

Custom-made compression garments in sport; Do they work for performance and recovery?

Jordon Bolessa
U1405642

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Dr Andy Galbraith
Dr Gary Doyle
Dr Richard Buscombe

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Abstract

The aim of this study was to investigate performance and recovery benefits of wearing custom-made versus 'off-shelf' CG, during and after a 5km running time trial. Eight recreational runners performed three 5km running time trials at self-selected pace, with a week separating trials. Runs were performed wearing running shorts (control), custom-made CG and 'off-shelf' CG, with trials completed in counter-balanced order. Custom-made CG were full-length lower limb design, custom-made to each participant (Kurio Compression, Nottinghamshire, UK). Performance CG were worn during the trial and recovery CG were worn for 8hr after the completion of the trial, with variations in applied pressure distinguishing between garments. 'Off-shelf' CG were fitted according to manufactures guidelines (height and weight). Run time, pre and post blood lactate and gas analysis data (VE , VO_2 , VO_2/kg) were recorded. Biomechanical analysis took place to assess COM displacement, stride length, frequency, cycle time and running velocity. Creatine kinase was taken pre, post and 24hr after the trials. Participants recorded perceived level of DOMS through a VAS, pre, post, 12hr and 24hr after running trials, thus assessing recovery. Run time was quickest wearing custom-made CG ($1378 \pm 144s$) with a significant difference versus 'off-shelf' ($p=.04$, $d=.24$, small effect) but no significant differences versus control ($p=.452$, $.09$, trivial effect). No significant differences ($p>.05$) between the two CG were found in heart rate, blood lactate, VO_2/kg , creatine kinase and biomechanical measures. Custom-made CG improved the perception of recovery best at 12 hours $-19.18 \pm 23.64\%$, with a moderate effect size versus other conditions (vs. control: $d=.62$, vs. 'off-shelf': $d=.64$). No significant differences ($p>.05$) at 24 hours were noted between all conditions, suggesting full recovery was achieved. This data suggests that CG provide some benefit during and after a 5km run, but superiority between custom-made and 'off-shelf' CG remain inconclusive.

Table of Contents

CHAPTER 1 INTRODUCTION	1
1.1 Increasing popularity of running	2
1.2 Sporting stress, muscle damage and how this affects performance	2
1.3 The introduction into recovery modalities and compression garments	3
1.4 Potential benefits of wearing compression garments in sport	4
1.5 Optimizing pressures	5
CHAPTER 2 REVIEW OF LITRATURE	7
2.1 Energy systems and physiology	8
2.2 Running mechanics	9
2.3 Training stress and overtraining syndrome	11
2.4 Introduction into recovery	12
2.5 Compression garments	14
2.5.1 Performance	15
2.5.2 Recovery	17
CHAPTER 3 METHODOLOGY	20
3.1 Study Design	20
3.2 Participants	21
3.3 Procedure	22
3.3.1 Preliminary Testing	22
3.3.2 Visit 1	22
3.3.3 Visit 2&3	24
3.4 Data Analysis	25
CHAPTER 4 RESULTS	25
4.1 Environment	25
4.2 Pressures	26
4.3 Performance	27
4.4 Recovery	33
4.5 Biomechanical Measures	37

CHAPTER 5.0 DISCUSSION	38
5.1 Pressures	38
5.2 Main Findings	39
5.3 Recovery	43
5.4 Limitations and Future Research	45
5.2 Practical Applications	46
CHAPTER 6.0 CONCLUSION	47
REFERENCES	49
APPENDICES	55
Ethics	55
Pre-Screening Questionnaire	57
Information Sheet	60
Physical Activity Readiness Questionnaire (PAR-Q)	62
Photo/Video Consent	63
Visual Analogue Scale	64
Biomechanical Analysis on Tracker	65
Biomechanical Equations	66
Risk Assessment	67
COSHH Risk Assessment	70

Contents for Figures and Tables

Figures

1. 'Off-the-shelf' CG manufacture sizing guidelines	20
2. 5km Run Time (seconds)	27
3. Mean \pm SD of heart rate	28
4. Mean \pm SD of minute ventilation	29
5. Mean \pm SD of maximum oxygen uptake	30
6. Mean \pm SD of minute oxygen circulation per kg of body mass	31
7. Mean \pm SD blood lactate percentage change	32
8. Mean \pm SD of creatine kinase percentage change	33
9. Visual analogue scores	35

Tables

1. Environment	25
2. Garment pressures (mmHg)	26
3. Biomechanical measures	37

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Chapter 1 Introduction

The transition into the 21st century marked the globalisation of sport. Due to improvements in infrastructure and technology, the media was able to provide better exposure of a variety of sports to a larger target audience, thus providing sponsorship, advertising and commercialised opportunities. Westernised countries and international companies saw this as a business opportunity, often investing in their athletes and or competitions to reap any monetary gains. Sparking the transition of sports people turning from amateur to professionals, this increased the number of training sessions and competitions on a daily/weekly basis, and therefore making full recovery increasingly difficult.

The emergence of long-distance running, whether competition involves running as a single mode of physical activity i.e. marathon running or integrated into a much larger endurance event i.e. triathlons, all require prolong use of large muscle groups (Hauswirth and Lehénaff, 2001). Successful long-distance running performances at submaximal intensities have been attributed to the athlete's ability to minimise energy expenditure at that given intensity (Ghosh, 2004). Additionally, individuals' oxygen uptake ($\dot{V}O_2$), oxygen cost and metabolic cost are also key factors to successful sporting performances (Hauswirth and Lehénaff, 2001). Athletes' will often utilize logistical and sequential planning of training programs in order to improve the aforementioned factors (Williams et al., 2017), however running has also become increasingly popular amongst the general population (Hauswirth and Lehénaff, 2001).

1.1 The increasing popularity of running

With government's ethos of generating a fitter population, the emergence of mass participation sporting events has aided the rise in participants meeting physical activity guidelines, increasing numbers from 37% to 48% (Bauman et al., 2009; Stevinson and Hickson, 2014). Parkrun is a nationwide, free, weekly, timed five-kilometre (5km) park run, starting in London in 2004 (<http://www.parkrun.org.uk/>, 30 April 2019, date last accessed). Parkrun is aimed at both regular runners and non-regular runners, with no age limits or specialised clothing and equipment, thus creating an encouraging environment to potentiate health benefits from vigorous exercise (Stevinson and Hickson, 2014).

1.2 Sporting stress, muscle damage and how this affects performance

Five-kilometre timed running trials can often be viewed as exhaustive bouts of exercise (Withee et al., 2017). The action of running consists of repetitive eccentric muscle actions causing the individual to experience oxidative stress and micro traumas to the muscle, potentiating inflammation known as oedema that can last up to 72-hours (Valle et al., 2014). The constant exposure to physical stress can frequently cause athletes to diverge from homeostatic functioning (Kellmann, 2010), exposing them to obstacles such as injury, illness, fatigue, training persistence, decrease in muscle functioning and diminished sporting performance (Cheung et al., 2003; Clarkson and Hubal, 2002; Khan et al., 2016; Withee et al., 2017). Although the overexposure to stress has been shown to decrease subsequent sporting performance (Cheung et al., 2003), the continuously growing body of research into recovery emphasize the importance of stress to elicit fitness and performance adaptations

1.3 The introduction into recovery modalities and compression garments

Experts have indicated that the strategic implementation of recovery modalities between training sessions, and or competitions, is essential when potentiating central, peripheral and neuromuscular adaptations (Hauswirth and Lehénaff, 2001). Contemporary research has invested into inexpensive and less invasive recovery strategies such as compression garments (CG), opposed to more traditionally popular modalities such as ice baths and cryotherapy. CG apply external pressures to the covered body segments, providing compression and stabilization to the underlying muscles (Partsch, 2005). The use of CG originated from the clinical environment, treating and preventing lymphatic and venous diseases, providing additional joint support and reducing inflammation within the body (Barnett, 2006; Kelechi et al., 2012). Clinical literature have reported that using CG elicit faster healing times through an increased venous return, allowing improved removal of metabolites and delivery of oxygen to the surrounding tissues (Araujo et al., 2018; Partsch, 2005). This information influenced sporting professionals to adopt the use of CG during and post competition or training, which are now utilised by all types of athletes in a variety of disciplines and levels (Engel et al., 2016). Leading companies in the CG market have invested large sums of money into product development, with athletes' now wearing compression stockings, sleeves, lower body tights and tops to elicit both performance and recovery benefits.

1.4 Potential benefits of wearing compression garments in sport

Rules and regulations within the majority of sports prevent the implementation of CG during competition. However, running events often permit the use of CG and current research highlights some inconclusive findings of both physiological and biomechanical advantages. It has been suggested that CG created a graduated pressure gradient to the muscles, from proximal to distal end of a limb, thus enhancing end-diastolic and stroke volume, ultimately leading to an increase in oxygen delivery to the working muscles (Broatch et al., 2018; Kraemer et al., 2004). Studies have observed improvements in running economy (Broatch et al., 2018), time to exhaustion (Galbraith et al, 2018, unpublished) and enhanced clearance of metabolites (Kraemer et al., 2004). Conversely, studies have reported no significant changes in most performance measures (Ali et al., 2007; Areces et al., 2015; Dascombe et al., 2011; Duffield and Portus, 2007), indicating that differences may be a result of heterogeneity between studies.

It has been suggested that wearing CG may alter individuals' running gait, however to the researcher's knowledge there have been limited studies investigating into any biomechanical differences. Kerhervé et al., (2017) reported increases in aerial time, leg stiffness, but no differences were highlighted in stride frequency and stride length (Galbraith et al., 2018. Unpublished) or range of motion (ROM) around the ankle joint (Heiss et al., 2018). Electromyography (EMG) data highlighted that major muscles used whilst running produced lower muscle activation when wearing CG compared to without, therefore potentiating performance improvement through increased exercise efficiency and delay of fatigue (Wang et al., 2015). Additionally, CG reduce wasted energy by minimizing oscillation of muscle activation after a heel strike and limb stability during the stance phase (Wang et al., 2015). Further investigation into this area is essential as any positive changes in running technique such as reduced hip flexion, larger knee flexion

during stance phase and greater thigh extension have been shown to improve running economy and ultimately performance (Hauswirth and Lehénaff, 2001).

The bulk of current research have investigated into recovery benefits of wearing CG, with reported reduction in the delayed onset of muscle soreness by 26.7% (Valle et al., 2014). CG have been suggested to provide better mechanical structure for the covered limbs, potentiating therapeutic functioning by decreasing the amount of muscle oscillation experienced during exercise (Geldenhuis et al., 2019; Wang et al., 2015). The graduated pressure gradient reduces space for inflammation, decreasing an individual's pain sensitivity whilst enhancing cytokine dissipation after exercise (Kraemer et al., 2004). However, conflicting findings indicate that CG may not be beneficial above popular sporting garments such as running under shorts or leggings (Beliard et al., 2015; MacRae et al., 2011; Marqués-Jiménez et al., 2015).

1.5 Optimizing pressures

In light of recent research, commercially purchased 'off-the-shelf' compression garments do not accommodate for differences in athletes' body structure, creating large variations in the levels of pressure applied; potentially influencing the above-mentioned benefits. Off-the-shelf CG are manufactured using a generalized sizing system (height and body-mass), leaving individuals susceptible to incorrect fitting as variations in body morphology (i.e. limb girth) are not accommodated for (MacRae et al., 2011). Thus, interfacial pressures exerted by the CG may demonstrate high inter-individual variability, potentially influencing the modalities effectiveness (Hill et al., 2015). Partsch (2005) advocated that reporting pressure measurements between the skin and CG are essential when determining the efficiency of the garment however, often studies fail to

report this (Bringard et al., 2006; Gill et al., 2006; Kraemer et al., 2010) or select to cross-reference from previous findings when using the same brand of CG (Ali et al., 2007; Davies et al., 2009). Hill et al (2015) reported a wide range of compression levels within some of the leading products when fitted to manufacturers' guidelines. 2XU ranged from 8-15 and 10.3-15 mmHg, Skins 7.7-16 and 9-22 mmHg, Linebreak 6-15 and 10.7-22 mmHg at the quadriceps and calf. In addition, posture also plays a role in pressure exerted with reported significant decreases in pressure values when an athlete is sitting/laying ($P=.01$) (Brophy-Williams et al., 2015), indicating that recovery garments may need to elicit higher pressure values. Hill et al (2015) estimated that the minimum amount of pressure required at the calf was 17.3mmHg, gradually decreasing to 15.1 mmHg at the quadriceps. This is to ensure the CG are effective in narrowing the covered blood vessels, thus increasing intravenous pressures (Partsch and Mosti, 2008). Nonetheless, studies have noted that if pressures are too high (30 mmHg) at the calf, then this could prevent the restrict blood flow and therefore venous return (Lawrence and Kakkar, 1980).The aforementioned pressure variability in 'off-the-shelf' CG creates some scope for the use of custom-made CG. This will ensure pressure values remain relatively the same between each participant (Hill et al., 2015), thus optimizing both performance and recovery benefits (Brown et al., 2017; Hill et al., 2014).

Current findings have displayed great heterogeneity in CG application timing, with a minimal time of 15 minutes wearing CG (Ménétrier et al., 2011) to a maximum of 60 hours (Heiss et al., 2018). Future studies should attempt to investigate optimal application timing and surface pressures, proving to be essential to promote both performance and recovery benefits.

The attainment of recovery and improved subsequent performance are the major reasons for athletes' use of CG. To date, there are limited studies on the performance and recovery benefits of custom-made compression garments, in comparison to commercially available garments and a control. Inconclusive research on the performance benefits of wearing compression garments have been predominantly conducted within a controlled environment, differentiating from a continuously changing sporting environment, therefore relevance of data may be limited. The aims of this study are to further current knowledge on compression garments in a natural sporting environment. This investigation will assess the physiological, psychophysiological and biomechanical effects of wearing custom-made compression garments versus 'off-the-shelf' compression garments, versus running shorts (control), during a 5km running time trial approved course. In addition, the present study will investigate the recovery properties of all compression garments and the control, at 12 hours and 24 hours after the 5km running time trial.

