164	162	158
6	159	154	153	158	148
7	151	159	162	166	163

Recordings for Running Speed for each 8 Minute Period During the Treadmill Run for the Test Group

	Running Speed (km/hr)				
	Run Period				
Subject	**1**	**2**	**3**	**4**	**5**
1	15.30	15.30	14.49	13.36	13.36
2	12.08	14.01	13.36	12.53	12.08
3	15.30	15.50	15.30	14.17	12.88
4	13.28	12.08	8.86	8.86	8.86
5	12.48	14.89	13.97	13.69	13.69
6	9.47	10.27	10.47	10.79	10.79
7	11.27	12.88	12.88	12.88	12.88

Results for Pre- and Post-run Lactate Recordings for the Test Group

	Lactate ($mmol^{-1}$)	
Subject	**Pre-run**	**Post-run**
1	2.20	2.00
2	2.40	2.00
3	1.60	4.00
4	3.90	4.90
5	3.60	4.60
6	3.90	3.70
7	3.00	6.00

Recordings Across Time of Left Leg Extensor Strength for the Test and Control Groups

		Left Leg Extensor Strength (Nm/kg)				
Group	**Subject**	**Baseline**	**Post-run**	**24 hours**	**72 hours**	**120 hours**
test	1	2.95	2.49	2.98	3.08	3.69
test	2	4.35	4.29	4.07	4.52	4.80
test	3	3.81	2.74	2.89	3.21	3.78
test	4	3.02	2.69	2.86	3.74	3.81
test	5	3.17	2.46	2.79	3.08	3.43
test	6	3.66	2.91	3.27	3.43	3.37
test	7	4.66	3.94	4.27	4.60	4.34
control	1	3.02	2.96	3.49	3.25	3.60
control	2	2.57	2.79	3.08	3.06	3.08
control	3	4.64	4.57	4.31	4.44	4.47
control	4	2.80	2.95	2.95	3.10	3.17
control	5	3.55	3.15	3.15	3.12	2.73

Recordings Across Time of Right Leg Extensor Strength for the Test and Control Groups

		Right Leg Extensor Strength (Nm/kg)				
Group	**Subject**	**Baseline**	**Post-run**	**24 hours**	**72 hours**	**120 hours**
test	1	3.50	2.49	2.78	3.08	3.79
test	2	3.71	4.07	3.74	4.24	4.24
test	3	3.64	2.45	2.60	3.12	3.67
test	4	2.96	2.76	3.02	3.35	3.58
test	5	3.37	2.23	2.43	2.72	3.37
test	6	3.43	2.98	3.30	3.11	2.91
test	7	3.55	3.02	3.25	3.71	3.51
control	1	3.20	3.17	3.66	3.31	3.31
control	2	2.99	3.20	3.34	3.29	3.55
control	3	4.25	4.04	4.41	4.33	4.25
control	4	2.72	2.77	2.72	2.97	3.02
control	5	4.01	3.68	3.09	3.55	3.68

Recordings Across Time of Left Leg Flexor Strength for the Test and Control Groups

		Left Leg Flexor Strength (Nm/kg)				
Group	**Subject**	**Baseline**	**Post-run**	**24 hours**	**72 hours**	**120 hours**
test	1	1.55	1.36	1.88	1.91	2.07
test	2	2.10	2.03	1.84	2.27	2.15
test	3	2.08	1.62	1.70	1.65	1.79
test	4	2.04	1.97	1.97	2.07	1.93
test	5	1.49	1.52	1.53	1.55	1.55
test	6	1.91	1.55	1.59	1.49	1.46
test	7	2.50	2.10	2.17	2.17	2.27
control	1	1.98	1.95	1.92	2.06	1.98
control	2	1.54	1.54	1.47	1.57	1.61
control	3	2.11	1.92	1.92	1.87	1.92
control	4	1.23	1.13	1.28	1.31	1.36
control	5	1.87	1.91	1.71	1.58	1.35

Recordings Across Time of Right Leg Flexor Strength for the Test and Control Groups

