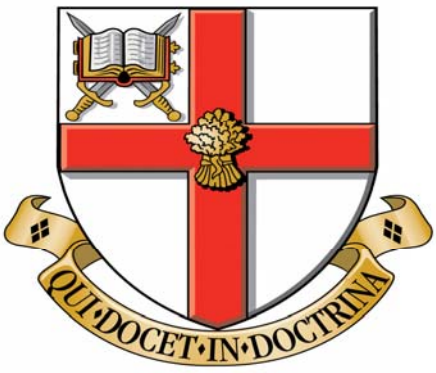


University of Chester

# THE EFFECT OF EXERCISE INDUCED MUSCLE DAMAGE (EIMD) ON OUTDOOR RUNNING PERFORMANCE

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A Research Project submitted in partial fulfilment of the requirements of the University of Chester for the degree of M.Sc Sport Sciences (Strength and Conditioning)

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**4507 words**

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During the completion of this thesis I have endured some rough patches but have always had people supporting me of which I am extremely grateful. I would therefore like to acknowledge these people. First I would like to acknowledge Dr Craig Twist who has been my supervisor throughout this thesis and has always been there when I have had questions or issues. Next I would like to thank the laboratory technicians at the University of Chester, specifically Richard Bott and Helen Marriott for their support within the laboratory and organising all the equipment I required to ensure it was available. Finally I would like to thank my family, girlfriend and friends who have all supported me through the last couple of years and gave me that little push when it was required.

## Abstract

This study examined the effect of exercise-induced muscle damage (EIMD) elicited by a bout of plyometrics on outdoor running performance. Seventeen males (mean ± SD: age 37 ± 8 years, height 180 ± 5.3 cm, body mass 75.4 ± 7.5 kg) were recruited from running and triathlon clubs within Cheshire. They were randomly assigned to the treatment (n = 8) or control group (n = 9) with the study adopting a randomized, controlled, repeated measures design. Before and 48 hours after treatment the subjects underwent testing on EIMD markers (muscle thigh circumference, muscle function and muscle soreness) and ran a 5 km outdoor time-trial. During the time-trial speed, heart rate and RPE were measured at each kilometre along with blood lactate at the finish. On completion of the 5 km run the treatment group completed a bout of 10 x 10 drop jumps from a 35 cm bench to elicit EIMD. Multiple independent *t*-tests along with multiple two-way and three-way ANOVAs were used for analysis. Muscle soreness significantly increased within the treatment group after EIMD ($p<0.05$), however no significant change occurred in muscle circumference and force production ($p>0.05$). During the time-trial RPE, heart rate, average running speed and blood lactate did not significantly change in the treatment group ($p>0.05$). Although average running speed did not significantly change, a decrease was observed with a significantly slower time-trial completion times between the two groups ($p<0.05$). In conclusion, EIMD significantly affects endurance performance among well-trained athletes through an altered perception of effort.

**Declaration**

No portion of the work referred to in this Research Project has been submitted in support of an application for another degree or qualification of this, or any other University or institute of learning.

The project was supervised by a member of academic staff, but is essentially the work of the author.



Signed ……..

Date ……

***N.B. You MUST include this statement and you MUST sign it!***

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## Introduction

The completion of unaccustomed eccentric muscular contractions, identified by a simultaneous lengthening and contraction of the muscle, has been identified as the primary cause of exercise-induced muscle damage (EIMD; Falvo & Bloomer, 2006; Tee, Bosch & Lambert, 2007). Eccentric muscular contractions cause EIMD through mechanical and metabolic mechanisms, with mechanical identified as the primary cause (Byrne, Twist & Eston, 2004) associated with a reduced fibre recruitment and high force production (Enoka, 1996; Falvo & Bloomer, 2006). The ability of the muscle to produce high force during eccentric contractions is attributable to the mechanical detachment of cross bridges in comparison to concentric actions where adenosine tri-phosphate (ATP) is utilised (Byrne et al., 2004; Eston, Byrne & Twist, 2003). This detachment of cross bridges causes disruption to the sarcomeres resulting in the muscle adopting a shorter length to enable a similar level of force to be produced (Byrne et al., 2004) coupled with a detrimental effect on the excitation-coupling system (Eston et al., 2003). The severity of EIMD is significantly influenced by the intensity and volume of the physical activity that athletes undertake (Clarkson & Hubal, 2002) along with whether the athlete is unaccustomed to the exercise bout (Tee et al., 2007). If the athlete has previous experience of eccentric training the severity of EIMD is reduced due to a protective mechanism referred to as ‘repeated bout effect’ (Eston et al., 2003; Falvo & Bloomer, 2006). Once an athlete has completed a bout of eccentric training the body adapts to prevent such high levels of EIMD on completion of subsequent bouts. A range of mechanisms have been proposed to underlie this theory including mechanical, cellular and neural however these mechanisms are not well understood (McHugh, 2003).

It is well documented that numerous symptoms are associated with EIMD, including delayed onset muscle soreness (DOMS), reduced force production, increase in limb circumference, increase creatine kinase (CK) levels, stiffness, reduced range of motion, damage to the structural aspects of the muscle and reduced strength (Byrne et al., 2004; Chen, Nosaka, Lin, Chen & Wu, 2009; Eston et al., 2003; Tee, Bosch & Lambert, 2007). The measuring of force production to assess the functional capability of the athlete is of greatest importance and has the greatest transfer to the applied setting. Previous research has identified the time course for peak muscle damage and recovery is individual and differs among markers, with DOMS peaking between 24-48 hours, swelling at 48 hours and force production taking up to 7 days to recover (Byrne et al., 2004; Falvo & Bloomer, 2006; Komi & Viitasalo, 1977). A range of direct and indirect measures including; muscle biopsy and Likert scales have been utilised in research to monitor the symptoms of EIMD (Warren, Lowe & Armstrong, 1999).

In recent years endurance athletes have begun utilising plyometrics as a training method to improve their performance. It is believed that plyometric exercise elicits improvements in power production (Spurrs, Murphy & Watsford, 2003) a physiological characteristic that might limit endurance performance (Noakes, 1998). Running economy appears to be the physiological characteristic with the greatest plasticity to the exposure of plyometrics resulting in the significant improvements in running performance (Markovic & Mikulic, 2010). An enhanced running economy has been associated with improvements in race times and illustrates the applied benefits of endurance athletes incorporating plyometrics into their training regime (Paavolainen, Hakkinen, Hamalainen, Nummela & Rusko, 1999; Spurrs, Murphy & Watsford, 2003). However the nature of plyometrics means that they often elicit symptoms of EIMD in the days after their application

(Burt & Twist, 2011; Jamurtas et al., 2000; Marcora & Bosio, 2007). Therefore it is imperative athletes and coaches are aware of the impact such training has on subsequent performance as plyometrics performed at a high intensity result in elevated neuromuscular and central nervous system stress that might impair endurance performance (Burt & Twist, 2011).