Chapter 2. Review of literature

Over the past two decades interest in endurance running has experienced a dramatic increase. Running is an essential movement used in most sports and is usually performed at high speeds in order to beat competition, whether that be in a race, to beat a defender or to achieve greater distance in a jump (Ounpuu, 1994). Running can be defined when there is a clear aerial phase, a moment where no limbs are in contact with the ground, thus running speed can be altered by changing duration of stance phase (time when a limb is touching the ground) (Ounpuu, 1994).

2.1 Energy systems and physiology

As expected an increase in the duration of a running event, equally the increased contribution of the aerobic energy system. After running at a continuous submaximal workload for several minutes, the consumption of oxygen equates to the energy demand of the working muscles, thus achieving 'steady state'. Whereby, physiological parameters such as cardiac output, heart rate and respiratory rate reach a plateau (Waters and Mulroy, 1999). Prolonged bouts of exercise experience a transfer between both aerobic and anaerobic energy systems, however the magnitude of change is highly dependent on exercise intensity (Åstrand and Rodahl, 1977). Performing submaximal exercise will often provide cells with sufficient oxygen to produce aerobic energy, therefore fulfilling individual's adenine triphosphate (ATP) requirements which can be sustained for a longer period of time (Åstrand and Rodahl, 1977).

Weyand et al (1993) recorded up to 97% contribution by the aerobic energy system in a 5000 meter event, similar results obtained during a 3000 metre event at up to 94% aerobic contribution (Duffield et al., 2005). Blood lactate concentrations are often used to assess the contribution of anaerobic energy systems with 8.6 mmol (Duffield et al., 2005) and 15.9 recorded post 3000-meter event (Shave et al., 2001), however it has been suggested that a poor correlation exists between blood lactate concentration and anaerobic energy contribution (Duffield et al., 2005).

The transition from aerobic to anaerobic energy systems can often be referred to as the lactate or ventilatory anaerobic threshold, and has been regarded as one of the most important physiological factors to endurance sport success (Ghosh, 2004). This is the definitive point during exercise at which metabolic acidosis and non-linear increases in

gas exchange occur within the lungs (Wasserman et al., 1973). Despite similar levels of VO_2 max, high level endurance athletes have demonstrated that the ability to perform at a high percentage of their VO_2 max with little to no blood lactate accumulation ((Conley and Krahenbuhl, 1980; Costill et al., 1973; Ghosh, 2004; Hagberg and Coyle, 1983), leads to improved performances. Kumagai et al (1982) indicated that higher ventilatory anaerobic thresholds presented strong correlations ($r = 0.95$ and 0.84) in 5000 and 10,000-meter running performance, coinciding with a strong correlation noted ($r = 0.98$) in marathon running performance (Farrell et al., 1979). Other physiological predictors of successful running performance include maximal output from the cardiovascular, musculoskeletal system (Sjödin and Svedenhag, 1985), efficiency in oxygen transportation and enhanced vascular systems (Keul et al., 1982; Parker et al., 1978). The participation in regular high intensity exercise have been correlated to a slight increase of 15-20% to the left ventricular wall thickness (Pluim et al., 2000), with magnitude reliant on demographic factors (age, gender, ethnicity, size, sporting discipline) (Rawlins et al., 2009). This hypertrophic adaptation causes higher stroke volumes, cardiac output and further increasing individuals maximal oxygen uptake (VO_2) (Paulsen et al., 1981).

2.2 Running mechanics

Research carried out by Sasaki and Neptune (2006) assessed muscle functioning during running at a specific speed. It was noted that the main muscles utilised whilst running included the gluteus maximus; the adductor magnus; anterior and posterior gluteus medius, psoas and iliacus; both heads of the hamstrings (biceps femoris long head, medial hamstrings); three sections of the vasti; rectus femoris; biceps femoris short head; tibialis anterior; lateral and medial gastrocnemius and the soleus muscles.

As previously stated, completion of a 5km running time trial requires a combination of all energy systems, directly influencing the type of muscle fibres recruited. All skeletal muscles contain muscle fibres of all three types, facilitating a conversation between fibre types (Booth and Thomason, 1991). However, highly trained runners predominantly recruit type IIa and type IIx during a 5km time trial, as these intermediate fibres consist of the aerobic capacity as type I, but can contract at high speeds and forcibility (Booth and Thomason, 1991). Type I fibres would also be used when an individual reaches steady state, as they are mitochondrialrich thus providing a prolonged supply of adenine triphosphate (ATP), making them more fatigue resistant due to their slower and less forceful contractibility nature (Booth and Thomason, 1991). Type IIb would be the lesser utilised fibre type predominantly during the start phase or potentially a sprint finish, however the fast and forceful contractibility cannot be sustained for a long duration (Booth and Thomason, 1991). Training level has been shown to directly impact the magnitude of specific muscle fibre recruitment. Trappe et al (2006) noted that after 13 weeks of marathon training with a three-week taper, experienced reduction in both type I and type II muscle fibre size, but a 60% increase in force per cross-sectional area.

As running is often not a taught skill, individuals tend to adopt a diverse range of techniques to achieve forward locomotion, therefore demonstrating large individualist differences in stride patterns (Cavanagh and Kram, 1989; Nummela et al., 2007) and kinematics (Ahn et al., 2014). In light of a recent review (Folland et al., 2017), running technique accounts for 39% of variance in running economy and 31% in performance, nevertheless heterogeneity in previous studies (Di Michele and Merni, 2014; J. Santos-Concejero et al., 2014; Tartaruga et al., 2012; Williams et al., 1987) have made it difficult to highlight any specific aspects of running biomechanics and their relationship

to running performance, and economy (Anderson, 1996). It has been proposed that vertical displacement of the centre of mass (COM) whilst running may potentially affect running economy and performance. Folland et al (2017) identified that tracking vertical movement of the pelvis during a running gait was best measure of COM displacement, reporting a reduction in COM vertical displacement was advantageous for running economy and performance ($r = -0.247$ to -0.341). The larger the COM displacement, the more an individual will need to perform against gravity, thus proving to be detrimental on economy and performance. Folland et al (2017) review suggested that shorter ground contact time was correlated to improved running performance ($r = -0.351$), coinciding with previous findings (Nummela et al., 2007; Jordan Santos-Concejero et al., 2014), however found to cause adverse effect on running economy (Di Michele and Merni, 2014). The inconsistency between running performance and economy have indicated that ground contact time is merely a resultant, rather than an element of improved running performance. Differentiating from the commonly adopted stride pattern (long stride length and slower stride rate), increasing stride rate and shortening stride length has shown to increase leg stiffness, reduce energy absorption at the working joints, thus achieving improved running performance and economy (Folland et al., 2017; Schubert et al., 2014). Stride parameters both coincide with a reduction in COM displacement, clearly demonstrating that all kinematic variables are inter-relatable and must be evaluated critically when viewed individually.

2.3. Training stress and overtraining syndrome

Progressive overload, graduated increases in training intensity, have been shown to improve athletic performance (Cadegiani and Kater, 2018). This style of training requires substantial planning of heavy to light periods, with adequate rest times to

maximise training stimulus and potentiate training adaptations (Cadegiani and Kater, 2018). With an expanding sporting calendar and training demands, athletes are often exposed to continuous physical and external stresses, thereby generating large imbalances between training load and recovery. These stresses can be a combination of illness, muscle damage, psychological stressors, inadequate recovery periods, alterations to normal sleep patterns and inadequate nutrition (Lehmann et al., 1993; Meeusen et al., 2013), thus reported to alter athletes' sporting performance and bodily functioning (Cadegiani and Kater, 2018; Clarkson and Hubal, 2002; Khan et al., 2016). Prolonged exposure to these imbalances forces the body and exposed tissues to enter survival mode, thus triggering non-functional overreaching and/or the overtraining syndrome (Cadegiani and Kater, 2018). Non-functional overreaching has been reported to reduce athletic performance up to a few weeks to months and requires full recovery, however original performance level may not be re-obtained (Meeusen et al., 2013). Alternatively, the overtraining syndrome is long term condition lasting longer than several months, indefinitely causing a decrease to sports performance and coinciding with psychological issues (Lehmann et al., 1993; Meeusen et al., 2013). The athlete will experience inefficient pathways and responses to inflammation, the metabolic system, neurological system, immune system and hormonal balances (Cadegiani and Kater, 2018). In light of a recent review (Flávio and Kater, 2017), athletes experienced chronic glycogen depletion when over trained, causing a lack of energy that hinders sporting performance.

2.4 Introduction into recovery

Endurance running largely relies on the athletes ability to withstand extensive workloads (Hauswirth and Lehénaff, 2001), as the overall movement involves

repetitive eccentric muscle actions specifically to the lower body (Brown et al., 2017; Fridén and Lieber, 1992; Vickers, 2001). The eccentric movement causes the Zline to stream and broaden, further displacing the sarcomeres within the myofibrils (Fridén and Lieber, 1992), commonly referred to as micro traumas. This triggers the acute inflammatory response known as oedema (Valle et al., 2014), later developing into the delayed onset of muscle soreness (DOMS), causing discomfort for up to 72 hours (Valle et al., 2014). The inflammation created around the damaged muscle fibres will saturate the site with enzymes that activate nociceptors, resulting in the sensation of pain (Cheung et al., 2003; Gregson et al., 2011). Subsequently, athletes' often experience a reduction in muscle force production, range of motion around the joints and overall negative impact to their running performance (Cheung et al., 2003). It is essential for athletes and coaches to integrate adequate recovery time between training sessions and, or competitions, thus facilitating central, peripheral and neuromuscular adaptations (Hauswirth and Lehénaff, 2001; Zatsiorsky, 1995). This is achievable through the methodical implementation of an active or passive recovery modalities within an athlete's training regime (Brown et al., 2017).

The large body of research into various recovery modalities highlights its importance to improve both the quantity and quality of training/competition for athletes (Kellmann, 2010). Cryotherapy is one of the more traditional and popular recovery strategies within sport and exercise science, with the goal to prevent the effects of acute soft tissue trauma and muscle damage (Jinnah et al., 2019; Parouty et al., 2010). Cryotherapy is a broad term to describe various forms of recovery modalities including, ice packs, cold water immersion and whole-body cryotherapy, with athletes exposing their bodies to extremely low temperatures ranging from -110°C to 10°C (Jinnah et al., 2019; Krueger

et al., 2019; Wilson et al., 2018). Physiological reasoning behind the use of cryotherapy is to reduce hypoxic cell death (cells deprived of oxygen), the development of oedema, muscle spasms and ultimately pain and inflammation (Jinnah et al., 2019; Lee et al., 2005; Ohkoshi et al., 1999). This is done as cryotherapy facilitates the response of vasoconstriction of peripheral blood vessels (Gregson et al., 2011), as intramuscular temperatures drop between 3°C–8°C (Sarver et al., 2017). Thus, reducing the rate of fluid into extracellular space, reduction of pressure on pain receptors and therefore signalling to elicit the acute inflammatory response, ultimately achieving body homeostasis (Ingram et al., 2009; Wilcock et al., 2006). Conversely, contemporary research has indicated that cryotherapy stunts training adaptations, noting losses in strength and muscle mass over a 12-week training phase (Roberts et al., 2015). This finding suggests that athletes utilising strength training to improve athletic performance should adopt alternative recovery methods, however may be useful within competition.

2.5 Compression garments

Inexpensive, less invasive and more accessible recovery modalities such as compression garments (CG), have become increasingly popular within the world of sport (Engel et al., 2016; Marqués-Jiménez et al., 2015). Originating from the treatment and prevention of lymphatic and venous diseases (Kelechi et al., 2012), CG provide an external pressure gradient to their covered surface areas, thus enhancing support around the joints and reducing the inflammatory response (Barnett, 2006; Partsch, 2005). Clinical literature has suggested that the graduated pressure gradient will increase venous return, thereby improving the removal of metabolites after a bout of intense exercise. This increase in blood flow will enhance the transportation of oxygen to the working muscles, thus improving exercise economy (Broatch et al., 2018),

accelerating the healing process and delaying the onset of inflammation (Araujo et al., 2018; Partsch, 2005). The pathophysiology of CG still remain unclear, however it has been suggested that the graduated pressure gradient reduces osmotic pressures, therefore decreasing cell movement and space for swelling (Kraemer et al., 2004), further limiting muscle oscillation (Davies et al., 2009) and ultimately the sensation of pain (Kraemer et al., 2004).

2.5.1 Performance

The majority of sports rules and regulations permit the use of CG during competition; therefore, research is limited on the performance benefits of wearing CG. To the researchers' knowledge, there has only been one unpublished study that used Kurio Compression custom-made CG (18-20 mmHg pressure), shown to improve running time to exhaustion by 88 seconds ($P < 0.05$) (Galbraith et al., 2018. Unpublished).

Conflicting studies have reported no significant differences ($P > 0.05$) in time to exhaustion (Dascombe et al., 2011), with unchanged measures in VO_2 max and blood lactate. It has been suggested that the magnitude of change in physiological measures may be highlighted if running was performed at submaximal intensities, in order for participants to reach steady state (Scribbans et al., 2016).