		Right Leg Flexor Stength (Nm/kg)				
Group	**Subject**	**Baseline**	**Post-run**	**24 hours**	**72 hours**	**120 hours**
test	1	1.78	1.91	1.94	2.01	2.14
test	2	2.30	2.04	1.98	2.21	2.30
test	3	2.05	1.85	1.73	1.39	1.79
test	4	1.74	1.61	1.64	1.97	1.97
test	5	1.55	1.49	1.51	1.55	1.55
test	6	2.07	1.68	1.49	1.65	1.78
test	7	2.56	2.14	2.30	2.20	2.14
control	1	2.21	2.12	2.21	2.30	1.86
control	2	1.40	1.59	1.45	1.45	1.54
control	3	2.05	1.97	1.81	1.92	1.71
control	4	1.23	1.21	1.21	1.23	1.46
control	5	2.10	1.74	1.71	1.61	1.68

Recordings Across Time of Extensor Strength for the Test and Control Groups

		Extensor Strength (Nm/kg)				
Group	**Subject**	**Baseline**	**Post-run**	**24 hours**	**72 hours**	**120 hours**
test	1	3.22	2.49	2.88	3.08	3.74
test	2	4.03	4.18	3.91	4.38	4.52
test	3	3.72	2.60	2.74	3.16	3.72
test	4	2.99	2.73	2.94	3.55	3.70
test	5	3.27	2.35	2.61	2.90	3.40
test	6	3.55	2.95	3.29	3.27	3.14
test	7	4.10	3.48	3.76	4.16	3.93
control	1	3.11	3.07	3.57	3.28	3.46
control	2	2.78	3.00	3.21	3.18	3.31
control	3	4.45	4.31	4.36	4.39	4.36
control	4	2.76	2.86	2.83	3.03	3.10
control	5	3.78	3.42	3.12	3.34	3.20

Recordings Across Time of Flexor Strength for the Test and Control Groups

		Flexor Strength (Nm/kg)				
Group	**Subject**	**Baseline**	**Post-run**	**24 hours**	**72 hours**	**120 hours**
test	1	1.67	1.64	1.91	1.96	2.10
test	2	2.20	2.03	1.91	2.24	2.22
test	3	2.06	1.73	1.72	1.52	1.79
test	4	1.89	1.79	1.81	2.02	1.95
test	5	1.52	1.51	1.52	1.55	1.55
test	6	1.99	1.62	1.54	1.57	1.62
test	7	2.53	2.12	2.23	2.18	2.20
control	1	2.09	2.03	2.06	2.18	1.92
control	2	1.47	1.57	1.46	1.51	1.58
control	3	2.08	1.95	1.87	1.89	1.81
control	4	1.23	1.17	1.25	1.27	1.41
control	5	1.99	1.82	1.71	1.59	1.51

Recordings Across Time of Peak Power for the Test and Control Groups

		Peak Power (W/kg)				
Group	**Subject**	**Baseline**	**Post-run**	**24 hours**	**72 hours**	**120 hours**
test	1	9.05	9.47	8.27	9.66	10.17
test	2	10.11	9.37	9.81	11.44	11.26
test	3	10.26	9.45	9.79	9.43	10.24
test	4	9.17	8.47	8.99	8.96	9.06
test	5	8.64	8.41	8.41	8.49	9.17
test	6	8.72	8.60	9.09	9.37	8.84
test	7	9.86	9.62	9.86	10.15	10.30
control	1	9.15	8.71	9.15	9.14	9.78
control	2	7.86	8.30	8.84	8.90	8.95
control	3	11.19	11.04	10.56	11.04	10.59
control	4	8.33	8.04	8.62	8.22	8.16
control	5	10.51	10.51	10.37	9.90	10.62

Recordings Across Time of Average Power for the Test and Control Groups

		Average Power (W/kg)				
Group	**Subject**	**Baseline**	**Post-run**	**24 hours**	**72 hours**	**120 hours**
test	1	7.50	7.22	7.21	7.56	7.49
test	2	7.72	7.61	7.71	8.17	8.07
test	3	7.43	6.45	6.62	6.84	7.29
test	4	6.76	6.43	6.26	6.14	6.15
test	5	7.55	7.02	7.03	7.15	7.18
test	6	7.53	7.08	7.41	7.58	7.44
test	7	7.96	7.88	8.19	8.04	8.09
control	1	7.13	7.34	7.63	7.82	7.90
control	2	6.91	6.81	6.37	6.65	6.83
control	3	8.18	8.19	7.91	7.75	8.08
control	4	5.64	5.69	5.68	5.84	5.69
control	5	7.69	7.60	7.45	7.11	7.51