The ability to measure EIMD and understand its impact on endurance performance *per se* is crucial. Studies have researched the effects of EIMD on endurance performance *per se*. Previous research has conclusively found EIMD to significantly reduce the distance covered during time-trials in running using moderately trained participants (Marcora & Bosio, 2007) and cycling in recreational participants (Burt & Twist, 2011; Twist & Eston, 2009). Findings regarding the effect of EIMD on varying physiological measures during endurance performance are conflicting among studies. Burt & Twist (2011) reported a significant decrease in heart rate and minute ventilation ($V_E$), however these measures remained unchanged during time-trials in Marcora & Bosio (2007) and Twist & Eston (2009) studies. The effect of EIMD on blood lactate is also not consistent among research with two studies in cycling reporting a decrease at 48 hours (Burt & Twist, 2007; Twist & Eston, 2009) and no change at 48 hours during a running protocol (Marcora & Bosio, 2007). Current research has reported significant changes in rate of perceived exertion (RPE) during time-trials proposing EIMD alters the participant's perception of effort (Marcora & Bosio, 2007; Twist & Eston, 2009). A possible explanation for this altered perception could be as a result of the elevated muscle soreness that occurs after the completion of eccentric exercise (Proske, Weerakkody, Percival, Morgan, Gregory & Canny, 2003). A more recent study by Burt & Twist (2011) found that a bout of eccentric exercise eliciting EIMD did not alter the participant's perception responses. These

differences could have occurred due to the differing time-trial protocols with Burt & Twist (2011) using 15 minute duration, Twist & Eston (2009) who used 5 minute duration and Marcora & Bosio (2007) who used a 30 minute time-trial. These contrasting protocols will have significantly affected the pacing strategy adopted and subsequently the perception of effort, with shorter time-trials requiring a greater power output in comparison to the maintenance of a slightly reduced power output over longer time-trials (Van Ingen Schenau, De Koning & De Groot, 1992).

However despite these findings providing a good starting point when looking into the effects of EIMD on endurance performance, all were based in a controlled laboratory setting. The surface and gradient have been identified as two variables that can significantly influence the pacing strategies adopted and the subsequent performance (Faulkner et al, 2008; Howatson & Milak, 2009). Therefore conducting research outdoors will allow these variables to be present, potentially providing innovative findings that coaches and athletes can apply to their training to improve their endurance performance. This is important as athlete's train and compete outdoors, not in a laboratory where the environment is stable.

There is no current research assessing the effect of EIMD on endurance performance using real-world performance scenarios. Furthermore the effects of EIMD on trained athletes is less well understood due to the reluctance of this group to participate in such research studies for fear of impairing performance (Falvo & Bloomer, 2006). Therefore this study will aim to identify the effect of EIMD on outdoor running performance in well-trained athletes. It is hypothesized that EIMD will impair 5 km running performance, specifically via an altered perception of effort with a reduction in running speed and no change in RPE.

## Method

### Participants

Seventeen (mean ± SD: age 37 ± 8 years, height 180 ± 5.3 cm, body mass 75.4 ± 7.5 kg) males classified as ‘well-trained’ were recruited to participate in the study from the running and triathlon clubs within Cheshire. In order to meet the ‘well-trained’ criteria, each participant was required to have run at least 30 minutes, three times a week for the previous 6 months. Females were excluded from participation within the study to reduce the possibility of sex-related variables influencing the findings (Eston et al., 2003).

The participants were provided with a participant information sheet (appendix B) and instructed to complete an informed consent form (appendix A) and health questionnaire (appendix C) prior to participating.

The study was approved by the Faculty of Applied Sciences Research Ethics Committee at the University of Chester.

The sample size was calculated using GPower3.1 (v.21, SPSS Inc., Chicago, IL, USA) based on an effect size statistic of 0.62 derived from the results from the study by Marcora & Bosio (2007), and using an error probability = 0.05 and, power = 0.8.

## Design

The study employed a randomized, controlled, repeated measures design (Figure.1). Each participant was randomly allocated to the control (no damage) or treatment (muscle damage) group. Running performance was the dependent variable with muscle damage the independent variable. Each participant was required to attend the University of Chester on three occasions. On the first visit the participants completed an incremental test on a treadmill to identify $VO_2$peak along with measurements of stature and body mass. Participants also completed a familiarization trial on the isokinetic dynamometer to reduce the potential of a learning effect occurring during subsequent trials (Burt & Twist, 2011). The participants then returned between 24 hours to 2 weeks later and completed the first trial. On arrival the three muscle damage markers; muscle function, delayed-onset muscle soreness (DOMS) and muscle thigh circumference were measured prior to the warm up. A 10 minute warm up preceded the outdoor 5 km time-trial run. On completion of the time-trial, the muscle damage protocol was completed by those allocated to the treatment group. Forty-eight hours later, the participants returned for the third and final visit. During this visit the same protocol as used in the second visit was repeated without the muscle damaging protocol. The decision to schedule the third visit 48 hours after the muscle damage protocol was based on previous research identifying that muscle damage markers peak between 24-72 hours (Tee et al., 2007). Participants were asked to refrain from participating in strenuous exercise 24 hours prior to their first visit and refrain from any form of exercise between their second and third visit. They were also asked to avoid using anti-inflammatory or analgesic agents.