Current research has found little to no improvements in running performance time when wearing CG clothing, with no significant difference ($P = 0.99$) in performance time wearing CG stockings during a 10km running time trial (Ali et al., 2011). Interestingly, leg power was significantly maintained ($P < 0.05$) when wearing the low pressure (12-15 mmHg) and medium pressure (18-21 mmHg) compression stockings (Ali et al., 2011). Aligning with research conducted by Brophy-Williams et al (2015) where there were no significant differences in performance time between two bouts of 5km treadmill running

when wearing CG stockings ($p=0.20$, $d=0.07$, trivial), however performance time significantly decreased in the control ($p<0.01$, $d=0.19$, small effect). This may be a result of improved muscle proprioception, reduction in muscle oscillation and positive psychophysiological abilities (Hill et al., 2014), thus better maintaining subsequent power outputs. It has also been suggested that CG improve adenosine triphosphate-phosphocreatine resynthesis (ATP-PC) and production during bouts of anaerobic exercise. Ballmann et al (2019) reported that Division I collegiate basketball players experienced significant improvements in mean power output ($p = 0.028$; $d = 0.35$), anaerobic capacity ($p = 0.018$; $d = 0.45$), and total work ($p = 0.027$; $d = 0.36$) when wearing lower body CG during an anaerobic test, however peak power output ($p = 0.319$; $d = 0.09$), anaerobic power ($p = 0.263$; $d = 0.23$), and fatigue index ($p = 0.749$; $d = 0.05$) remained unchanged. Further research is needed to understand exact physiological processes, and CG impact on sporting performance.

Heart rate can be used as an indirect measure of venous return, as CG have been suggested to enhance end-diastolic and stroke volume, potentiating a decrease in heart rate for equal cardiac output (Broatch et al., 2018). Results to date are inconclusive with no significant changes (Ali et al., 2011; Dascombe et al., 2011; Kerhervé et al., 2017; Galbraith et al., 2018, unpublished), significant increases (Houghton et al., 2009) or reductions (Driller and Halson, 2012) to heart rate when wearing CG clothing. Changes in heart rate are highly sensitive to the exercise protocol, therefore the large heterogeneity between studies will influence results. Broatch et al (2018) investigated the effect of CG on blood flow and oxygen delivery to the working muscles using a fNIRS system, noting a 18% improvement in mean blood flow and oxygen transportation, thus improving mean peak power (W) during repeated sprint cycling. Aligning with Kerhervé et al (2017), indicating that calf CG improved muscle

oxygenation before and after 24km trial running and (Sear et al., 2010) with reported oxygen delivery enhancement wearing whole body CG during intermittent exercise over multiple days. Studies have reported significant improvements ($p < 0.05$) in muscle oxygenation, but no significant ($p > 0.05$) changes to performance parameters (Dascombe et al., 2011; Scanlan et al., 2008), whereas others have noted no significant findings ($p > 0.05$) in fNIRS or performance measurables when comparing CG to a control. (Ménétrier et al., 2011). Ultimately, it has been suggested that the graduated pressure gradient increases blood flow, therefore enhancing oxygen transportation to the working muscles/tissues allowing the individual to exercise longer at a higher intensity.

2.5.2 Recovery

Previous research have predominantly investigated the effects of wearing CG on recovery, with an overarching acceptance that they enhance the rate of recovery (Araujo et al., 2018; Barnett, 2006; Brown et al., 2017). Mechanisms suggest that the CG increase intravenous pressures and enhance mechanical structure for the covered muscles, furthermore reducing muscle oscillation and space for the inflammatory response (Duffield et al., 2010; Kraemer et al., 2004; Marqués-Jiménez et al., 2015). Valle et al (2014) noted improvements in muscle function and control when wearing CG, thus reducing exercise induced muscle damage by 26.7%. Current literature has failed to identify specific physiological processes to enhance recovery when wearing CG, however conflicting results may be consequential of the large heterogeneity displayed between studies, for example the exercise protocol, intensity, duration, CG type and application timing.

Physiological biomarkers are often adopted to investigate the recovery properties of wearing CG, such as blood lactate and creatine kinase. With CG providing an external pressure gradient to the muscle, it has been suggested that larger amounts of blood lactate are better retained (Barnett, 2006; Marqués-Jiménez et al., 2015), thus potentiating lactate metabolism and improved physical performance. Studies have reported no changes in lactate oxidation (Barnett, 2006), with no significant differences ($p>0.05$) in blood lactate two hours post an anaerobic exercise protocol (Duffield et al., 2008) or 80-minute simulated rugby match (Duffield et al., 2010). In light of a recent meta-analysis across 23 studies and 294 participants (da Silva et al., 2018), no significant differences ($p>0.05$) were noted in blood lactate levels post CG trial. Creatine kinase has presented some equivocal findings, with significant decreases ($p<0.05$) 24 hours post repeated sprint exercise (Duffield and Portus, 2007) and no significant changes ($p>0.05$) 12 hours post plyometric exercise protocol (Jakeman et al., 2010) when wearing CG. This may indicate that the aforementioned physiological biomarkers may be an indirect measure of recovery (Duffield et al., 2010, 2008). Krueger et al (2019) indicated that creatine kinase levels often peak at 72 hours after performing intense exercise. Therefore, other myocellular proteins that are more sensitive to exercise induced muscle damage and inflammation (C-Reactive Protein, SICAM), are better measures when investigating into the recovery benefits of wearing CG (Krueger et al., 2019).

The perception scores of recoveries have been thoroughly researched within the field of CG research through the use of visual analogue scale (VAS), with Hill et al (2013) meta-analysis calculating a moderate reduction on the severity of DOMS ($g=0.403$). There have been reported recovery improvements within 66% of the study's population (Duffield and Portus, 2007; Hill et al., 2014), however overall research has highlighted some equivocal findings. To the researchers' knowledge, there has only been one study

to assess the recovery benefits when wearing Kurio custom-made CG, with reported significantly improvement in perception of recovery 12hr ($p= 0.01$, $d= 0.6$, moderate effect) and 24hr ($p= 0.01$, $d= 0.8$, moderate effect) post time to exhaustion running protocol (Galbraith et al., 2018. Unpublished). This aligns with Upton et al (2017) with significant improvements ($p<0.001$) in the perception of recovery 48hr after a simulated rugby protocol. Significant improvements ($p<0.05$) have also been noted between 1-72hr post plyometric, high intensity running and heavy resistance training (Chan et al., 2016; Duffield et al., 2010; Jakeman et al., 2010; Pruscino et al., 2013). Conflicting findings (Ali et al., 2011; Trenell et al., 2006) showed no significant effects to perceptual recovery, however sample size, exercise familiarity, timing of data collection and human error will impact results. Interestingly, Mizuno et al (2016) observed no significant improvements ($p>0.05$) in muscle soreness between downhill and flat surface running trials, although CG facilitated faster recovery of subsequent jumping performance. Improvements in subsequent sporting performance is one of the major reasons why athletes and coaches adopt CG into their training regime, previously shown to improve strength/power recovery (Hill et al., 2014; Lee et al., 2006) and counter movement jump performance (Hill et al., 2017). Opposingly, 10 kilometre (km) running performance was not significantly improved ($p>0.05$) after wearing CG (Ali et al., 2011), however the nature of endurance performance elicits lesser muscle damage in comparison to heavy resistance training, thus potentiating a smaller magnitude effect on performance recovery (Brown et al., 2017). The subjunctive nature of VAS leaves scores vulnerable to inaccurate information as a result of external factors stated previously, therefore future research should investigate physiological markers of recovery (creatine kinase, SICAM, C-Reactive Protein) and cross reference data with perceptual ratings, thus gaining complete understanding of the effects of recovery when wearing CG.

Chapter 3. Methodology

3.1 Study Design

Study design was adapted from methods performed in Galbraith et al (2018. Unpublished) and was approved by the University of East London Health and Bioscience Ethics Committee (UREC 1819 15: see Appendix A). The current study followed a randomised repeated measures design to mitigate any order effect. Participants completed three 5km running trials; wearing 'custom-made' compression garments during one trial; wearing 'off-the-shelf' compression garments and running shorts (control) during the other trials. All running trials were separated by a minimum of 7 days, with each participants' trials completed within a 3-week period.

The 'off-the-shelf' compression garments physically replicated the 'custom-made' compression garment, however attempted to offer a commercially manufactured level of compression, thus mitigating any expectancy effect. Off-the-shelf compression garment sizing was generated based on participants' height and weight, in reflection to the manufacturers sizing guideline (S, M, L, XL, 2XL) presented in Figure 1.



HEIGHT													
cm	ft												
140	4.6												
150	5												
160	5.3												
165	5.5	S			M			L			XL		
170	5.7	S			M			L			XL		
175	5.9	S			M			L			XL		
180	6	S			M			L			XL		
185	6.1	S			M			L			XL		
190	6.3	S			M			L			XL		
195	6.5	S			M			L			XL		
WEIGHT	ib	110	125	135	145	155	165	165	175	195	205	215	225
	kg	50	56	61	65	70	75	80	84	89	94	98	103

Figure 1: 'Off-the-shelf' compression garment manufacturers sizing guideline based on individual's height and weight.

Pressure values were obtained prior the commencement of each running trial using the Kikuhime (TT Meditrade, Denmark). Landmarks used for pressure readings included the anterior midpoint of the quadriceps, medial point of the calf at the point of maximal girth and two centimetres above the medial point of the ankle, for both 'custom-made' (performance and recovery) and 'off-the-shelf' compression garments (Hill et al., 2015). Pressure readings were taken with the participant standing in the anatomical zero position, with weight evenly distributed on both feet. Each pressure point was taken on the right leg for a number of three times, and then a mean value was calculated (Hill et al., 2015).

3.2 Participants

Eight recreational runners (N=4 Male and N= 4 Female), age 35 ± 9 years, body mass 70.1 ± 9.4 kilograms (kg), height 172 ± 9.1 centimetres (cm)) voluntarily participated in this study. All participants had a minimum of 3 years of training experience, one-year competitive experience and 5km running personal bests ranging from 18:48 minutes (m) – 27:05 m, self-reported through the pre-screening questionnaire (see Appendix B). Inclusion criteria required participants to be free of any impeding health conditions, injuries, prescription medication and non-smokers. Prior to the commencement of running trials, participants were advised to avoid any high intensity training and stimulants (i.e. Coffee) 24 hours before testing. All participants were provided a participant information sheet (see Appendix C) and informed written consent was acquired (see Appendix D). Individual's completed a compulsory physical activity readiness questionnaire (Par-Q) (Thomas *et al.*, 1992) (see Appendix E) and a consent for photography/visual recordings forms (see Appendix F) were required. The recruitment criteria aimed to recruit recreational runners to ensure a wide range of

abilities were accounted for, shown in the great range of self-reported 5km personal best times. Thus, making results produced more applicable to larger number of individuals within the runners' population.

3.3 Procedure

3.3.1 Preliminary Testing

Participants visited a controlled laboratory where anthropometric characteristics were assessed using the Seca 96 Stadiometer (Seca, Birmingham, UK) and Seca 761 Dial Scale (Seca, 97 Birmingham, UK). Additional measurements of the legs, waist and hips were taken using a 3D scan of the lower body (Artec Eva, Artec 3D, Luxembourg), and processed through Kurio Compression owned software to manufacture two graduated 'custom-made' compression garments to fit participants individually. A 'performance' compression garment (6-15.3 mmHg), which the participants wore during the running trial, and a 'recovery' compression garment (6-34 mmHg), which the participants were instructed to wear for 8 hours immediately post running trial as recommended by Kurio Compression. Height and mass obtained during the preliminary visit were used to produce S/M/L/XL/2XL 'off-shelf-compression garment (0-22 mmHg). All pressure values stated previously are presented as ranges from overall lowest-highest values, however detailed pressure readings can be found in Table 2.

3.3.2 Visit 1

Participants completed a 5 km running time trial in one of the three assigned conditions on an approved Run England 5km park course, environmental conditions can be found in Table 1. This was an attempt to simulate a competitive 5km race, making results more accurate measures of running performance. Participants undertook a self-selected

warm-up of 5 minutes to increase muscle elasticity, readiness to perform and reduce the risk of injury. Participants will self-select exercises to optimize their running performance, accounting for inter-individual differences. Participants commenced the completion of the 5km running time trial, with the objective to cover the distance in the fastest time possible. Time in seconds (s) was recorded once the individual completes the 5km park course. Participants assigned to custom-made CG, they will be instructed to wear the performance CG during the 5km running trial and recovery CG 8 hour's post, as instructed by manufacturer guidelines. Participants assigned 'off-the-shelf' CG will be instructed to wear the same CG during the 5km running trial and 8 hours post. Participants assigned running shorts will be instructed to refrain from wearing any type of CG.

Physiological Analysis. Expired air (Cosmed K5, Cosmed, Italy) was collected throughout the running trials, assessing minute ventilation (VE), maximal oxygen uptake (VO₂) and minute oxygen circulation per kilogram of bodyweight (VO₂/kg). Maximal and average heart rate (Premium Heart Rate Monitor, Garmin Ltd, USA) was also measured during these runs. Fingertip capillary blood samples were taken using a single use lancet (Unistick 3, Owen Mumford Ltd, UK) to puncture the skin, measuring blood lactate levels using pre-prepared testing strips (Lactate Pro 2, ARKRAY Inc., Kyoto, Japan). Using identical methods, 30 microliters of blood was also collected in the Microsafe Tubes (Safe-Tec, USA) and analysed through the Reflotron Plus (Bio-Stat Healthcare Group, UK), for the assessment of creatine kinase. Both blood bio-markers were collected pre, post, 12 hours and 24 hours after 5km running trial.

Kinematic Analysis. Reflective landmarks were placed on participants' left iliac crest, greater trochanter, femoral condyle, malleoli and fifth metatarsal. Data was collated

using two tripod mounted digital video cameras (Exilim EX-ZR1000, Casio, Japan) sampling at 240 Hz, orthogonal to the sagittal plane along a section of the 5km running route. A 50-centimetre (cm) scaling rod was placed in shot of each camera and participants were instructed to run with their left foot as close to the scaling rod as possible. Centre of mass vertical displacement; hip, knee flexion/extension and ankle dorsi-flexion during foot strike, take off and ROM during stance phase; stride frequency and length will be determined from two-dimensional video analysis.