Pre-Wingate Lactate Recordings Across Time for the Test and Control Groups

		Pre-test lactate ($mmol^{-1}$)				
Group	**Subject**	**Baseline**	**Post-run**	**24 hours**	**72 hours**	**120 hours**
test	1	2.70	2.10	2.00	2.50	2.40
test	2	2.60	2.90	2.00	3.00	4.00
test	3	2.10	3.60	1.70	1.80	2.80
test	4	3.60	3.70	2.70	2.10	2.00
test	5	4.50	3.60	3.30	2.20	4.10
test	6	4.50	4.30	5.40	5.00	4.20
test	7	5.00	5.40	4.80	4.60	4.60
control	1	3.30	5.00	4.70	5.00	4.00
control	2	2.70	2.60	2.70	3.10	2.20
control	3	4.70	5.00	4.60	4.50	4.20
control	4	4.50	4.50	4.10	4.90	5.10
control	5	4.50	5.00	4.50	5.10	4.40

Post-Wingate Lactate Recordings Across Time for the Test and Control Groups

		Post-test lactate ($mmol^{-1}$)				
Group	**Subject**	**Baseline**	**Post-run**	**24 hours**	**72 hours**	**120 hours**
test	1	8.90	10.30	13.30	9.80	11.10
test	2	13.00	12.50	10.80	13.20	8.20
test	3	13.20	10.00	9.40	13.40	12.20
test	4	11.80	11.00	11.20	11.80	11.90
test	5	14.20	10.70	9.00	11.30	11.60
test	6	12.30	11.40	10.10	11.70	11.20
test	7	11.00	11.90	13.40	11.30	13.20
control	1	13.20	13.90	14.20	12.90	14.90
control	2	6.30	6.20	6.20	7.60	7.30
control	3	13.70	12.20	12.70	12.00	12.50
control	4	11.20	11.40	10.60	10.50	14.70
control	5	14.30	12.20	12.30	12.10	12.50

Pre-Wingate Heart Rate Recordings Across Time for the Test and Control Groups

		Pre-test heart rate (bpm)				
Group	**Subject**	**Baseline**	**Post-run**	**24 hours**	**72 hours**	**120 hours**
test	1	96	83	94	70	75
test	2	84	92	86	86	74
test	3	85	108	76	74	91
test	4	78	74	94	79	86
test	5	74	72	70	60	66
test	6	99	96	104	104	94
test	7	106	83	94	91	98
control	1	96	100	106	93	106
control	2	108	98	87	106	98
control	3	116	111	99	118	110
control	4	112	102	97	102	97
control	5	102	105	86	96	98

Post-Wingate Heart Rate Recordings Across Time for the Test and Control Groups

		Post-test heart rate (bpm)				
Group	**Subject**	**Baseline**	**Post-run**	**24 hours**	**72 hours**	**120 hours**
test	1	160	169	161	163	170
test	2	163	179	170	169	185
test	3	183	173	175	175	180
test	4	179	175	181	182	180
test	5	186	181	182	186	179
test	6	190	180	191	187	181
test	7	197	184	183	195	197
control	1	186	189	192	190	190
control	2	159	164	156	163	163
control	3	179	172	183	186	181
control	4	173	173	173	170	171
control	5	197	197	193	190	194

Recordings Across Time of Plasma CK for the Test and Control Groups

		Plasma CK (U/l)				
Group	**Subject**	**Pre-run**	**Post-run**	**24 hours**	**72 hours**	**120 hours**
test	1	210	284	741	373	288
test	2	285	292	641	283	358
test	3	130	229	511	199	349
test	4	70	102	116	53.3	73
test	5	32.30	61.5	198	86.9	179
test	6	70.50	61.8	221	137	122
test	7	300.00	420	1630	563	571
control	1		98.2	104	72.1	72.3
control	2		70.6	86.2	72.9	85.2
control	3		173	130	133	178
control	4		54.7	95.8	49.2	39.1
control	5		179	133	171	179

Pre-run Recordings of Soreness in the Left Leg for the Test Group

	Gluteals		Quads			Hamstrings			Calf		
Subject	Medial	Lateral	Medial	Lateral	Proximal	Medial	Lateral	Proximal	Medial	Lateral	A. Tib
1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1.5	1.5	1	1	1	1	1	1	1
3	1	1	1	1	1	1	1	1	1	1	1
4	1	1	1	1	1	1	1	1	1	1	1
5	1	1	1	1	1	1	1	1	1	1	1
6	1	1	1	1	1	1	1	1	1	1	1
7	1	1	1	1	1	1	1	1	1	1	1