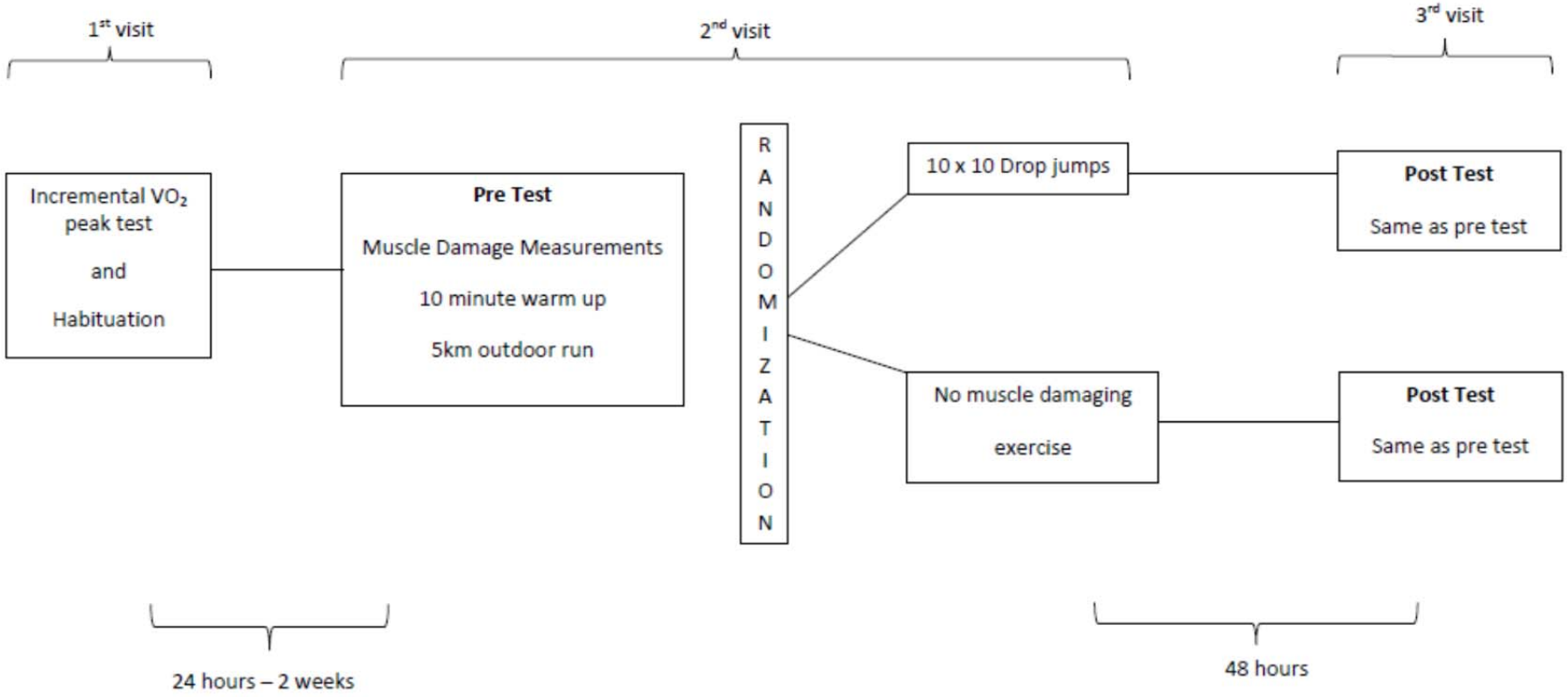



**Figure 1:** A schematic of the experimental design

## Procedures

### *Assessment of $VO_{2peak}$*

The participant's stature and body mass was measured with them in their underwear using a wall mounted stadiometer (Harpenden, Wall mounted, Holtain, Crymych, Dyfed, UK) and digital scales (Tanita, BWB-800, Tanita corporation, Tokyo, Japan) respectively. The participants then completed an incremental $VO_2$peak test on a motor-driven treadmill (Woodway, PPS 55sport-I, GmbH, Germany), with the incline set at 1%. Each participant was instructed to complete a 10 minute warm up progressively increasing the intensity prior to commencing the test. The test began at 12 $km \cdot h^{-1}$ increasing by 1 $km \cdot h^{-1}$ at 3 minute increments until the participant reached exhaustion. Throughout the test expired air was collected using an online metabolic system (Viasys, Oxycon Pro, Viasys Healthcare, Hoechberg, Germany), which was be calibrated prior to each test. At the end of each 3 minute stage, heart rate (Polar FS1, Polar Electro, Oy, Finland), blood lactate (Lactate Pro, Arkray, Kyoto, Japan) and rate of perceived exertion (Borg, 1998) was recorded.

### *Outdoor 5 km time-trial*

Each participant was instructed to complete a 10 minute standardized warm up comprising jogging and mobility exercises prior to commencing the time-trial. On completion of the warm up, a 5 Hz global positioning unit (GPS; SPI-Pro, GPSports, Canberra, Australia) was attached to the participant along with a heart rate monitor and an RPE chart with a pen to their wrist (Figure. 2). The GPS was fitted into a pocket on the back of a vest and used to record running speed and distance. The GPS has been shown to possess good reliability for these measures.

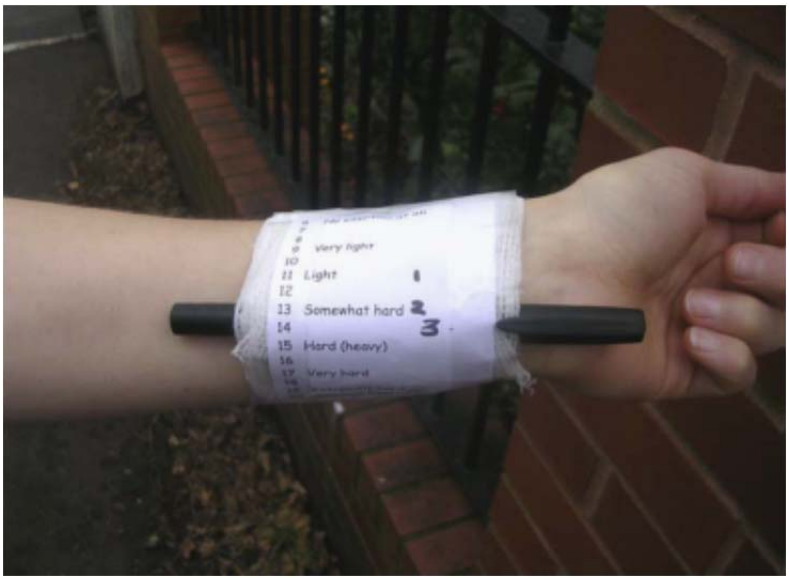



**Figure 2:** An example of the RPE chart used to record the athletes RPE at each km as used by Faulkner et al., (2008).

The run followed an out and back course, with the participants running for 2.5 km before turning around and running 2.5 km back to the start on an undulating concrete surface. At 1 km checkpoints the participants were required to mark the chart with their current RPE (Faulkner et al, 2008), which together with the data generated from the GPS device was used to measure running performance. The participants were encouraged to complete the 5 km time-trial as fast as possible. On completion of the time-trial, a blood sample was taken from the fingertip and analysed for blood lactate concentration (Lactate Pro, Arkray, Japan).

*Visit 3*

*Experimental treatment*

The muscle damaging protocol involved the participant performing 10 sets of 10 drop jumps from a 35 cm box, with a 1 minute rest period between each set. An infrared timing system (Optojump, Microgate S.r.1., Bolzano, Italy) was used to assess a maximal drop jump prior to each participant commencing the protocol. The participant was then instructed to aim to achieve this height throughout the protocol. Each jump was performed with the participant dropping from the box with hands on their hips, landing on the floor with both feet, squatting to approximately 90° angle at the knee then jumping as high as possible. Evidence of muscle damage has been achieved through similar protocols in previous research (Burt & Twist, 2011; Marcora & Bosio, 2007).

*Muscular force production*

An isokinetic dynamometer (Biodex, Multi-joint System 3, Biodex Medical, New York, USA) was used to assess muscular force production of the participant's dominant leg. Prior familiarization consisted of setting up the correct position allowing the participants to get used to the secure nature of the dynamometer whilst completing two sets of five knee extensions and flexion's. The participants were seated in an upright position with a 90° angle at the knee and hip with the ankles securely fastened to the dynamometer arm. The participants were instructed to apply maximal force to the ankle pad in both the extension and flexion phase. Each participant completed 3 submaximal warm-up efforts at 50% of maximum prior to 5 maximal efforts at $60° \cdot s^{-1}$ of which the highest value was be recorded.