Perceptual Analysis. A visual analogue scale (VAS) were completed to assess the individual's perception of muscle soreness pre, post 12 and 24 hours after the running trial (see Appendix G). Muscle soreness was rated on a VAS from 0-100 mm, with 'no pain' represented by 0 mm and 'unbearable pain' represented by 100 mm.

3.3.3 Visit 2& 3

Visit 2 and 3 followed the same procedure as visit 1, however "custom-made", "off-the-shelf" and running shorts (control) switched around in a counter balanced manner. Measurables such as 5km running time: maximal and average heart rate: VE, VO₂, VO₂: blood lactate: creatine kinase and 2D video analysis of running technique were collected as stated above. The "custom-made" group were instructed to wear their performance compression garments during the 5km running trial and recovery compression garments 8 hours post. The "off-the-shelf" group were instructed to wear the same pair of leggings during the running trial and 8 hours post. The running shorts (control) group were instructed to refrain from wearing any type of compression during and 8 hours post 5km running trial.

3.4 Data Analysis

All data analysis was carried out using SPSS 25 .0 (SPSS Inc., Chicago, IL, USA). Descriptive statistics such as mean \pm standard deviation (SD) were performed for all outcome measures. Biomechanical data (centre of mass (COM) displacement, stride length, cycle time) was analysed using the Tracker software (www.physlets.org/tracker) (as demonstrated in Appendix H), with stride rate and running velocity calculated through equations as shown in Appendix I. A repeated measures ANOVA and follow-up paired samples T-test were used to check for any significant differences in parameters across the three conditions. Microsoft Excel Office 365 was used for further analysis, using Cohens d effect size calculation to identify any effect sizes among all measurable.

Chapter 4. Results

4.1 Environment

Table 1: (N=8) Mean \pm standard deviation of temperature ($^{\circ}$ C), humidity (%), pressure (mb) and wind speed (m/s) for each condition.

	Temperature ($^{\circ}$ C)	Humidity (%)	Pressure (mb)	Wind Speed (m/s)
Control <i>Control vs. Custom</i>	17 \pm 3 (d=.27)	77.7 \pm 9.61 (d=.79)	1011 \pm 11 (d=.49)	1.2 \pm 1.2 (d=1.05)
Custom <i>Custom vs. Off-Shelf</i>	18 \pm 4 (d=.42)	62.5 \pm 16.1 (d=.70)	1018 \pm 12 (d=.05)	3.1 \pm 1.5 (d=.39)
Off-shelf <i>Off-Shelf vs. Control</i>	19 \pm 3 (d=.73)	69.7 \pm 12.5 (d=.20)	1015 \pm 9 (d=.51)	1.3 \pm 1.7 (d=.30)

A repeated measures ANOVA indicated that there were no significant differences ($F(6,2)= 1.472$, $p= .211$) in temperature ($^{\circ}$ C), humidity (%), pressure (mb) and wind speed (m/s). As shown in Table 1 with effect sizes (d=) there were some meaningful variations in environmental measures which may potentially affect running performance. Temperature ($^{\circ}$ C) was highest during 'off-shelf' compression garments at 19 \pm 3 $^{\circ}$ C with a

moderate effect size ($d=.73$) compared to control and small effect size ($d=.42$) compared to custom. Humidity (%) was highest during the 'control' condition at $77.7\pm 9.61\%$ with a moderate effect size ($d=.79$) compared to 'custom' and small effect size ($d=.7$) compared to 'off-shelf'. Wind Speed (m/s) was highest during 'custom' compression garments at 3.1 ± 1.5 (m/s) with a moderate effect size ($d=1.05$) compared to control and small effect size ($d=.39$) compared to 'off-shelf'.

4.2 Pressures

Table 2: (N=8) Mean \pm standard deviation, range and p-values of pressures (mmHg) obtained at the three sites thigh (T=), calf (C=), ankle (A=) in all compression garments.

	Thigh (mmHg)	Calf (mmHg)	Ankle (mmHg)	Range	P- Value
Custom Performance <i>Custom Performance vs. Off-Shelf</i>	9.4 \pm 4.7	8.2 \pm 3.1	10.3 \pm 4.5	T= 6-20.3 C= 2-11.3 A= 2-15.3	T= .56 C= .76 A= .02
Off-Shelf Recovery <i>Off-Shelf vs. Custom Recovery</i>	7.5 \pm 6	7.6 \pm 5.2	2.3 \pm 2.5	T= 4-22 C= 3.3-19 A= 0-7	T= .78 C= .04 A= .002
Custom Recovery	8.3 \pm 1.4	15.3 \pm 5.7	17 \pm 7.7	T= 6-10 C= 11-26.3 A= 9.3-34	

A repeated measures ANOVA indicated that there were significant differences ($F(4,2)=7.645$, $p<.01$) in pressures applied (mmHg) at the three specified landmarks in both custom and 'off-shelf' compression garments. There were no significant differences at the thigh ($t(8)=.611$, $p=.560$, $d=.35$, small effect) and calf ($t(8)=.297$, $p=.775$, $d=0.15$, trivial effect) between performance custom CG and 'off-shelf' CG. There were significantly higher pressures in the custom compression garments at the ankle for both performance ($t(8)=4.17$, $p=.002$, $d=2.21$, very large effect) and recovery ($t(8)= -4.87$, $p=.002$, $d=2.57$, very large effect), compared to 'off-shelf' CG. Additionally the custom

recovery CG applied significantly greater pressure at the calf ($t(8) = -2.56$, $p = .038$, $d = 1.42$, moderate effect size) compared to 'off-shelf' CG. Overall, as seen in Table 2, all CG showed a large range in pressures applied and did not always follow a graduated pressure pattern.

4.3 Performance

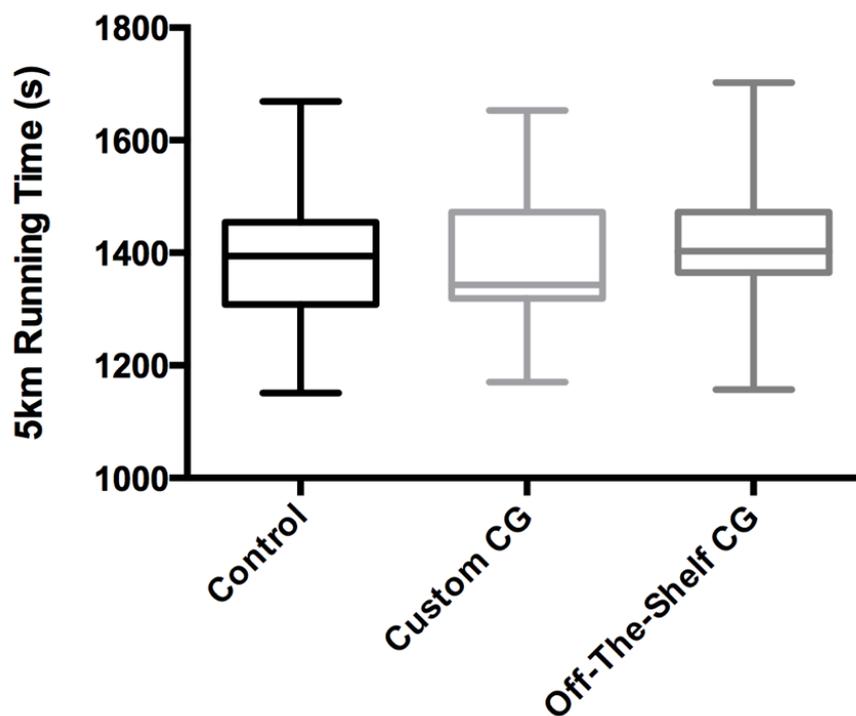


Figure 2: (N=8) 5km running time in seconds (s) during all conditions with standard deviation presented as error bars.

A repeated measures ANOVA indicated that there were significant differences ($F(36,2) = 1.841$, $p = .003$) in performance measures. As displayed in Figure 2, a paired samples T-Test indicated that there was a significant difference ($t(8) = -2.523$, $p = .04$, $d = .24$, small effect) in 5km running time when wearing custom CG against 'off-shelf' CG. The custom CG group produced the quickest running time at 1378 ± 144 seconds (s), compared to the control group 1392 ± 149 s ($t(8) = .796$, $p = .452$, $d = .09$, trivial effect). The 'off-shelf' CG

group produced slowest running times 1413 ± 151 s and had no significant difference ($t(8)=1.133$, $p=.295$, $d=.14$, trivial effect) in comparison to the control group.

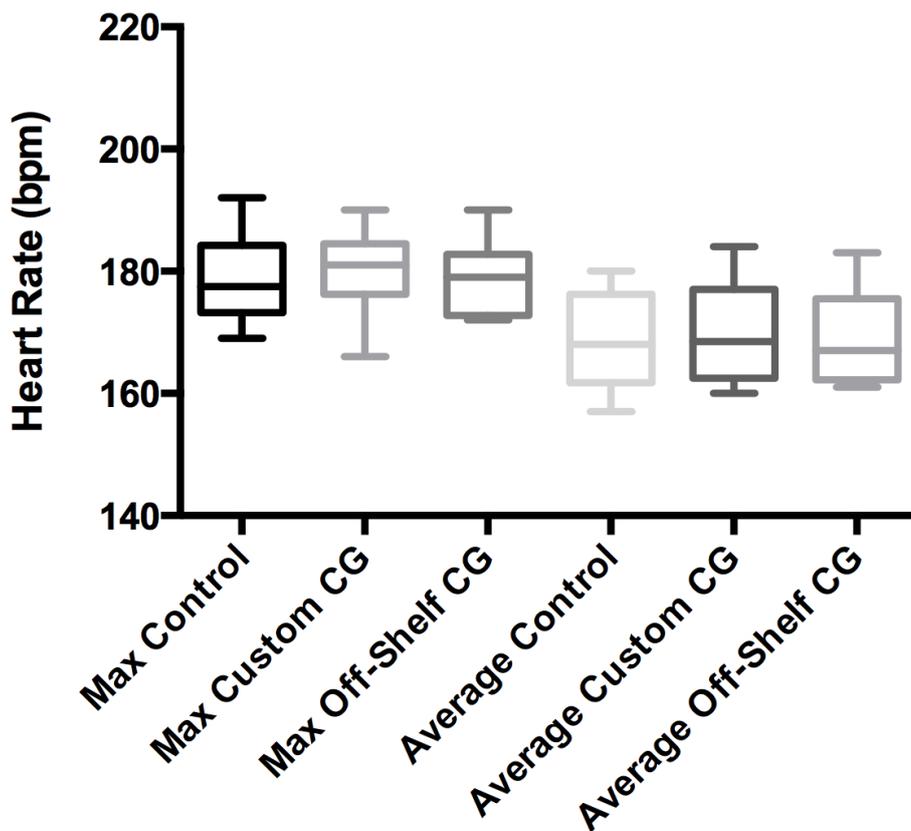


Figure 3: (N=8) Maximum and average heart rate in beats per minute (bpm) during all conditions with standard deviation presented as error bars.

Maximal heart rate was similar across all conditions with control at 179 ± 7 bpm, custom CG at 180 ± 7 bpm and 'off-shelf' CG at 179 ± 6 bpm. No significant differences were found between control vs custom ($t(8)= -.396$, $p=.704$, $d=.15$, trivial effect), custom vs 'off-shelf' ($t(8)= .328$, $p=.753$, $d=.13$, trivial effect) and control vs 'off-shelf' ($t(8)= -.191$, $p=.854$, $d=.04$, trivial effect). Average heart rate was identical across all conditions with control at 169 ± 8 bpm, custom CG at 169 ± 8 bpm and 'off-shelf' CG at 169 ± 8 bpm. No significant differences were found between control vs custom ($t(8)= -.552$, $p=.598$, $d=.15$, trivial effect), custom vs 'off-shelf' ($t(8)= .297$, $p=.775$, $d=.09$, trivial effect) and control vs 'off-shelf' ($t(8)= .342$, $p=.743$, $d=.06$, trivial effect).

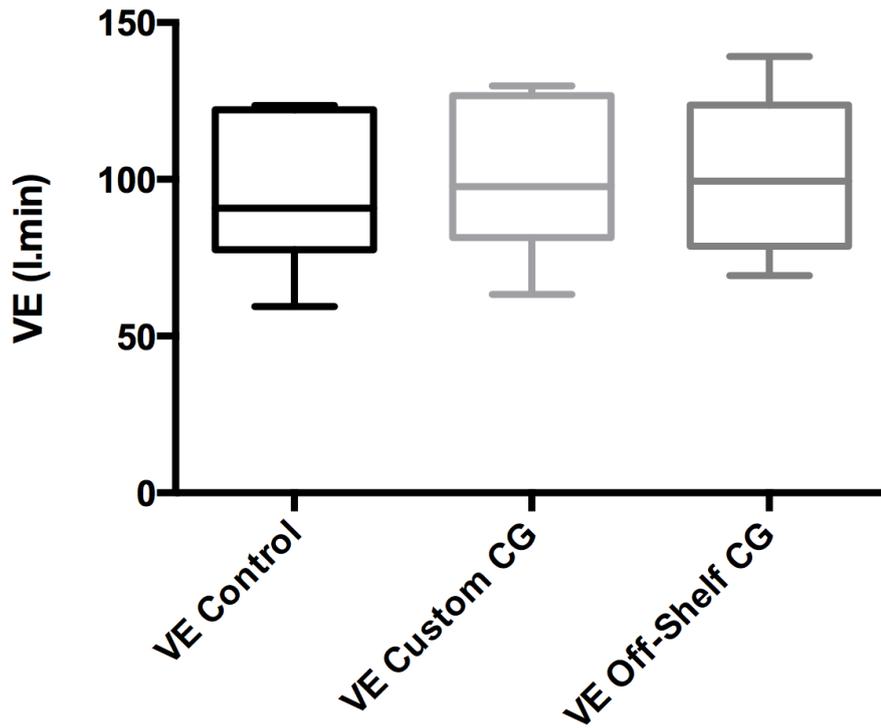


Figure 4: (N=8) Minute ventilation (VE) during all conditions with standard deviation presented as error bars.