Pre-run Recordings of Soreness in the Right Leg for the Test Group

	Gluteals		Quads			Hamstrings			Calf		
Subject	Medial	Lateral	Medial	Lateral	Proximal	Medial	Lateral	Proximal	Medial	Lateral	A. Tib
1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1.5	1.5	1	1	1	1	1	1	1
3	1	1	1	1	1	1	1	1	1	1	1
4	1	1	1	1	1	1	1	1	1	1	1
5	1	1	1	1	1	1	1	1	1	1	1
6	1	1	1	1	1	1	1	1	1	1	1
7	1	3	1	1	1	1	1	1	1	1.5	1

Pre-run Recordings of Tenderness in the Left Leg for the Test Group

	Gluteals		Quads			Hamstrings			Calf		
Subject	Medial	Lateral	Medial	Lateral	Proximal	Medial	Lateral	Proximal	Medial	Lateral	A. Tib
1	100	100	100	100	100	100	100	100	100	100	100
2	100	100	100	100	100	100	100	100	100	100	100
3	100	100	100	100	100	100	100	100	100	100	100
4	100	100	100	100	100	100	100	100	100	100	100
5	100	100	100	100	100	100	100	100	100	100	100
6	100	100	100	100	100	100	100	100	100	100	100
7	100	100	100	100	100	100	100	100	100	100	100

Pre-run Recordings of Tenderness in the Right Leg for the Test Group

	Gluteals		Quads			Hamstrings			Calf		
Subject	Medial	Lateral	Medial	Lateral	Proximal	Medial	Lateral	Proximal	Medial	Lateral	A. Tib
1	100	100	100	100	100	100	100	100	100	100	100
2	100	100	100	100	100	100	100	100	100	100	100
3	100	100	100	100	100	100	100	100	100	100	100
4	100	100	100	100	100	100	100	100	100	100	100
5	100	100	100	100	100	100	100	100	100	100	100
6	100	100	100	100	100	100	100	100	100	100	100
7	100	100	100	100	100	100	100	100	100	100	100

Post-run Recordings of Soreness in the Left Leg for the Test Group

	Gluteals		Quads			Hamstrings			Calf		
Subject	Medial	Lateral	Medial	Lateral	Proximal	Medial	Lateral	Proximal	Medial	Lateral	A. Tib
1	7	7	6.5	1	1	1	1	1	1	1	1
2	1	1	1	1	1	1	1	1	8	8	1
3	1	6	1	2	1	1	1	1	4	5	1
4	1	1	1	1	1	1	1	1	6	6	2
5	1	2	3	1	1	2	1	1	4	4	3
6	1	1	1	1	1	1	1	1	3	1	1
7	1	1	1	1	1	1	1	5	1	1	1

Post-run Recordings of Soreness in the Right Leg for the Test Group

	Gluteals		Quads			Hamstrings			Calf		
Subject	Medial	Lateral	Medial	Lateral	Proximal	Medial	Lateral	Proximal	Medial	Lateral	A. Tib
1	1	1	6.5	1	1	1	1	1	1	1	1
2	1	1	1	1	1	1	1	1	8	8	1
3	1	1	1	5	1	1	1	1	3	1	1
4	1	1	1	1	1	1	1	1	6	6	2
5	1	2	3	1	1	2	1	1	4	4	3
6	1	1	3	1	1	1	1	3	3	1	1
7	1	4	1	1	1	1	1	5	1	1	1

Post-run Recordings of Tenderness in the Left Leg for the Test Group

	Gluteals		Quads			Hamstrings			Calf		
Subject	Medial	Lateral	Medial	Lateral	Proximal	Medial	Lateral	Proximal	Medial	Lateral	A. Tib
1	100	100	100	100	100	100	100	100	100	100	100
2	100	100	100	100	100	100	100	100	100	100	100
3	100	100	100	100	100	100	100	100	100	100	100
4	100	100	100	100	100	100	100	100	100	100	100
5	100	100	100	100	100	100	100	100	100	100	100
6	100	100	100	100	100	100	100	100	100	100	100
7	100	100	100	100	100	100	100	100	100	100	100

Post-run Recordings of Tenderness in the Right Leg for the Test Group

	Gluteals		Quads			Hamstrings			Calf		
Subject	Medial	Lateral	Medial	Lateral	Proximal	Medial	Lateral	Proximal	Medial	Lateral	A. Tib
1	100	100	100	100	100	100	100	100	100	100	100
2	100	100	100	100	100	100	100	100	100	100	100
3	100	100	100	100	100	100	100	100	100	100	100
4	100	100	100	100	100	100	100	100	100	100	100
5	100	100	100	100	100	100	100	100	100	100	100
6	100	100	100	100	100	100	100	100	100	100	100
7	100	100	100	100	100	100	100	100	100	100	100