*Delayed onset muscle soreness (DOMS)*

Each participant was instructed to rate their perceived muscle soreness on the seven-point likert scale (Vickers, 2001). The scale ranges from 0-6 with each rating corresponding to a descriptive phrase. Participants were required to rate muscle soreness in the quadriceps, hamstrings and gastrocnemius, with these muscles commonly perceived as sore post eccentric exercise (Howatson & Milak, 2009).

0 – A complete absence of soreness

1 – A light pain felt only when touched/a vague ache

2 – A moderate pain felt only when touched/a slight persistent pain

3 – A light pain when walking up and down stairs

4 – A light pain when walking on a flat surface/painful

5 – A moderate pain, stiffness, or weakness when walking/very painful

6 – A severe pain that limits my ability to move

*Muscle circumference*

Muscle circumference was measured using a tape measure at mid-thigh, defined as the midpoint between the superior ridge of the patella and the crease of the groin. To ensure the mid-point was consistent throughout the trials, it was indicated using a marker pen. Three measurements were recorded per participant, with the average measurement used for statistical analysis.

## Statistical analysis

All data are presented as mean ± standard deviation (SD) and were analysed using SPSS (v.20, IBM SPSS Statistics, Chicago, IL, USA) with a p-level of 0.05. Prior to conducting further statistical tests the data was checked for normal distribution and equal variances using a Shapiro wilk test and levene's test respectively. Multiple independent *t*-tests were then performed to assess any existing differences within baseline measures between the experimental and control group. To assess changes in performance, muscle damage, physiological and perceptual measures, multiple two-way (group [2] x test [2]) ANOVAs with repeated measures were conducted. Multiple three-way (group [2] x test [2] x time [2]) ANOVAs with repeated measures were carried out to analyse changes in speed, time of completion and RPE. If changes were present on completion of the ANOVAs, *t*-tests were used with a Bonferoni adjustment to identify where the differences occurred.

## Results

Independent *t*-tests demonstrate that the allocation of participants to the treatment and control groups was successful in forming two groups of similar ability.

Table 1. Treatment and control subject's descriptive characteristics

| | Treatment (n=8) | Control (n=9) |
|---|---|---|
| Age (y) | 35 ± 8 | 39 ± 7 |
| Stature (cm) | 181.3 ± 4.1 | 178.8 ± 6.1 |
| Body Mass (kg) | 76.4 ± 9.7 | 74.5 ± 5.3 |
| $VO_2$ Peak ($ml \cdot kg^{-1} \cdot min^{-1}$) | 59.5 ± 6.5 | 58.1 ± 2.8 |

Values are presented as mean ± SD.

*Muscle damage markers*

Interaction effects of group x time on muscle soreness revealed increases at 48 hours in the hamstring (F=8.726, *p*=0.01) and gastrocnemius (F=4.764, *p*=0.045) for the treatment group after the damaging protocol. Soreness in the quadriceps was not different over time between the groups (F=0.706, *p*=0.414). There was no difference in muscle circumference over time between the groups (F=0.506, *p*=0.488) suggesting minimal muscle swelling occurred. There was no significant interaction of group x time for flexion (F=2.148, *p*=0.163) and extension (F=2.592, *p*=0.128) at 48 hours. However the treatment groups force production decreased from (99.0 ± 9.1to 94.2 ± 13.9N·m) for flexion and (184.6 ± 17.3 to 176.9 ± 27.6N·m) for extension between pre and post, whilst the control groups force production increased (Table 2).

Table 2. Effect of experimental treatment on muscle damage markers

| Variable | Group | Pre | Post | P |
|---|---|---|---|---|
| DOMS Quad | EIMD | 0.38 ± 0.744 | 2.00 ± 1.690 | 0.414 |
| | Control | 0.33 ± 1.000 | 1.22 ± 1.922 | |
| DOMS Ham | EIMD | 0.88 ± 0.991 | 3.00 ± 1.690 | 0.01 |
| | Control | 0 | 0 | |
| DOMS Gastrocnemius | EIMD | 0.50 ± 1.069 | 2.38 ± 2.264 | 0.045 |
| | Control | 0.89 ± 1.833 | 1.11 ± 2.421 | |
| Muscle Circumference (cm) | EIMD | 53.31 ± 3.515 | 52.69 ± 4.543 | 0.488 |
| | Control | 53.39 ± 3.140 | 53.22 ± 3.032 | |
| Force Production Extension (N·m) | EIMD | 184.6 ± 17.3 | 176.9 ± 27.6 | 0.128 |
| | Control | 194.3 ± 28.0 | 202.0 ± 30.4 | |
| Force Production Flexion (N·m) | EIMD | 99.0 ± 9.1 | 94.2 ± 13.9 | 0.163 |
| | Control | 104.2 ± 18.1 | 104.7 ± 20.6 | |

Values are presented as mean ± SD. P-values refer to the trial x group interaction of two-way ANOVA with repeated measures. DOMS=delayed onset muscle soreness, Quad=quadriceps, Ham=hamstring.

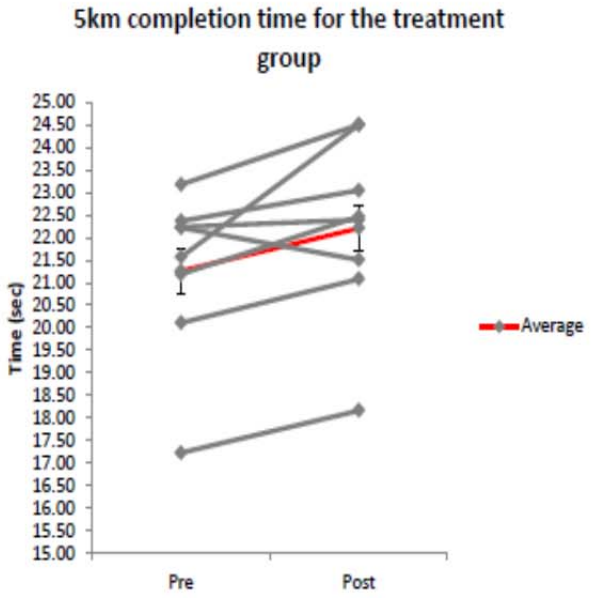
*Physiological responses and performance measure*

There was no significant interaction of group x time for average heart rate (F=0.559, *p*=0.466), average RPE (F=0.175, *p*=0.682), average running speed (F=1.469, *p*=0.244) and post time-trial blood lactate concentration (F=3.275, *p*=0.09). Although no significant interaction occurred (F=1.469, *p*=0.244), average running speed decreased non-significantly by half a kilometre from 13.1 ± 1.7 to 12.5 ± 2.7km·h$^{-1}$ for the treatment group between pre and post. In comparison, the control group ran marginally quicker 13.5 ± 0.9 to 13.7 ± 0.7km·h$^{-1}$ (Table 3, Figure 2), however it was not significant. Interaction effects of group x time on 5 km time-trial completion time revealed increases at 48 hours (F=8.975, *p*=0.009, figure1) for the treatment group after the damaging protocol.