The online gas analyser reported no significant differences in minute ventilation (VE) (l.min) during all conditions. 'Off-shelf' CG produced the highest VE at 101.34 ± 26.62 l.min with no significant differences observed versus custom CG ($t(8) = -.103$, $p = .921$, $d = .02$, trivial effect) and control ($t(7) = .383$, $p = .715$, $d = .07$, trivial effect). Following was custom CG at 100.86 ± 25.04 l.min and finally control at 96.22 ± 25.18 l.min ($t(7) = -.860$, $p = .423$, $d = .14$, trivial effect).

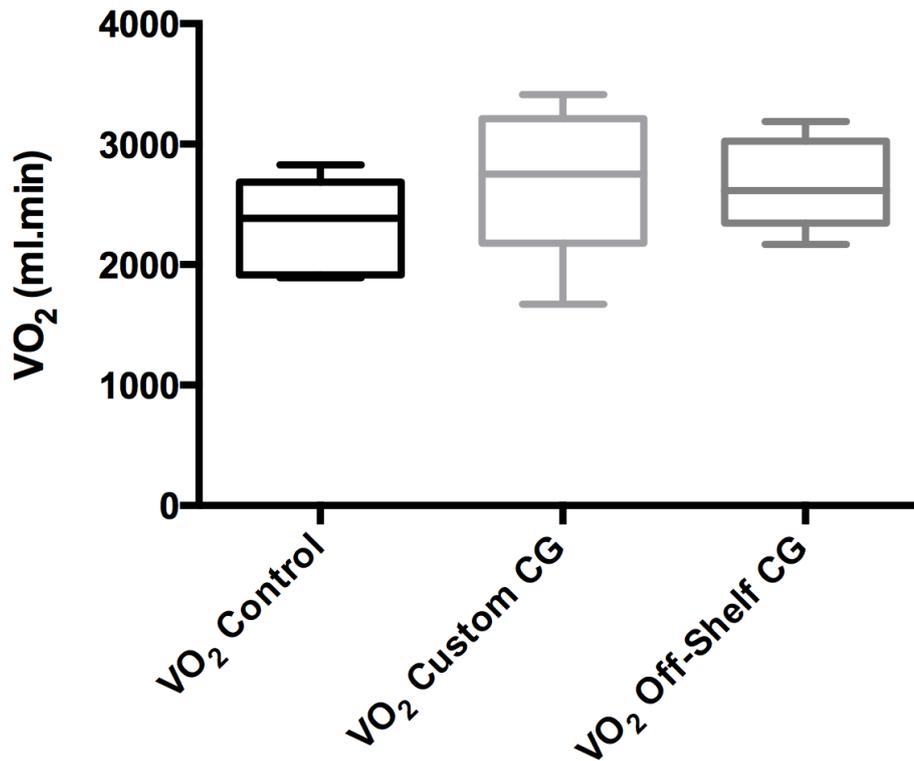


Figure 5: (N=8) Maximal oxygen uptake (Vo2) during all conditions with standard deviation presented as error bars.

As shown in Figure 5, custom CG produced the highest maximal oxygen uptake (VO₂) at 2679.09±590.48 ml.min with no significant differences observed verses control 2323.04±401.39 ml.min ($t(7) = -1.731$, $p = .134$, $d = .63$, moderate effect) and 'off-shelf' CG at 2671.63± 362.53 ml.min ($t(8) = .066$, $p = .949$, $d = .02$, trivial effect). 'Off-shelf' CG condition produced significantly higher VO₂ values compared to the control condition ($t(7) = 2.737$, $p = 0.034$, $d = .78$, moderate effect).

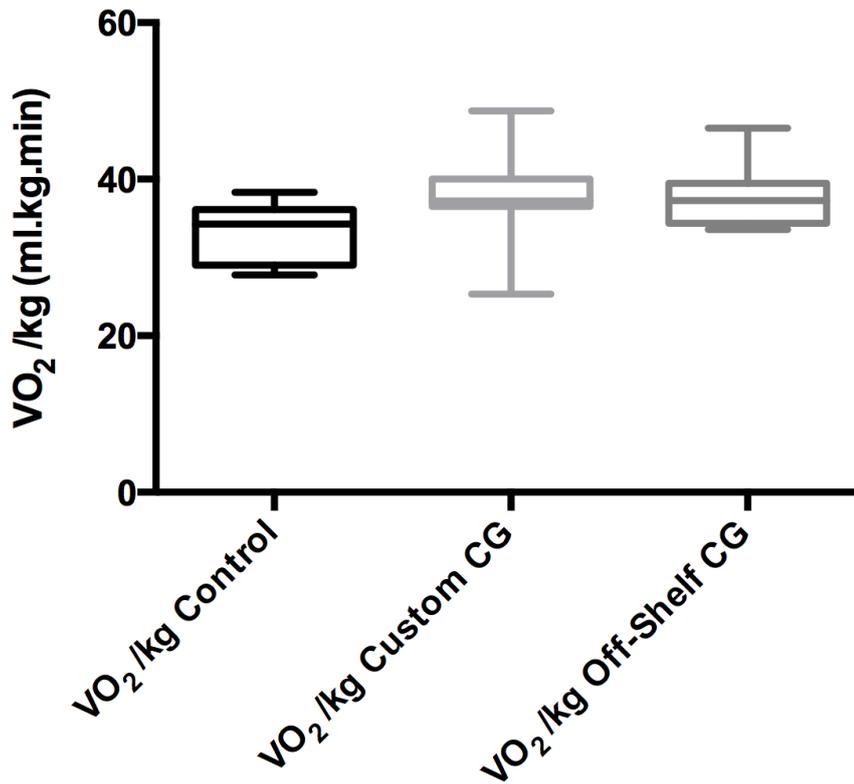


Figure 6: (N=8) Minute oxygen circulation per kilogram of bodyweight (ml.kg.min) during all conditions with standard deviation presented as error bars.

Figure 6 indicates that 'off-shelf' CG produced near identical minute oxygen circulation per kilogram of bodyweight (VO_2/kg) at 37.81 ± 4.19 ml.kg.min to custom CG at 37.69 ± 6.41 ml.kg.min ($t(8) = -.072$, $p = .944$, $d = .02$, trivial effect). Control produced the lowest at 33.23 ± 3.75 ml.kg.min, with no significant differences observed versus custom CG ($t(7) = -1.630$, $p = .154$, $d = .83$, moderate effect) and a significant difference reported when compared to 'off-shelf' CG ($t(7) = 2.565$, $p = .043$, $d = 1.05$, moderate effect).

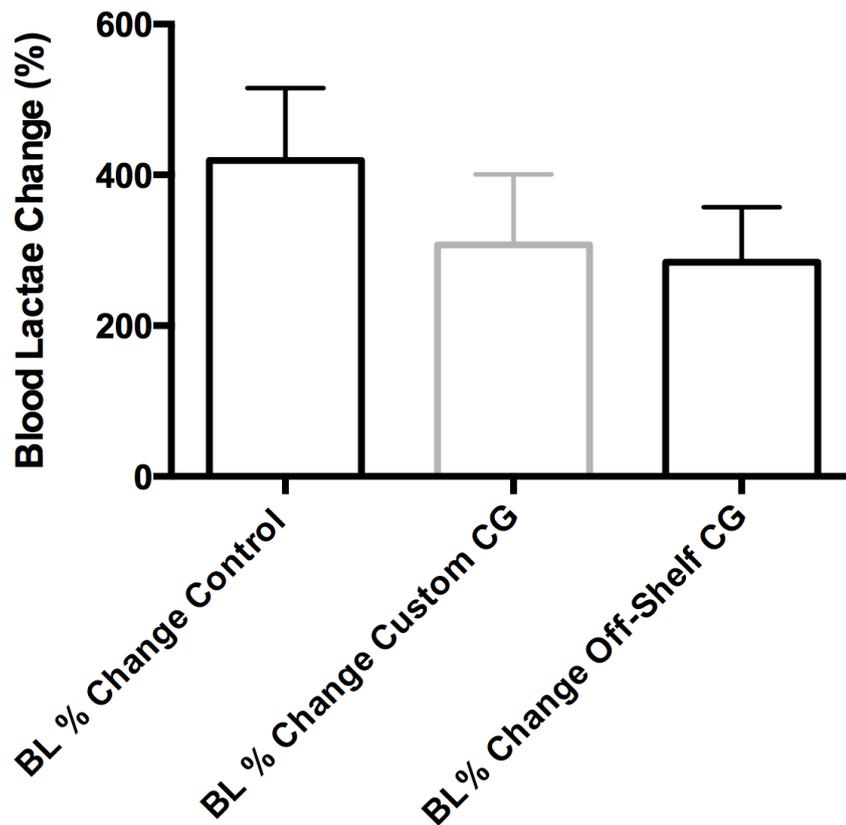


Figure 7: (N=8) Percentage difference (%) in blood lactate (mmol) pre and post 5km running trials during all conditions, with standard deviation presented as error bars.

Figure 7 displays that percentage change (%) in blood lactate (mmol) from pre to post 5km running trials was highest after the control condition at 419 ± 272 %, indicating that participants had to work harder during this condition. A significant difference was observed versus 'off-shelf' CG at 284 ± 206 % ($t(8) = -2.804$, $p = 0.026$, $d = 0.56$, moderate effect), but no significant difference versus custom at 306 ± 263 % ($t(8) = 1.292$, $p = 0.237$, $d = 0.42$, moderate effect). No significant difference between custom CG and 'off-shelf' was observed ($t(8) = 0.309$, $p = 0.767$, $d = 0.09$, trivial effect), thus indicating that participants completed running time trial at equal intensities.

4.4 Recovery

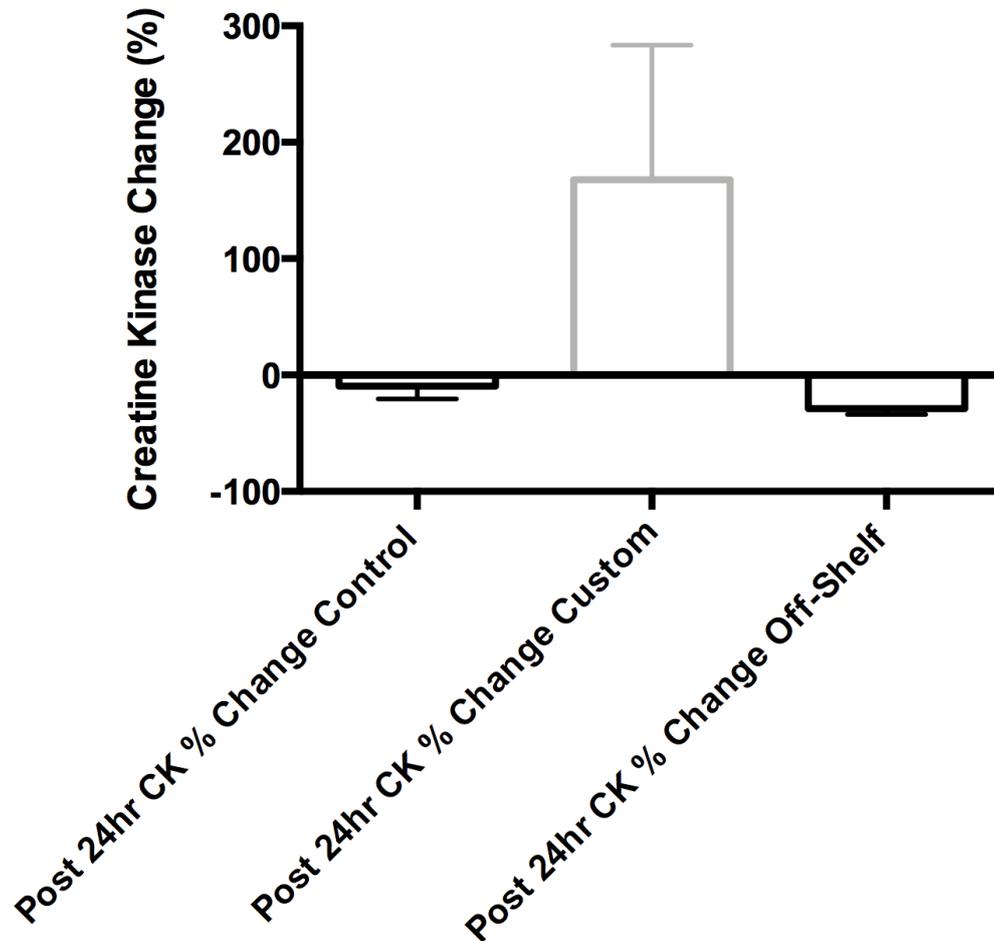


Figure 8: (N=8) Creatine Kinase (U/1) percentage change (%) from post to 24 hours(hr) after 5km running trials during all conditions, with standard deviation presented as error bars.

A repeated measures ANOVA indicated that there were no significant differences ($F(12,2)= 1.493$, $p= .143$) in recovery measures. Creatine kinase (CK) levels in the control trial pre were reported as 183 ± 122 U/1 and post 214 ± 163 U/1 with no significant difference ($t(8)= -1.501$, $p=.177$, $d=.21$, small effect). CK levels in the custom CG trial pre were reported as 267 ± 308 U/1 and post 251 ± 305 U/1 with no significant difference ($t(8)= .601$, $p=.567$, $d=.05$, trivial effect). CK levels in the 'off-shelf' trial pre were reported as 127 ± 66 U/1 and post 199 ± 89 U/1 with a significant difference ($t(8)= -2.567$, $p=.037$, $d=.92$, moderate effect). The large standard deviations, variation in both significant differences and effect sizes in each condition, could lead to the assumption

that 5km running time trial did not consistently elicit sufficient muscle or oxidative damage to see any definitive changes in recovery.