Recordings of Soreness in the Left Leg for the Test Group 24 hours Post-run

	Gluteals		Quads			Hamstrings			Calf		
Subject	Medial	Lateral	Medial	Lateral	Proximal	Medial	Lateral	Proximal	Medial	Lateral	A. Tib
1	1	1	8	5	1	1	1	1	1	1	2
2	1	4	2	1	1	1	1	1	4	6	1
3	1	6	4	3	5	2	2	2	3	6	3
4	5	5	1	1	3	1	1	3	8	4	4
5	1	6	6	6	6	3	4	3	1	6	1
6	3	3	5	5	5	5	5	5	3	1	1
7	5	5	1	1	1	1	1	1	1	1	1

Recordings of Soreness in the Right Leg for the Test Group 24 hours Post-run

	Gluteals		Quads			Hamstrings			Calf		
Subject	Medial	Lateral	Medial	Lateral	Proximal	Medial	Lateral	Proximal	Medial	Lateral	A. Tib
1	7	7	8	5	1	1	1	1	1	1	2
2	1	4	2	1	1	1	1	1	4	6	1
3	1	6	4	3	5	2	2	2	3	6	3
4	5	5	1	1	3	3	3	3	8	4	4
5	1	6	6	6	6	3	4	3	1	6	1
6	3	3	5	5	5	5	5	5	3	1	1
7	5	5	1	1	1	1	1	1	1	1	1

Recordings of Tenderness in the Left Leg for the Test Group 24 hours Post-run

	Gluteals		Quads			Hamstrings			Calf		
Subject	Medial	Lateral	Medial	Lateral	Proximal	Medial	Lateral	Proximal	Medial	Lateral	A. Tib
1	100	100	5	5	5	100	100	100	100	100	25
2	100	5	100	100	100	100	100	100	100	100	100
3	30	80	5	20	5	35	65	35	60	25	5
4	50	45	30	35	40	70	50	20	35	20	55
5	100	60	70	50	10	40	50	40	60	5	70
6	70	40	5	40	10	60	40	50	40	60	90
7	90	80	80	50	60	80	80	90	60	50	80

Recordings of Tenderness in the Right Leg for the Test Group 24 hours Post-run

	Gluteals		Quads			Hamstrings			Calf		
Subject	Medial	Lateral	Medial	Lateral	Proximal	Medial	Lateral	Proximal	Medial	Lateral	A. Tib
1	100	100	5	5	5	100	100	100	100	100	25
2	100	5	100	100	100	100	100	100	100	100	100
3	20	80	5	5	5	35	40	20	20	20	5
4	45	50	5	35	30	60	50	40	40	40	15
5	100	60	90	40	20	60	60	25	50	5	60
6	90	40	5	30	40	50	20	40	50	50	100
7	90	60	50	50	20	80	60	20	90	70	80

Recordings of Soreness in the Left Leg for the Test Group 72 hours Post-run

	Gluteals		Quads			Hamstrings			Calf		
Subject	Medial	Lateral	Medial	Lateral	Proximal	Medial	Lateral	Proximal	Medial	Lateral	A. Tib
1	1.5	1.5	7.5	8	6.5	1	1	1	1	1	2
2	1.5	1.5	1	1	1	1	1	1	3	3	1
3	1	1	5	3	3	1	1	1	2	3	1
4	1	1	2	2	1	1	1	1	3	1	2
5	1	3	5	5	5	1	1	1	3	1	1
6	4	4	5	5	1	5	5	1	1	4	1
7	1	1	1	1	1	1	1	2	1	1	1

Recordings of Soreness in the Right Leg for the Test Group 72 hours Post-run

	Gluteals		Quads			Hamstrings			Calf		
Subject	Medial	Lateral	Medial	Lateral	Proximal	Medial	Lateral	Proximal	Medial	Lateral	A. Tib
1	1.5	1.5	7.5	8	6.5	1	1	1	1	1	2
2	1.5	1.5	1	1	1	1	1	1	3	3	1
3	1	1	4	3	3	1	1	1	2	3	1
4	1	1	2	2	1	1	1	1	3	1	2
5	1	3	5	5	5	1	1	1	3	1	1
6	4	4	5	5	1	5	5	1	1	4	1
7	5	5	1	1	1	1	1	1	1	1	1