Table 3. Changes in physiological variables after EIMD

| Variable | Group | Pre Test | Post Test | P |
|---|---|---|---|---|
| Average Heart Rate (bpm) | EIMD | 168.88 ± 8.008 | 170.50 ± 8.718 | 0.466 |
| | Control | 169.78 ± 12.647 | 174.44 ± 11.631 | |
| Average RPE | EIMD | 16.38 ± 1.061 | 16.13 ± 1.458 | 0.682 |
| | Control | 15.67 ± 1.225 | 15.22 ± 1.093 | |
| Average Running Speed (km·h$^{-1}$) | EIMD | 13.050 ± 1.7188 | 12.475 ± 2.7364 | 0.244 |
| | Control | 13.478 ± 0.9458 | 13.711 ± 0.6864 | |
| Completion Blood Lactate (mmol·l$^{-1}$) | EIMD | 9.43 ± 1.528 | 9.650 ± 1.7138 | 0.09 |
| | Control | 8.61 ± 2.079 | 7.411 ± 1.8401 | |
| 5 km Completion Time (min) | EIMD | 21.3 ± 1.9 | 22.2 ± 2.1 | 0.009 |
| | Control | 21.8 ± 1.5 | 21.6 ± 1.1 | |

Values are presented as mean ± SD. P-values refer to the trial x group interaction of 2-way ANOVA with repeated measures. RPE=rate of perceived exertion.



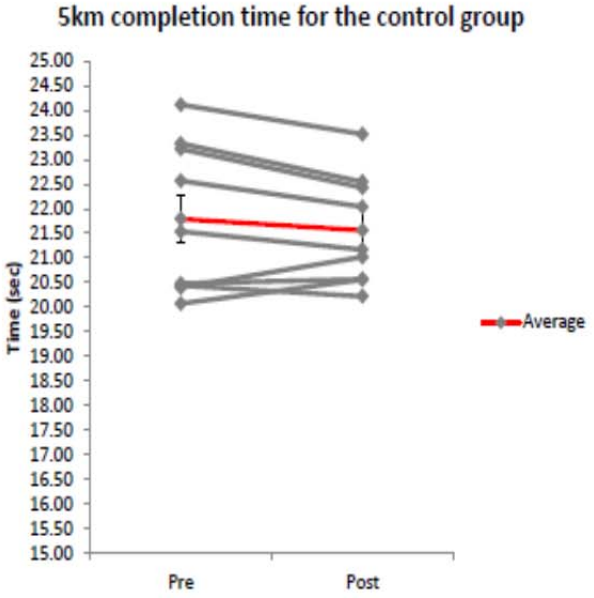
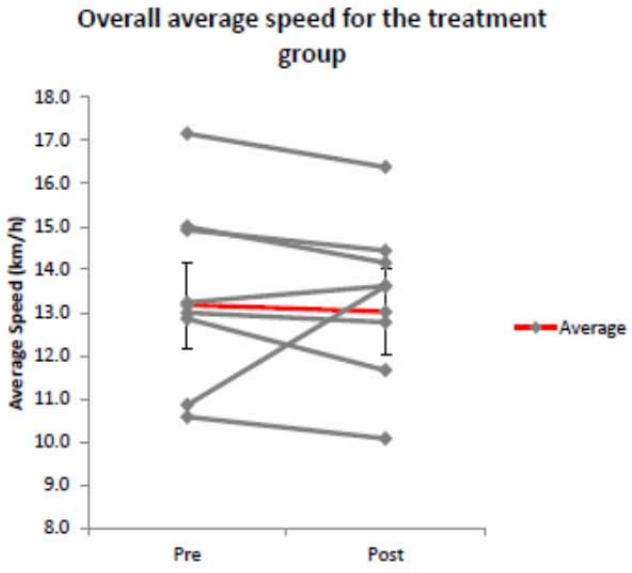




Figure 3: Individual changes in time trial completion time.



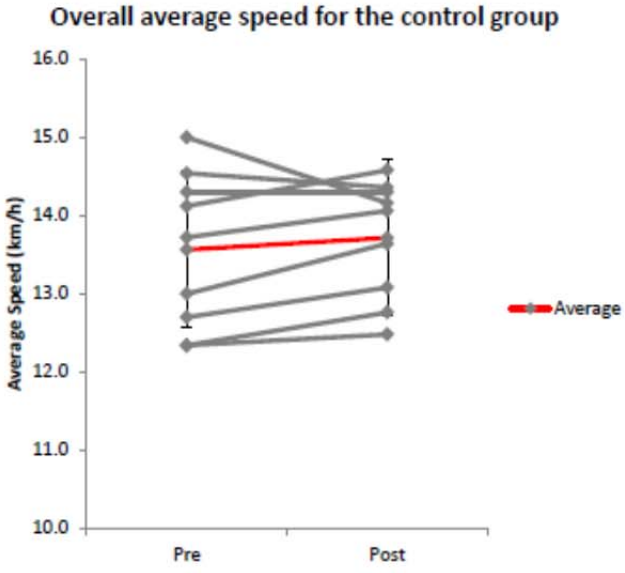




Figure 4: Individual changes in overall average running speed.

Analysis of heart rate and RPE for each kilometre of the time-trial did not reveal an interaction effect of group x time x distance (F=1.364, *p*=0.27 & F=0.668, *p*=0.617 respectively). Interaction effects of group x time x distance revealed a significant interaction between the treatment and control group at each kilometre (F=2.807, *p*=0.003).

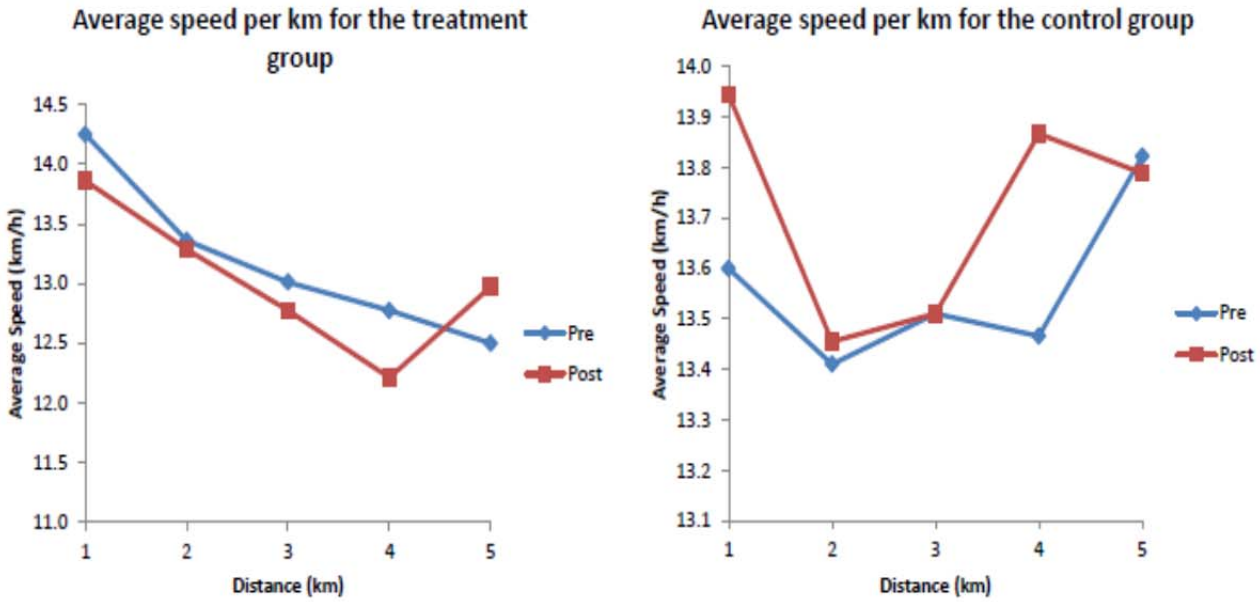



Figure 5: Average running speed at each km of the time trial.