Figure 8 displays that 'off-shelf' CG ($-28.87 \pm 13.90\%$) and control ($-9.38 \pm 31.09\%$) both created decreases in percentage CK change 24hr post 5km running trial. Alternatively, custom CG generated percentage increases ($167.77 \pm 327.54\%$) in CK change 24hr post running trial. A paired samples t-test highlighted there were no significant differences in any of the conditions (control vs. custom, custom vs. off-shelf, off-shelf vs. control) ($t(8) = -1.608$, $p = .152$, $d = .81$, moderate effect) ($t(8) = 1.708$, $p = .131$, $d = .76$, moderate effect) ($t(8) = -2.094$, $p = .075$, $d = .85$, moderate effect). Evidence is inconclusive, there is a large standard deviation and therefore we cannot assume that the compression garments improved recovery. No significant differences but moderate effect sizes were found in creatine kinase percentage change 24hrs post running trial, therefore the assumption that no matter what condition all participants were able to fully recover 24hrs post 5km running trial.

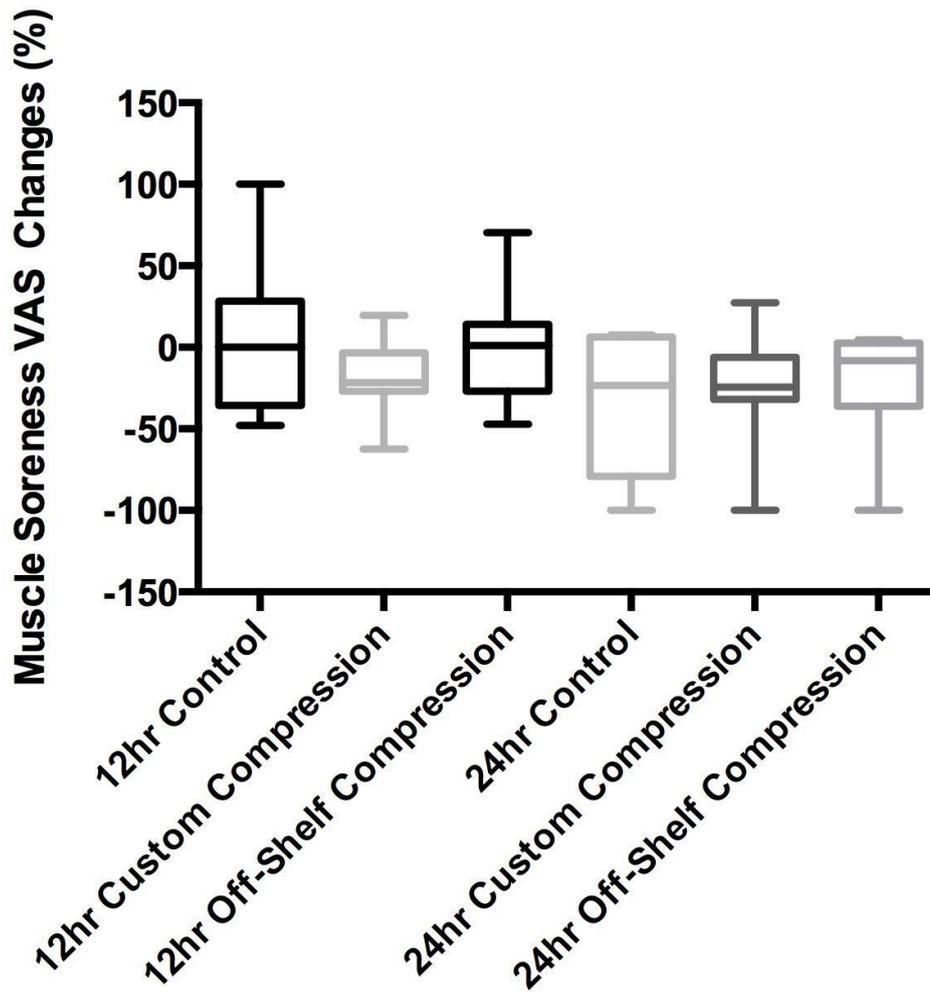


Figure 9: (N=8) Muscle soreness visual analogue scale (VAS) percentage change (%) during all conditions from post-12hours(hr) and 12hr-24hr.

Muscle soreness visual analogue scale (VAS) in the control trial pre were reported as 24.44 ± 21.70 millimetres (mm) and post 29.94 ± 22.05 mm with no significant difference ($t(8) = -.664$, $p = .528$, $d = .25$, small effect). VAS in the custom CG trial pre were reported as 32.31 ± 27.08 mm and post 44.38 ± 31.93 mm with no significant difference ($t(8) = -1.541$, $p = .167$, $d = .41$, small effect). VAS in the 'off-shelf' trial pre were reported as 17.94 ± 18.69 mm and post 37.68 ± 22.16 mm with a significant difference ($t(8) = -2.095$, $p = .074$, $d = .96$, moderate effect). The large standard deviations, variation in both significant differences and effect sizes in each condition, aligns with the assumption made analysing the creatine kinase data. The 5km running time trial did not potentiate

the perception of sufficient muscle or oxidative damage, to see any differences in recovery.

Figure 9 highlights that the custom CG improved the perception of recovery the best at 12hrs post running trial at $-19.18 \pm 23.64\%$, followed by 'off-shelf' CG at $-.099 \pm 35.28\%$ and then control at $17.94 \pm 18.69\%$. No significant differences were found in VAS percentage change 12hr post running trial (control vs. custom, custom vs. off-shelf, off-shelf vs. control) ($t(8) = 1.240$, $p = .255$, $d = .62$, moderate effect) ($t(8) = -1.101$, $p = .307$, $d = .64$, moderate effect) ($t(8) = -1.175$, $p = .278$, $d = .58$, moderate effect). At 24hr post 5km running trial, all conditions were near identical, with the control improving the perception of recovery the most at $-33.58 \pm 44.73\%$, followed by custom CG at $-24.85 \pm 35.95\%$ and then 'off-shelf' CG at $-20.98 \pm 35.42\%$. Again, no significant differences were found in VAS percentage change 24hr post running trial (control vs. custom CG, custom CG vs. 'off-shelf' CG, 'off-shelf' CG vs. control) ($t(8) = -.534$, $p = .610$, $d = .22$, small effect) ($t(8) = -.653$, $p = .535$, $d = .11$, trivial effect) ($t(8) = .770$, $p = .467$, $d = .31$, small effect).

4.5 Biomechanical Measures

Table 3: (N=8) Mean \pm standard deviation for centre of mass (COM) displacement, stride length (SL), cycle time (CT), stride rate (SR), and running velocity for each condition.

	COM	SL	CT	SR	Velocity
Control	.19 \pm .14	2.76 \pm .40	0.66 \pm .05	1.53 \pm .11	4.21 \pm .60
Custom	.13 \pm .03	2.73 \pm .41	0.65 \pm .04	1.56 \pm .10	4.26 \pm .83
Off-Shelf	.12 \pm .03	2.70 \pm .31	0.64 \pm .05	1.57 \pm .13	4.26 \pm .75

A repeated measures ANOVA showed no significant differences in any biomechanical measures ($F(8,2) = .059$, $p = .981$). Centre of mass (COM) was lowest during 'off-shelf' followed by custom CG. There was a moderate effects size between control and custom CG ($d = 0.58$), trivial effect size between custom CG and 'off-shelf' ($d = .19$) and a moderate effects size between control and 'off-shelf' ($d = .64$). Stride length was highest during control, followed by custom CG and shortest in 'off-shelf' CG. All conditions had trivial effect sizes (control vs. custom, custom vs. off-shelf, off-shelf vs. control) ($d = .09$, $d = .06$, $d = .16$). Cycle time was quickest during 'off-shelf' CG followed by custom CG and slowest during the control trial. There was a small effect size between control and custom CG $d = .30$, a trivial effect size between custom CG and 'off-shelf' CG $d = .08$, and a small effect size between control and 'off-shelf' CG $d = .35$. Stride rate was highest during 'off-shelf' CG, followed by custom CG and slowest during control. There was a small effect size between control and custom CG $d = .26$, a trivial effect size between custom CG and 'off-shelf' CG $d = .11$, and a moderate effect size between control and 'off-shelf' CG $d = .34$. Running velocity was virtually identical across both CG conditions, with trivial effect sizes in all (control vs. custom, custom vs. off-shelf, off-shelf vs. control) ($d = .06$, $d < .01$, $d = .07$). Results indicate that wearing any form of CG within this study had a mild effect on biomechanical measures.

Chapter 5. Discussion

The aims of this investigation were to compare the performance and recovery effects of wearing custom-made lower-limb CG against an 'off-the-shelf' CG and a control (running shorts), during and after a 5-kilometre running time trial.

5.1 Pressures

It is worth noting that with this study reporting multi-site pressure measurements, adds to the current body of CG literature as studies often fail to report pressures between skin and garment or cross-reference from others (Partsch, 2005). The use of custom-made CG within this study was an attempt to prevent large pressure variability previously reported in commercially available CG (Hill et al., 2015), thus maximizing any performance and recovery benefits (Brown et al., 2017; Hill et al., 2014). However, large ranges of pressures (mmHg) were measured in all types of CG (Performance Custom CG: Thigh (T)= 6-20.3, Calf (C)= 2-11.3, Ankle(A)= 2-15.3; Off-the-shelf CG: T= 4-22, C= 3.3-19, A= 0-7; Recovery Custom CG: T= 6-10, C= 11-26.3, A= 9.3-34) and the mean values presented in Table 2 display that only the recovery custom-made CG followed the recommended graduated pressure pattern (T= 8.3 ± 1.4 , C= 15.3 ± 5.7 , A= 17 ± 7.7)(Hill et al., 2015). A significantly higher pressure was reported at the ankle in the performance CG ($p=.002$, $d=2.21$, very large effect), the ankle ($p=.002$, $d=2.57$, very large effect) and calf ($p=.038$, $d=1.42$, moderate effect size) for the recovery custom-CG, in comparison to the 'off-the-shelf' CG. According to Hill et al (2015), all CG used within this study failed to meet the minimum estimated pressure required (Calf= 17.3 mmHg, Thigh= 15.1 mmHg) to elicit narrowing of the blood vessels, thus enhancing blood-flow to the working tissues (Partsch and Mosti, 2008). The performance custom-made CG reported mean pressures at the calf of 8.2 ± 3.1 mmHg, thigh of 9.4 ± 4.7 mmHg,

'off-the-shelf' CG at the calf of 7.6 ± 5.2 mmHg, thigh of 7.5 ± 6 mmHg and recovery custom-CG at the calf of 15.3 ± 5.7 mmHg, thigh 8.3 ± 1.4 mmHg). Additionally, it has been suggested that recovery garments should elicit higher pressure values due to sitting/laying making a significant difference in pressures applied (Brophy-Williams et al., 2015), however the present study failed to achieve this, thus impacting any potential recovery benefits.

5.2 Main Findings

The main findings of this study were participants produced quickest five kilometre (5km) run times at 1378 ± 144 s when wearing custom-made CG, reporting significant differences versus an 'off-the-shelf' CG ($p=.04$, $d=.24$, small effect). Aligning with Galbraith et al (2018, unpublished), Broatch et al (2018) and Kerhervé et al (2017), possible mechanisms could be a result of the external pressure gradient increasing venous return, therefore increase in blood flow will improve transportation of oxygen to the working muscles/tissues, thus prolonging the participants' ability to run at higher intensities (Broatch et al., 2018). This is supported further as maximal oxygen uptake (ml.min) values were highest when wearing the custom-made CG (2679.09 ± 590.48 ml.min), with no significant differences found versus 'off-the-shelf' ($p=.949$, $d=.02$, trivial effect) and control ($p= .134$, $d=.63$, moderate effect). In addition, maximum oxygen uptake per kilogram of body mass (ml.kg.min) was near identical between custom-made (37.69 ± 6.41 ml.kg.min) and 'off-the-shelf' (37.81 ± 4.19 ml.kg.min) CG, with no significant differences noted ($p= .944$, $d= .02$, trivial effect). Aligning with previous research (Broatch et al., 2018; Galbraith et al., 2018. Unpublished), this study suggests that wearing either garment (custom-made or 'off-the-shelf') enabled participants to better utilize oxygen, therefore reducing energy and cardiorespiratory demands and ultimately improving exercise efficiency. Interestingly, the 'off-the-shelf' CG produced slowest

times at 1413 ± 151 s with no significant differences ($p = .295$, $d = .14$, trivial effect) versus the control, with reported times of 1392 ± 149 s. No significant differences ($p = .452$, $d = .09$, trivial effect) were also noted between the custom CG and control groups, proving to cause difficulty when attempting to distinguish an overall trend for performance times. Nevertheless, in a competitive sporting environment, this study suggests that lower-limb custom-made CG will cause a small decrease in 5km running times, potentially making the difference between winning and losing. Future CG research should look to assess running economy within a controlled environment at a controlled running speed, with the introduction of localised oxygen transportation measures at the working muscles/tissues.

Biomechanical data from the present study highlighted no significant differences ($p = .981$) in any biomechanical measures, therefore rejecting the idea that CG change running gait and furthermore running efficiency (Wang et al., 2015). Centre-of-mass vertical displacement noted moderate effect sizes in both custom-made ($d = 0.58$) and 'off-the-shelf' CG ($d = .64$) versus the control, but a trivial effect size when comparing both garments ($d = .19$). A similar pattern was identified in cycle time and stride rate, with cycle time showing small effect sizes in both custom-made ($d = .30$) and 'off-the-shelf' CG ($d = .35$) versus the control, but again a trivial effect size when comparing both garments ($d = .08$). Stride rate differed from previous findings (Kerhervé et al., 2017a; Galbraith et al., 2018, unpublished), showing a small effect size in custom-made ($d = .26$) and a moderate effect size in 'off-the-shelf' CG ($d = .34$) when compared to the control, but a trivial effect size when comparing both garments ($d = .11$). Aligning with previous findings (Kerhervé et al., 2017a; Galbraith et al., 2018, unpublished), trivial effect sizes ($d < .20$) were observed in stride length across the three conditions. The majority of biomechanical measures indicate that wearing either CG was more beneficial to running

technique than the control. This demonstrates that the use of the 'off-the-shelf' CG was an effective way when implementing a blind to the study, however it may have caused a placebo effect to occur. Future studies should conduct in-depth three dimensional biomechanical analysis when investigating the performance effects of wearing CG, assessing joint angles and ranges of motion around the hip, knee and ankle, as positive changes have shown improvements in running performance (Hauswirth and Lehénaff, 2001).