Recordings of Tenderness in the Left Leg for the Test Group 72 hours Post-run

	Gluteals		Quads			Hamstrings			Calf		
Subject	Medial	Lateral	Medial	Lateral	Proximal	Medial	Lateral	Proximal	Medial	Lateral	A. Tib
1	100	100	30	25	25	100	100	100	100	100	15
2	100	100	100	100	100	100	100	100	100	100	100
3	100	70	5	40	5	40	40	20	45	40	5
4	100	100	50	50	50	50	60	60	80	100	65
5	100	95	20	70	10	70	80	40	70	50	100
6	80	40	5	45	35	40	40	55	50	50	70
7	95	70	70	55	80	100	80	80	25	65	100

Recordings of Tenderness in the Right Leg for the Test Group 72 hours Post-run

	Gluteals		Quads			Hamstrings			Calf		
Subject	Medial	Lateral	Medial	Lateral	Proximal	Medial	Lateral	Proximal	Medial	Lateral	A. Tib
1	100	100	30	25	25	100	100	100	100	100	15
2	100	100	100	100	100	100	100	100	100	100	100
3	100	30	5	45	5	50	50	30	60	20	5
4	100	100	30	65	70	50	60	50	70	100	50
5	100	70	20	25	15	100	100	100	85	100	100
6	80	40	15	20	60	50	60	60	80	50	100
7	100	70	80	50	40	100	100	60	30	70	100

Recordings of Soreness in the Left Leg for the Test Group 120 hours Post-run

	Gluteals		Quads			Hamstrings			Calf		
Subject	Medial	Lateral	Medial	Lateral	Proximal	Medial	Lateral	Proximal	Medial	Lateral	A. Tib
1	1	1	3	3	3	1	1	1	1	1	1
2	1	1	1	1	1	1	1	1	1.5	1.5	1
3	1	1	1	1	3	1	1	1	1	1	1
4	1	1	1	1	1	1	1	1	2	1	2
5	1	1	1	1	2	1	1	1	1	1	1
6	1	1	1	1	2	1	1	2.5	1	1	1
7	1	1	1	1	1	1	1	1	1	1	1

Recordings of Soreness in the Right Leg for the Test Group 120 hours Post-run

	Gluteals		Quads			Hamstrings			Calf		
Subject	Medial	Lateral	Medial	Lateral	Proximal	Medial	Lateral	Proximal	Medial	Lateral	A. Tib
1	1	1	3	3	3	1	1	1	1	1	1
2	1	1	1	1	1	1	1	1	1.5	1.5	1
3	1	1	1	1	3	1	1	1	1	1	1
4	1	1	1	1	1	1	1	1	2	1	2
5	1	1	1	1	2	1	1	1	1	1	1
6	1	1	1	1	2	1	1	2.5	1	1	1
7	3.5	3.5	1	1	1	1	1	1	1	1	1

Recordings of Tenderness in the Left Leg for the Test Group 120 hours Post-run

	Gluteals		Quads			Hamstrings			Calf		
Subject	Medial	Lateral	Medial	Lateral	Proximal	Medial	Lateral	Proximal	Medial	Lateral	A. Tib
1	100	100	100	100	100	100	100	100	100	100	100
2	100	100	100	100	100	100	100	100	100	100	100
3	100	100	60	45	50	40	40	5	60	40	30
4	100	100	100	100	100	100	100	100	100	100	100
5	100	100	100	100	100	100	100	100	100	100	100
6	100	100	100	100	100	100	100	100	100	100	100
7	95	80	100	100	100	100	100	100	100	100	100

Recordings of Tenderness in the Right Leg for the Test Group 120 hours Post-run

	Gluteals		Quads			Hamstrings			Calf		
Subject	Medial	Lateral	Medial	Lateral	Proximal	Medial	Lateral	Proximal	Medial	Lateral	A. Tib
1	100	100	100	100	100	100	100	100	100	100	100
2	100	100	100	100	100	100	100	100	100	100	100
3	100	100	45	40	60	40	30	5	60	30	35
4	100	100	100	100	100	100	100	100	100	100	100
5	100	100	100	100	100	100	100	100	100	100	100
6	100	100	100	100	100	100	100	100	100	100	100
7	95	85	100	100	100	100	100	100	100	100	100