## Discussion

*Speed*

The key finding of this study was the treatment group, who completed a bout of plyometrics to elicit muscle damage, ran the 5 km at a lower speed as hypothesized resulting in a significantly slower completion time equating to a 4% change in comparison to those who did not perform plyometrics. These findings are in agreement with Marcora & Bosio (2007) and Burt & Twist (2011) who both found that participants with EIMD completed a shorter distance during a specific time period in running with moderately trained individuals and cycling with recreational individuals respectively. As this study was conducted outside, the

participants encountered differing surfaces and gradients that could have led to contrasting findings compared to the previous research that has been conducted within a laboratory however this was not the case and suggests that the surface and gradient had no significant effect on running speed. These findings illustrates that participants who are well-trained still experience impaired endurance performance outdoors after a bout of eccentric exercise eliciting EIMD. Therefore careful consideration should occur when programming exercises such as plyometrics into an athlete's training programme as their performance will be affected for at least 48 hours.

*RPE*

Although the participants ran at a reduced speed during the time-trial their perception of effort remained unchanged, agreeing with the findings of Burt & Twist (2011), Marcora & Bosio (2007) and Twist & Eston (2009). This means that the participants perceived their effort to be of a similar level for a reduced intensity illustrating that EIMD altered their perception responses. This supports the hypothesis for the study, and illustrates that these findings are consistent with previous research using varying protocols with time-trial distances varying from 5 to 30 minutes. When performing shorter time-trials a greater power output is typically produced resulting in a higher RPE, whereas when performing a time-trial over a more prolonged period of time the power output will be slightly lower resulting in a reduced RPE to ensure they can complete the distance (Van Ingen Schenau et al, 1992). The experience of the participants within this study could have affected the findings as those with greater experience will likely have completed more time-trials and have a better understanding of their body's ability

and the optimum pacing strategy to adopt (Abbiss & Laursen, 2008), however this does not seem to be the case.

*Heart rate*

Analogous to the findings of Marcora & Bosio (2007) and Twist & Eston (2009) EIMD had no significant effect on heart rate, which is in contrast to Burt & Twist (2011) who found a significant decrease in heart rate under EIMD. The vast majority of research including the findings from this study, suggest that cardiorespiratory responses are not a primary cause of impaired endurance performance in the presence of EIMD.

*Muscle Damage Markers*

Elevated levels of muscle soreness were found among those who completed the bout of plyometrics; however no significant change occurred in both force production and muscle circumference. This illustrates that although the muscle damaging protocol elicited muscle soreness, the functional capability of the athletes was not affected. These findings are in contrast to the vast majority of research who have found a significant decrease in muscular force production (Burt & Twist, 2011; Chen, Nosaka & Tu, 2007; Chen et al, 2009; Marcora & Bosio, 2007) when EIMD is present, with the protocol used to elicit EIMD identical to that used by Marcora & Bosio (2007) and Burt & Twist (2011). A possible explanation for the contrast in findings could be attributed to the differing standards of participants with well-trained runners taking part in this study in comparison to moderately trained participants used by Marcora & Bosio (2007) and recreational participants used by Burt &Twist (2011). A possible mechanism responsible for these differences in muscular force production is the repeated bout affect; with McHugh (2003) suggesting those athletes with greater training experience are less

susceptible to EIMD in comparison to their counterparts due to this mechanism. The repeated bout effect refers to the prior exposure of eccentric loading whereby the muscle undergoes structural damage; specifically to the sarcomere length resulting in a shorter length adopted preventing such high levels of damage on completion of future bouts of exercise (Eston et al, 2003; Falvo & Bloomer, 2006; Tee et al, 2007). However the onset of muscle soreness still occurs despite this structural change (Tee et al, 2007) as observed during this study. Previous research has questioned the use of muscle soreness as a primary measure to identify the extent of muscle damage due to a delay in the onset of muscle soreness that is preceded by function impairment and followed by greater damage when the soreness has subsided (Byrne et al, 2004). This explains the common agreement within research that muscular force production is the optimal muscle damage marker (Warren et al, 2009) and has the greatest relation to sporting performance. Due to a non-significant difference in force production within this study a different mechanism must be responsible for the decline in running speed and 5 km completion time.

This decrease in endurance performance could be attributed to the altered perception of effort through the ‘central governor model’. This mechanism protects the athlete by signalling the body to terminate the exercise bout in order to prevent severe damage occurring and homeostasis failure (Noakes, 2007). The model suggests that the brain controls the intensity, at which the exercise is undertaken, reducing the neural drive to the muscles. This may have been the cause for the reduced speed during the second time trial among the treatment group as they aimed to complete the time trial as fast as possible identified by a similar RPE however, the neural drive to the muscles may have been reduced by the central nervous system to protect the participants from further damage. A recent study

has shown that over shorter distance time-trials fatigue is more peripherally based compared to longer time-trials where central fatigue is of greater dominance in cycling (Thomas, Goodall, Stone, Howatson, Gibson & Ansley, 2014). The shortest time-trial (4 km) was of a similar distance to that used within this study, however due to the significant differences in locomotion speed between cycling and running the completion times are significantly different, with the 20km completion time closer to the times observed within this study. The findings of Thomas et al. (2014) suggest that the fatigue experienced by these well-trained runners could be attributed to central more so than peripheral linking to the 'central governor model'. Although this study was conducted in cycling and a non-EIMD state, the findings could help provide some insights into which method of fatigue is of dominance during runners after a bout of muscle damaging exercise. A similar mechanism has been proposed previously by Marcora & Bosio (2007) referring to the requirement of an elevated central motor command to enable participants with EIMD and subsequently weaker muscles to maintain similar running speeds. The intensity at which participants are able to maintain may also be effected by the inflammatory response that impacts the brain, in particular cytokines such as interleukin (IL)-1 causing central fatigue. The presence of IL-1 in the cortex and cerebellum has been shown to impair endurance performance in mice under EIMD (Carmichael et al, 2005) and could explain the observed impairment in endurance performance, specifically among male runners during a time-trial (Marcora & Bosio, 2007).