One of the novel components of this study was that it investigated the effects of custom-made CG in the natural 5km running environment. Although there were no significant differences across all environmental measures ($p=.211$), the calculation of effect size displayed some meaningful differences. Temperature ($^{\circ}\text{C}$) was highest during the 'off-the-shelf' condition ($19\pm 3^{\circ}\text{C}$, vs control $d= .73$, moderate effect size, vs custom-made $d= .42$, small effect size), humidity (%) was highest during the control condition ($77.7\pm 9.61\%$, vs custom $d= .79$, moderate effect size, vs 'off-the-shelf' $d= .20$, small effect size) and wind speed (m/s) was greatest in the custom-made condition (3.1 ± 1.5 (m/s), vs control $d= 1.05$, moderate effect size, vs 'off-the-shelf' $d= .39$, moderate effect size). All of the aforementioned environmental parameters may affect running performance and skew gas analysis data, however minute ventilation (l.min) was unaffected as no significant differences ($p>.05$) or effect sizes ($d<.20$) were observed.

A potential explanation for differences in performance times were the participants' levels of motivation when completing the 5km time trial, directly impacting the level of intensity they ran at. Percentage change in blood lactate indicate that participants may have worked hardest during the control condition ($419\pm 272\%$), with a significant difference

observed verses 'off-the-shelf' CG (284 ± 206 %, $p=0.26$, $d=.56$, moderate effect). Additionally, there was no significant difference between control and custom-made CG (306 ± 263 %, $p=.237$, $d=.42$, moderate effect), but a moderate effect size suggests there was some differences between participants level of running intensity between the two trials. No significant differences were found between custom-made and 'off-the-shelf' CG ($p=.767$, $d=.09$, trivial effect), indicating that both trials were completed at equal intensities. However, it could also be suggested that the use of any type of CG may prolong the individuals ability to perform at their lactate threshold, as blood lactate change (%) was highest in the control, therefore regarded as one of the most important factors to endurance sporting success (Conley and Krahenbuhl, 1980; Costill et al., 1973; Ghosh, 2004; Hagberg and Coyle, 1983; Kumagai et al., 1982). Further research into performing at lactate threshold when wearing commercially available or custom-made CG is necessary.

Data using heart rate values, as an indirect measure of venous return, have previously suggested that wearing compression will improve end-diastolic and stroke volume, furthermore eliciting a reduction in heart rate for equal cardiac output (Broatch et al., 2018; Kraemer et al., 2004). The present study observed no significant changes to maximum heart rate in all conditions ($p>0.05$, $d<0.2$, trivial effect). Maximum heart rate was marginally higher wearing custom-made CG at 180 ± 7 bpm, followed by 'off-the-shelf' (179 ± 6 bpm) and control (179 ± 7 bpm). Average heart rate was identical across the three trials (custom-made: 169 ± 8 bpm; 'off-shelf': 169 ± 8 bpm; control: 169 ± 8 bpm), with no significant differences found ($p>0.05$, $d<0.2$, trivial effect). Consistent with previous findings (Ali et al., 2011; Dascombe et al., 2011; Kerhervé et al., 2017; Galbraith et al., 2018, unpublished), heart rate may be a less sensitive measure to changes in venous return when performing a 5km run, thus further research needs to be

conducted using physiological measures that are highly sensitive to any changes in venous return.

5.3 Recovery

To the researcher's knowledge, the present study is the first to assess the recovery benefits of custom-made lower-body CG by looking at both a physiological marker of muscle damage (creatinine kinase) and perceptual markers (VAS). Creatinine kinase levels reported inconclusive findings pre and post 5km running time trial (Control pre/post: 183 ± 122 / 214 ± 163 U/l, $p = .177$, $d = .21$, small effect, Custom pre/post: 267 ± 308 / 251 ± 305 U/l, $p = .567$, $d = .05$, trivial effect, 'Off-Shelf' pre/post: 127 ± 66 / 199 ± 89 U/l, $p = .037$, $d = .92$, moderate effect), suggesting that the experimental protocol may not have consistently elicited sufficient muscle or oxidative damage. A small and moderate effect size in the control and 'off-the-shelf' were noted pre and post 5km performance, indicating that the inescapable nature of running produced large eccentric loading, potentially eliciting some exercise induced muscle or oxidative damage (Brown et al., 2017; Fridén and Lieber, 1992; Vickers, 2001), opposed to the custom-made condition. Conversely, it can also be suggested that the custom-made CG did provide some recovery benefit, reducing the severity of exercise induced damage to occur, thus justifying no significant differences ($p = .567$) and trivial effect size ($d = .05$) calculated.

The present study observed decreases in creatinine kinase percentage changes 24 hours post 5km running time trial in both 'off-the-shelf' ($-28.87 \pm 13.90\%$) and control ($-9.38 \pm 31.09\%$) but increases in creatinine kinase percentage changes during the custom-made condition ($167.77 \pm 327.54\%$). Equivocal findings may be a consequence of the initial insufficient exercise induced muscle damage. Aligning with Galbraith et al (2018).

Unpublished), it can also be proposed that participants achieved higher work outputs when completing the custom-made trial, consequential of a preconceived belief that the custom-made CG improved running performance, potentiating a placebo effect. Additionally, creatine kinase levels have been shown to peak at 72 hours post exercise, justifying the greater increase in creatine kinase percentage 24 hours post custom-made running trial. External factors such as training regime between 5km time trials, nutritional strategies, stress levels and sleep cycles were uncontrolled within this study and are all contributing factors to the inconclusive levels of recovery achieved. Future studies should look to investigate changes in creatine kinase levels at smaller time increments when wearing CG. No significant differences were identified between all conditions (control vs. custom, custom vs. off-shelf, off-shelf vs. control) ($t(8) = -1.608$, $p = .152$, $d = .81$, moderate effect) ($t(8) = 1.708$, $p = .131$, $d = .76$, moderate effect) ($t(8) = -2.094$, $p = .075$, $d = .85$, moderate effect), aligning with Duffield et al (2010, 2008) and Jakeman et al (2010). However, moderate effect sizes were noted in all conditions, leading to the assumption that all participants fully recovered 24 hours after the 5km running trial, regardless of the experimental condition.

Differentiating from the aforementioned creatine kinase values pre and post, VAS pre and post indicated no significant differences in control ($p = .528$, $d = .25$, small effect) and custom ($p = .167$, $d = .41$, small effect), but a significant difference in 'off-the-shelf' ($p = .074$, $d = .96$, moderate effect). Small and moderate effect sizes in all conditions demonstrate that the 5km time trial run facilitated sufficient perceptual muscle or oxidative damage.

Custom-made CG improved the perception of recovery best at 12 hours post running trial at $-19.18 \pm 23.64\%$, aligning with previous studies (Duffield et al., 2010; Galbraith et al., 2018, unpublished; Jakeman et al., 2010; Pruscino et al., 2013). Exact mechanisms promoting recovery benefits when wearing CG remain inconclusive, however it has been accepted that compression of the lower limbs create an external pressure gradient, thus reducing muscle oscillation and space for the inflammatory response (Kraemer et al., 2004). The application of the lower-limb custom-made CG may have attenuated osmotic pressure within the worked muscle and decreases fluid movement into extracellular space. This in turn decreases pressure on the pain receptors, limiting the inflammatory response and moreover improving recovery (Kraemer et al., 2004). Coinciding with creatine kinase findings, VAS values noted no significant differences ($p > .05$) in percentage change 24hr post running trial, thus full recovery was achieved after 24 hours in all conditions. Furthermore, required percentage change from 12-24hr in the control ($-33.58 \pm 44.73\%$) to obtain full recovery was greater than custom-made ($-24.85 \pm 35.95\%$), with 'off-the-shelf' ($-20.98 \pm 35.42\%$) presenting similar values, highlights custom-made CG's superiority as a recovery modality (Chan et al., 2016; Duffield and Portus, 2007; Galbraith et al., 2018, unpublished; Hill et al., 2013; Upton et al., 2017). This would be most beneficial for athletes who are required to compete or train with rest periods of 12 hours or less.

5.4 Limitations and Future Research

Custom-made CG pressure values, in both performance and recovery, were not as expected by displaying large ranges of pressures and not consistently following a graduated pressure gradient. Therefore, product development or research into alternative custom-made products may need to take place. The attempt of using a blind

('off-the-shelf' CG) within this study was to overcome major limitations experienced in the majority of CG literature. Unfortunately, differences in pressure values between custom-made and 'off-the-shelf' CG may influence participants' preconceived ideas, thus leading to the assumption that any performance or recovery benefits may be attenuated to participant's self-belief. Researchers' acknowledge that self-paced 5km runs were also governed by multiple external factors such as, level of motivation, mood state, nutritional status, sleep cycle, training regime or any pre-existing fatigue. Implementing training, recovery and nutritional guidance may mitigate any potential training effects, or differences in energy metabolism. Although, abidance of these control measures is heavily reliant on participants commitment level. The present study highlighted that custom-made CG had some benefit on short term, therefore assessment of recover over smaller time frames is essential. Adoption of alternative blood biomarkers such as C-Reactive and SICAM proteins may prove essential, as they're more sensitive to exercise induced muscle damage compared to creatine kinase. When completing trials in the field the changing outside environment needs to be accounted for and potentially impacted results. To mitigate this, future research should implement distance specific task at a set speed within a controlled environment, thus providing a better indicator of CG physiological, biomechanical and psychophysiological processes.

5.5 Practical Application

The aim of this study was to compare custom-made and 'off-the-shelf' compression garments, and if they had any significant effect on 5km running performance and recovery. The present study clearly identifies that wearing lower-limb custom-made compression garments enhances 5km running performances, however exact

mechanisms remain inconclusive. Nevertheless, any marginal improvements to running time can be the difference in athletes' winning or losing. The studies data indicates that full recovery was achieved 24 hours post 5km running trial, regardless of the condition. However, wearing the custom-made compression garments enhanced recovery at 12 hours post running trial, therefore would prove most beneficial for athletes who are required to compete or train with rest periods of 12 hours or less. Research provides coaches or athletes general guidelines on product selection and application timing of the compression garments to elicit performance and recovery benefits.

Chapter 6. Conclusion

The use of lower-limb custom-made compression garments would seem to provide some performance benefit during a 5km running time trial. Primary mechanism has been suggested that compression garments create an external pressure gradient, increasing blood-flow and the efficiency of oxygen transportation to the working muscles, thus prolonging the individuals' ability to run at equal high intensities. However, the present study observed no significant differences between custom-made and 'off-the-shelf' in running economy, both of which enabled participants to better utilize oxygen and reduce cardiorespiratory demands. This can be attributed to both garments showing large variations in pressure readings, despite the assumption that custom-made would accommodate for incorrect fittings, large inter-individual pressure variability and ultimately the compression garments' effectiveness. Further research comparing custom-made to 'off-the-shelf' compression garments within a controlled environment, at a specific intensity is necessary. Custom-made compression garments improved perceptual recovery at 12 hours after the 5km time trial, however full recovery was attained at 24 hours in all conditions. Mechanisms proposed were that the external pressure gradient improved the covered limbs mechanical structure, therefore reducing space for muscle oscillation and the magnitude inflammation. Additionally, reductions in

osmotic pressure decreased fluid movement into extracellular space and facilitation of the inflammatory response. Overall, both mechanisms reduce pressure applied to the pain receptors and ultimately enhanced recovery. The current study suggest that compression garments provide some performance and recovery benefit after a 5km running time trial, but superiority between custom-made and 'off-the-shelf' compression garments remain inconclusive. Custom-made compression garments have shown to marginally reduce 5km run time and recovery time, enhancing the ability to participate in subsequent activity and ultimately achieve sporting success.

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Appendices

Appendix A- Ethics



10th October 2018

Dear Jordon,

Project Title:	The effects of custom-made compression garments on recovery and performance indicators, during and after a 5km running time trial.
Principal Investigator:	Dr Andy Galbraith
Researcher:	Jordon Bolessa
Reference Number:	UREC 1819 15

I am writing to confirm the outcome of your application to the University Research Ethics Committee (UREC), which was considered by UREC on **Wednesday 19 September 2018**.

The decision made by members of the Committee is **Approved**. The Committee's response is based on the protocol described in the application form and supporting documentation. Your study has received ethical approval from the date of this letter.

Should you wish to make any changes in connection with your research project, this must be reported immediately to UREC. A Notification of Amendment form should be submitted for approval, accompanied by any additional or amended documents: <http://www.uel.ac.uk/wwwmedia/schools/graduate/documents/Notification-of-Amendment-to-Approved-Ethics-App-150115.doc>

Any adverse events that occur in connection with this research project must be reported immediately to UREC.

Approved Research Site

I am pleased to confirm that the approval of the proposed research applies to the following research site.

Research Site	Principal Investigator / Local Collaborator
UEL, Docklands Campus & Run England 5km park course	Dr Andy Galbraith



Approved Documents

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

<i>Document</i>	<i>Version</i>	<i>Date</i>
UREC application form	2.0	4 October 2018
Participant Information sheet	1.0	6 September 2018
Consent form	1.0	6 September 2018
BASES Pre-test questionnaire	1.0	6 September 2018
Debrief sheet	2.0	4 October 2018

Approval is given on the understanding that the [UEL Code of Practice in Research](#) is adhered to.

The University will periodically audit a random sample of applications for ethical approval, to ensure that the research study is conducted in compliance with the consent given by the ethics Committee and to the highest standards of rigour and integrity.

Please note, it is your responsibility to retain this letter for your records.

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

Yours sincerely,

Fernanda Silva
Administrative Officer for Research Governance
University Research Ethics Committee (UREC)
Email: researchethics@uel.ac.uk



Compression Garment Study 2019 Recruitment Questionnaire

This is a quick recruitment questionnaire to express your interest in participating in the 2019 Compression Garment Study at the University of East London. This does not mean you are now fully committed as we will be selecting participants out of this recruitment pool and I would like to thank you for expressing your interest.

Kind Regards
Jordon

Email address *

Valid email address

This form is collecting email addresses. [Change settings](#)

Full Name *

Short answer text

Gender

- Female
- Male
- Prefer not to say
- Other...

D.O.B *

Month, day, year



Height (cm)

Short answer text

Phone number

Short answer text

Availability for the following dates (Will take 15 minutes)?

- 9th March 2019
- 16th March 2019
- 23rd March 2019
- 30th March 2019

Section 2 of 3



Running History

Description (optional)

Training History (How often do you train? What are you training for? What does your typical training week look like?) *

Long answer text

Top 3 competition accomplishments and dates, do not worry if you haven't got a total of 3 (This can be from a park run time - marathon time) *

Long answer text

5km PB Time

Short answer text

Compression Garment Use

Description (optional)

Do you use compression garments? *

Yes

No

If yes, what brand do you use?

Short answer text
.....

Select your compression garment size based on the image below? *

S

M

L

XL

2XL

Appendix C- Participant information Sheet

INFORMATION SHEET FOR PARTICIPANTS

Programme of Study: MRes Sport and Exercise Science

Title of Project: Custom-made compression garments in sport; Do they work for performance and recovery?

Dear Participant,

You are being invited to take part in a research study. Before you decide whether 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 ask us 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.

What is the purpose of the study?

- The growing research into physical and mental recovery over recent years indicates the importance it has on daily performance. Improving recovery within sport is crucial and has been stated as a major factor when achieving sporting success. The purpose of this study is to assess the effects of compression garments on running performance and recovery.
- You need to be aged between 18-50, with a minimum of 3 years of training experience, one-year competitive running experience and injury free. You need to be clear of any medication, not a smoker and 24 hours before all visits free from alcohol consumption and any intense training/competition.

What will I have to do if I take part?

You will be asked to initially visit the UEL Sports Science Laboratory. Various measurements will be taken from your legs, waist and hips so your 'custom made' compression garments can be made.

Visits 1-3 will take place over a three-week period and take place on an approved Run England 5km park course, exact location may differ between participants. You will be asked to complete the 5km park course, with the aim to cover the distance in the fastest time possible. If you are given a pair of compression garments, you will be required to wear them during the 5km running trial and 8 hours after. Compression garments or running short will be randomly allocated between each of your visits. Running time, heart rate and expired air through a special mask that will cover your mouth and nose, will be measured during these runs. In addition, a number of surface probes will be attached to the skin surface of your hips, knees, ankles and foot. During sections of the runs you will be filmed with a digital video camera, to allow us to measure your running technique. A fingertip blood test will be collected before, immediately after, 12 hours and 24 hours after each running trial, allowing markers of exercise recovery to be measured. You will also be required to complete a muscle soreness questionnaire before, immediately after, 12 hours and 24 hours after each run.

What are the possible advantages of taking part?

- You will be provided with a full write up detailing your results across the three tests.
- You will be able to keep your very own 'custom-made' compression garments.

What are the possible disadvantages or risks of taking part?

- The potential disadvantages of taking part is that you're at risk of injury and muscle soreness that could last for 5-7 days.

Do I have to take part?

You are under no obligation to participate in this study. If you do decide to take part, you are free to withdraw at any time without giving a reason. If you do not take part or withdraw from the study at a later date, it will not disadvantage you.

What will happen to the information?

Your participation in this study and all information collected will be kept strictly confidential. Where necessary, information collected will be coded so that you cannot be recognised from it. The results of this study will be reported as part of my degree programme and may be further disseminated for scientific benefit. The results will be available to you on request.

Who should I contact for further information or if I have any problems/concerns?

- Student Name: Jordon Bolessa
- Email: u1405642@uel.ac.uk

- Supervisor Name: Andy Galbraith
- Email: A.J.Galbraith@uel.ac.uk

Appendix D- Physical Activity Readiness Questionnaire (Par-Q)

Physical Activity and Readiness Questionnaire PAR-Q and YOU



Please read the following questions carefully and tick the appropriate box for each question. If you have any doubts or queries please ask.

Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?

Yes No

Do you feel pain in your chest when you do physical activity?

Yes No

In the past month, have you had chest pain when you were not doing physical activity?

Yes No

Do you lose your balance because of dizziness or do you ever lose consciousness?

Yes No

Do you have a bone or joint problem that could be made worse by a change in your physical activity?

Yes No

Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?

Yes No

Do you know of any other reason why you should not do physical activity?

Yes No

If you answered **NO** to all questions

If you answered Par-Q honestly, you have reasonable assurance of your present suitability for:

- **A graduated exercise programme.** A gradual increase in proper exercise promotes good fitness development while minimising or eliminating discomfort
- **A fitness appraisal.** Simple or more complex test of fitness

If you answer **YES** to one or more questions

If you have not recently done so, consult your doctor **BEFORE** increasing your physical activity or **BEFORE** a fitness appraisal

Name _____ Date _____

Signature _____

Appendix E- Photography and Video Recording Consent Form

Consent for Photography/ Visual Recordings



Project title: The effects of compression garments on recovery and performance indicators, during and after high-intensity running

Dear Participant,

Thank you for agreeing to take part in the above study. We would like to take some visual recordings of you while you are working with us during the course of the study. We will use the recordings for Data Analysis in order to determine various biomechanical variables during your running and we will ensure that your identity is obscured on the recordings. You do not have to be recorded and it will not affect your participation in the study. We will ask you to complete this form only if you are happy and willing to have your visual recordings taken for the above purposes.

I, the undersigned, freely consent to visual images being taken and used for the purpose stated above.

Participant Name:

Participant Signature:

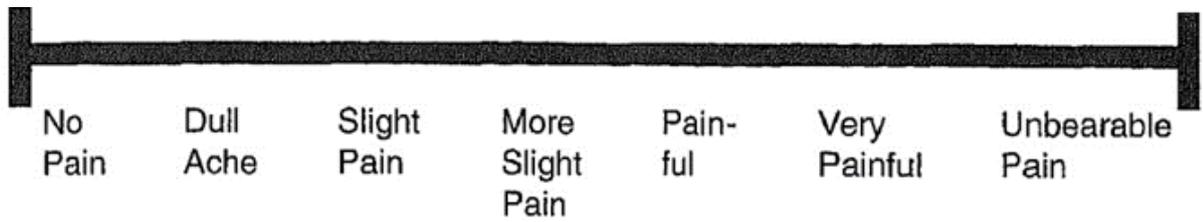
Date:

Witness Name:

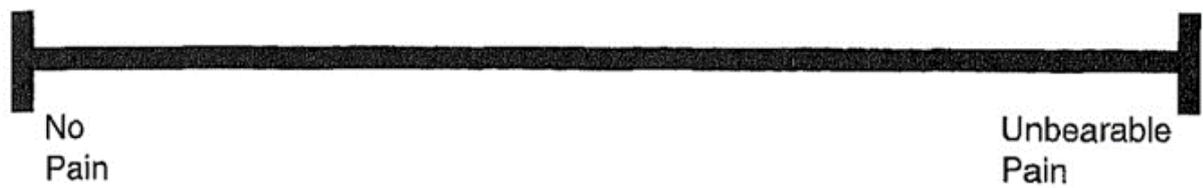
Witness Signature:

Date:

Appendix F- Visual Analogue Scale (VAS)



Graphic Rating Scale



Visual Analog Scale

Appendix G- Biomechanical Analysis on Tracker Software

Tracker

File Edit Video Track Coordinate System View Help

Now available: version <DOCTYPE HTML PUBLIC "-//IETF//DTD HTML 2.0//EN"> <html><head> <title>301 Moved Permanently</title> </head><body> <h1>Mov

Plot **Iliac Crest**

Iliac Crest (t, x)

x (m)

t (s)

t=2.536 s x=0.472 m

Table **Iliac Crest**

t (s)	x (m)	y (m)
2.009	0.673	0.972
2.102	0.667	0.966
2.135	0.656	0.961
2.169	0.644	0.955
2.202	0.626	0.948
2.236	0.612	0.942
2.269	0.594	0.933
2.302	0.581	0.928
2.336	0.559	0.920
2.369	0.546	0.914
2.402	0.532	0.909
2.436	0.518	0.903
2.469	0.504	0.899
2.502	0.489	0.894
2.536	0.472	0.890

x=-0.459 y=-0.194

076 100%

Charlotte F Custom-Gate A.trk

Appendix H- Biomechanical Equations

Running Velocity

$$SL / CT$$

SL= Stride Length

CT= Cycle Time

Stride Rate

$$VT / SL$$

VT= Running Velocity

SL= Stride Length

Appendix I- Risk Assessment

Risk Assessment Form

Assessment no:

Brief outline of work/activity	Custom-made compression garments in sport; Do they work for performance and recovery?	Assessor:	Jordon Bolessa
Location	ASES Laboratory (Sports Dock) Approved Run England 5km park course, with local courses including; Beckton Parkrun, Victoria Dock Parkrun, Mile End Parkrun, Hackney Marshes Parkrun, Wanstead Flats.	Signed off by Head of School or H&S coordinator	

Hazards identified	Who might be at risk	Existing controls	Likelihood H M L	Severity H M L	Residual risk 1-9	Additional control measures required	Date actioned	Estimated residual risk
Participants experiencing musculoskeletal injury during exercise.	Participants	Participants complete a ParQ health screening test prior to exercise, to ensure there are no contraindications to exercise. Participants are accustomed to running a 5km time trial. Participants instructed to perform warm up/stretching prior to exercise. Visits 1-3, participants are able to self select their running pace and free to stop at any time. First aid will be on hand. A first aider will be present for all exercise trials.	L	M	2		19/10/2018	

Risk of infection from gas analyser mask	Participants and Researchers	Participants will all use a different mouthpiece, which has been cleaned with a safe disinfectant called descogen (15g of powder to every 1L of warm water), check COSHH Risk Assessment for more details. Researchers will wear gloves when handling mouthpieces.	L	L	1		19/10/2018	
Cross contamination during blood sampling.	Participants and Researchers	Researchers will be wearing sterile gloves when handling blood sampling. Clinical waste will be appropriately disposed of in a sharps bin and incinerated. Single use, retractable lancets will be used. Researchers will get a hepatitis B vaccination.	L	L	1		19/10/2018	
Slip or trip hazards along the approved Run England 5km park course.	Participants and Researchers	Before the commencement of visit 1-3, the researcher will perform a thorough check of any slip or trip hazards along the course, and remove them if necessary. The researcher will verbally inform the participants of the current parkrun conditions, as they may be subject to change. A first aider will be present for all exercise trials.	L	M	2		19/10/2018	

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KEY

Likelihood

- L.** Low (seldom) [1 point]
- M.** Medium (frequently) [2 points]
- H.** High (certain or near certain) [3 points]

Severity

- L.** Slight (less than 3 days off work) [1 point]
- M.** Serious (over 3 days off work) [2 points]
- H.** Major (major injury/death) [3 points]

Residual Risk (Likelihood x Severity)

- 1 - 2** No action/low priority
- 3 - 4** Medium
- 6 - 9** High priority/urgent action

Review Date

19/10/2020



					le lan cet s	cin ation		
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Laboratory Containment Level (directly related to Hazard Group of the biological agent-see Appendix for definition. Work must be conducted at the containment level appropriate to the Hazard Group).

Additional Control Measures

Detail the operation, which will be undertaken with the above chemicals/biologicals:
15g of Descogen Powder, 1L of warm water
Sterile gloves will be worn at all times, a single use retractable lancet will be used and all waste disposed of in a sharps bin.

What measures will be undertaken to reduce the risk to the operator and/or the environment?
Reduce the risk of infection from gas analyser mask.
Reduce the risk of cross contamination during blood sampling.

What equipment will be used to perform these procedures?
Safe disinfectant.
Sterile gloves.
Single use retractable lancets.

Has the equipment been checked for safety?*	X
Will the users be trained to carry out their task?*	X
Will all users be trained to use the protective equipment correctly?*	X

Who will provide the training? University of East London, Human Physiology Team

Procedures for monitoring, if required.

Health surveillance, if required.

*The answers to these questions must be "yes" before progressing

Chemical/ Procedure	Concentration/ Volume/Quantity	Hazard Index (HI)	Occurrence Index (OI)	Assessment Index (HI X OI)
Descogen	15g per 1L of warm water	1	1	1

Key

Hazard Index (HI) L. Slight (less than 3 days off work) [1 point] M. Serious (over 3 days off work) [2 points] H. Major (major injury/death) [3 points]	Occurrence Index (OI) L. Low (seldom) [1 point] M. Medium (frequently) [2 points] H. High (certain or near certain) [3 points]	Assessment Index (Hazard x Occurrence) 1 – 2 No action/low priority 3 – 5 Medium 6 – 9 High priority/urgent action
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Estimate of Exposure

Risk	Technician	Student	Researcher	Tutor	Cleaner
High					
Medium					
Low	X	X	X	X	X



School of Health, Sport and Bioscience
University of East London

There are no less hazardous reagents or biologicals that can be used in this procedure and the precautions listed on the form together with good laboratory practice will reduce all associated risks to a negligible level.

		02/08/2017
Name (Academic/H&S committee)	Signature	Date