The ambient conditions were a unique variable that could have affected the results of the study due to its uncontrollable nature although these helped make the study novel. To try keep the ambient conditions as similar as possible for each participant the testing occurred within a 3 month period. Another factor that could

have implications on the result is the wide age range of the participants, however they all met the selection criteria, primarily well-trained and had similar $VO_{2peaks}$. The diet of the participants around the testing could have affected the results too, with caffeine consumption (Abu-Kasim & Chen, 2013) and hydration levels (Murray, 2013) two aspects that could significantly alter performance.

Future research could attempt to analyse the effect of EIMD on endurance performance at varying time points, possibly 24, 48 and 72 hours providing in depth information regarding the recovery over time. Future research could also attempt to assess how EIMD affects endurance performance among females and any differences that exist between genders.

This is the first study to assess the effect of EIMD on outdoor endurance performance, in particular running. The findings illustrate that EIMD significantly effects endurance performance among well-trained athletes primarily through an altered perception of effort, supporting previous research that has been conducted within a controlled laboratory using recreational participants. Coaches and athletes should be aware of these findings regarding the effect programming plyometric type activity will have on performance in subsequent days even if their athletes are well-trained.

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## Appendix A

### INFORMED CONSENT FORM

**Title of Project:** The effect of exercise-induced muscle damage (EIMD) on outdoor running performance

**Name of Researcher:** Oliver Graham

Please tick the box if you agree with the statement:

I confirm that I have read and understood the participant information sheet for the above-named study, and have had the opportunity to ask the lead researcher any questions. ☐

I understand that my participation is voluntary, and that I am free to withdraw from participating in the study at any time, without giving any reason and without my rights being affected. ☐

☐

I agree to take part in the above study. ☐

---

Name of Participant Date Signature

N/A

---

Name of Person taking consent Date Signature

(if different from researcher)

Oliver Graham

---

Name of Researcher Date Signature

(*1 for participant; 1 for researcher*)

## Appendix B

# Participant Information Sheet

**Title of the study:** The effect of exercise-induced muscle damage (EIMD) on outdoor running performance

Dear participant,

You are being invited to participate in a research study. Prior to agreeing to participate, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Please feel free to ask me if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part.

Thank you for reading this.

**What is the purpose of the study?**

The purpose of this study is to assess the effect EIMD has on outdoor running performance, in particular 5km. The results from this applied study will help coaches and athletes to understand the effect a high intensity training session that causes EIMD has on the ability to train in subsequent days.

**Why have I been chosen?**

You have been selected to participate in this study as you meet the criteria required. The participants must be of male sex and be 'run trained' whereby they have been running 3 times a week for the past 6 months to a year.

**Do I have to take part?**

It is up to you to decide whether or not to take part. If you decide to take part you will be given this information sheet to keep and be asked to sign a consent form. If you decide to take part you are still free to withdraw at any time and without giving a reason. A decision to withdraw at any time, or a decision not to take part, will not affect the standard of care you receive in any way.

**What will happen to me if I take part?**

The study will require you to visit the University of Chester 3 times. On your first visit you will be required to complete a VO2max test on a treadmill in the laboratory and a habituation of the protocol used to measure muscle damage. Within 2 weeks you will be required to complete your second visit, which will require you to have muscle damage measurements taken and complete a 5km run outdoors along the cycle path towards North Wales. If you are selected to be part of the experimental group, after the 5km you will be required to complete a bout of plyometrics to cause muscle damage. Then 48 hours later you will be required to complete the same process as the second visit without the plyometrics.

**What are the possible disadvantages and risks of taking part?**

This study will require you to push yourself to exhaustion, which will be uncomfortable. You will also be required to give a blood sample for blood lactate analysis during your second and third visits.

**What are the possible benefits of taking part?**

The benefits of participating in this study are that you will be able to find out your VO2max, which you may use for future training programmes to improve your performance along with being part of a novel study.

**What if something goes wrong?**

If you wish to complain or have any concerns about any aspect of the way you have been approached or treated during the course of this study, please contact Professor Sarah Andrew, Dean of the Faculty of Applied and Health Sciences, University of Chester, Parkgate Road, Chester, CH1 4BJ, 01244 513055.

If you are harmed by taking part in this research project, there are no special compensation arrangements. If you are harmed due to someone's negligence (but not otherwise), then you may have grounds for legal action, but you may have to pay for this.

**Will my taking part in the study be kept confidential?**

All information which is collected about you during the course of the research will be kept strictly confidential so that only the researcher carrying out the research will have access to such information. All data will be coded to ensure your remain anonymous.

**What will happen to the results of the research study?**

The results of this project might be published but any data included will in no way be linked to any specific participant.

You are most welcome to request a copy of the results of the project should you wish.

The data collected will be securely stored in such a way that only those mentioned above will be able to gain access to it.

**Who is organising and funding the research?**

The Department of Sport and Exercise Sciences at the University of Chester will be involved in organising and carrying out the study.

**Who may I contact for further information?**

If you have any questions about the project, either now or in the future, please feel free to contact Oliver Graham ( @chester.ac.uk).

**Thank you for your interest in this research.**

**Appendix C**

# DEPARTMENT OF SPORT AND EXERCISE SCIENCES UNIVERSITY OF CHESTER

**PRE-TEST HEALTH QUESTIONNAIRE**

*(Please note that this information will be confidential)*

Name…… DOB……
Age……....

Resting blood pressure (mmHg) ……. /……. Resting heart rate (b.min$^{-1}$)
……

Practical/Project
Title……

Please answer these questions truthfully and completely. The purpose of this questionnaire is to ensure that you are fit and healthy enough to participate in this laboratory practical/research project.

| | Yes | No |
|---|---|---|
| 1. Have you in the past suffered from a serious illness or accident. If Yes, please provide details. | ☐ | ☐ |

……
……
……...

| | Yes | No |
|---|---|---|
| 2. Have you consulted your doctor the last 6 months If Yes, please provide details | ☐ | ☐ |

……
……
……

3. Do you suffer, or have you suffered from:

| | Yes | No |
|---|---|---|
| Asthma | ☐ | ☐ |
| Diabetes | ☐ | ☐ |

| | | |
|---|---|---|
| Bronchitis | ☐ | ☐ |
| Epilepsy | ☐ | ☐ |
| High blood pressure | ☐ | ☐ |

| | Yes | No |
|---|---|---|
| 4. Is there any history of heart disease in your family | ☐ | ☐ |

| | Yes | No |
|---|---|---|
| 5. Are you suffering from any infectious skin diseases, sores, wounds, or blood infections i.e., Hepatitis B, HIV, etc.? If Yes, please provide brief details. | ☐ | ☐ |

……
……
……

| | Yes | No |
|---|---|---|
| 6. Are you currently taking any medication If Yes, please provide details. | ☐ | ☐ |

……
……
……
……

| | Yes | No |
|---|---|---|
| 7. Are you suffering from a disease that inhibits the sweating process | ☐ | ☐ |

| | Yes | No |
|---|---|---|
| 8. Is there anything to your knowledge that may prevent you from participating in the testing that has been outlined to you? | ☐ | ☐ |

If Yes, please provide details.

……
……
……
……

**Your Recent Condition**

| | Yes | No |
|---|---|---|
| • Have you eaten in the last 2 hours? | ☐ | ☐ |

If Yes, please provide details

……
……
……

- Evaluate your diet over the last two days. **Poor** **Average** **Good** **Excellent**

| | **Yes** | **No** |
|---|---|---|
| • Have you consumed alcohol in the last 24hr | ☐ | ☐ |
| | **Yes** | **No** |
| • Have you had any kind of illness or infection in the last 2 weeks | ☐ | ☐ |
| | **Yes** | **No** |
| • Have you exercised in the last 2 days? | ☐ | ☐ |

If Yes, please describe below

……
……
……
……

Persons will not be permitted to take part in any experimental testing if they:-

- have a known history of medical disorders (i.e. hypertension, heart or lung disease)
- have a fever, suffer from fainting or dizzy spells
- are currently unable to train because of a joint or muscle injury
- have had any thermoregulatory disorder
- have gastrointestinal disorder
- have a history of infectious diseases (i.e. HIV or Hepatitis B)
- have, if pertinent to the study, a known history of rectal bleeding, anal fissures, haemorrhoids or any other similar rectal disorder.

**My responses to the above questions are true to the best of my knowledge and I am assured that they will be held in the strictest confidence.**

**Name: (Participant)…….**
**Date:……**

**Signed (Participant): …… ..**

**Name: (Lecturer/technician)…….**
**Date:……**

Signed (Lecturer/technician): ……..

## Appendix D


***Faculty of Applied Sciences***

***Research Ethics Committee***

frec@chester.ac.uk

Oliver Sebastian Graham
Chester

5th July 2013

Dear Oliver,

| | |
|---|---|
| **Study title:** | **The effect of exercise induced muscle damage (EIMD) on outdoor running performance in adult males.** |
| **FREC reference:** | **810/13/OG/SES** |
| **Version number:** | **1** |

Thank you for sending your application to the Faculty of Applied Sciences Research Ethics Committee for review.

I am pleased to confirm ethical approval for the above research, provided that you comply with the conditions set out in the attached document, and adhere to the processes described in your application form and supporting documentation.

The Committee would like to make the following recommendation:-

- Remove Q. 7 from the Pre-test Health Questionnaire
  Please forward an amended copy to frec@chester.ac.uk

The final list of documents reviewed and approved by the Committee is as follows:

| Document | Version | Date |
|---|---|---|
| Application Form | 1 | May 2013 |
| Appendix 1 – List of References | 1 | May 2013 |
| Appendix 2 – C.V. for Lead Researcher | 1 | May 2013 |
| Appendix 3 – Letter of Invitation | 1 | May 2013 |
| Appendix 4 – Participant Information Sheet | 1 | May 2013 |
| Appendix 5 – Participant Consent Form | 1 | May 2013 |
| Appendix 6 – Advertisement Material | 1 | May 2013 |
| Appendix 7 – Risk Assessment Form | 1 | May 2013 |
| Response to FREC request for further information and clarification | | June 2013 |
| Appendix 4 – Participant Information Sheet | 2 | June 2013 |
| Appendix 6 – Advertisement Material | 2 | June 2013 |
| Appendix 7 – Risk Assessment Form | 2 | June 2013 |
| Appendix 8 – Pre-test Health Questionnaire | 1 | June 2013 |

With the Committee's best wishes for the success of this project.

Yours sincerely,

**Dr. Stephen Fallows**

Chair, Faculty Research Ethics Committee

Enclosures: Standard conditions of approval.

Cc. Supervisor/FREC Representative

## Appendix E

| | | T1 | T2 | Trial | | Trial x Group | |
|---|---|---|---|---|---|---|---|
| | | M±SD | M±SD | F | P-Value | F | P-Value |
| **Muscle Circumference** | **T** | 53.31 ± 3.515 | 52.69 ± 4.543 | 1.51 (1,15) | 0.238 | 0.506 (1,15) | 0.488 |
| | **C** | 53.39 ± 3.140 | 53.22 ± 3.032 | | | | |
| **Extension Force Production** | **T** | 184.625 ± 17.3455 | 176.938 ± 27.5940 | <0.05 (1,15) | 0.999 | 2.592 (1,15) | 0.128 |
| | **C** | 194.333 ± 28.0485 | 202.011 ± 30.4127 | | | | |
| **Flexion Force Production** | **T** | 98.950 ± 9.1400 | 94.225 ± 13.9095 | 1.418 (1,15) | 0.252 | 2.148 (1,15) | 0.163 |
| | **C** | 104.244 ± 18.0638 | 104.733 ± 20.6361 | | | | |
| **DOMS Quadricep** | **T** | 0.38 ± 0.744 | 2.00 ± 1.690 | 8.233 (1,15) | 0.012 | 0.706 (1,15) | 0.414 |
| | **C** | 0.33 ± 1.000 | 1.22 ± 1.922 | | | | |
| **DOMS Hamstring** | **T** | 0.88 ± 0.991 | 3.00 ± 1.690 | 8.726 (1,15) | 0.01 | 8.726 (1,15) | 0.01 |
| | **C** | 0 | 0 | | | | |
| **DOMS Calf** | **T** | 0.50 ± 1.069 | 2.38 ± 2.264 | 7.670 (1,15) | 0.014 | 4.764 (1,15) | 0.045 |
| | **C** | 0.89 ± 1.833 | 1.11 ± 2.421 | | | | |
| **Average Heart Rate** | **T** | 168.88 ± 8.008 | 170.50 ± 8.718 | 2.391 (1,15) | 0.143 | 0.559 (1,15) | 0.466 |
| | **C** | 169.78 ± 12.647 | 174.44 ± 11.631 | | | | |
| **Average RPE** | **T** | 16.38 ± 1.061 | 16.13 ± 1.458 | 2.233 (1,15) | 0.156 | 0.175 (1,15) | 0.682 |
| | **C** | 15.67 ± 1.225 | 15.22 ± 1.093 | | | | |

## Appendix F

| | | T1 | T2 | Trial | | Trial x Group | | Trial x Group x Distance | |
|---|---|---|---|---|---|---|---|---|---|
| | | M±SD | M±SD | F | P-Value | F | P-Value | F | P-Value |
| **Heart Rate** | **T** | | | | | 0.612 | | | |
| | **C** | | | 2.266 (1,15) | 0.153 | (1,15) | 0.446 | 1.364 (4,60) | 0.27 |
| **RPE** | **T** | | | | | 0.032 | | | |
| | **C** | | | 0.845 (1,15) | 0.372 | (1,15) | 0.861 | 0.668 (4,60) | 0.617 |
| **Speed** | **T** | | | | | 0.457 | | | |
| | **C** | | | <0.05 (1,15) | 0.989 | (1,15) | 0.509 | 2.807 (4,60) | 0.033 |