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Title: Investigate the effects of a self-myofascial release (SMR) warm up on the endurance performance of athletes, using a ten-kilometre cycling time trial

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1.0 ABSTRACT

Self-myofascial release has become a popular pre-event warm up technique to enhance performance, however, the literature on self-myofascial release is rudimentary and there is a lack of empirical evidence supporting that a self-myofascial release warm up improves performance. The purpose of this study was to investigate the effects of a self-myofasical release warm up on the endurance performance of athletes, using a ten-kilometre cycling time trial. Twelve club level cyclists (n = 12) consisting of nine males (Age = 40.0 ± 1.9 yrs; Height = 180.6 ± 2.7 cm; Weight = 77.4 ± 2.6 kg) and three females (Age = 33.3 ± 3.7 yrs; Height = 163.1 ± 5.8 cm; Weight = 57.8 ± 4.7 kg) volunteered to take part in the study. A counterbalanced, cross over within subjects design was used, with participants switching between two experimental conditions. Trial A consisted of a non-foam rolling warm up, flexibility measurements and ten-kilometre time trial. Trial B comprised of a ten-minute foam rolling warm up, flexibility tests and a ten-kilometre time trial. Paired-samples t-tests found no significant differences for time taken ($p = 0.37$), peak power ($p = 0.97$) and fatigue index ($p = 0.60$) between both trials. Non-significant blood lactate differences were reported by a one-way ANOVA at 2km ($p = 0.66$), 4 km ($p = 0.63$), 6 km ($p = 0.56$), 8 km ($p = 0.94$) and 10 km ($p = 0.51$) between both trials. A Wilcoxon signed-rank test found no significant differences in left leg quadriceps ($p = 0.61$), right leg quadriceps, ($p = 0.56$), left leg hamstring, ($p = 0.88$) and right leg hamstring ($p = 1.00$) flexibility between both trials. Non-significant fatigue differences were also reported by a Wilcoxon signed-rank test at 2km ($p =0.75$), 4 km ($p = 0.86$), 6 km ($p = 0.66$), 8 km ($p = 0.74$) and 10 km ($p = 0.43$) between both trials. The self-myofascial release warm up had no significant impact on the time trial performance of cyclists, which suggests a self-myofascial release warm up should not be used as a pre-event technique to enhance physical performance.

Keywords: Self-myofascial release, foam rolling, peak power, blood lactate, fatigue index, flexibility, cyclists, fascia, microtrauma.

2.0 INTRODUCTION

Regular physical exertion can result in fatigued metabolic, nervous and musculoskeletal systems (Pearcey, et al., 2015), or lead to soft tissue microtrauma and muscle damage (Cantu and Grodin, 2001; Healey, et al., 2014). The degree of muscle damage, discomfort or inflammation depends on the duration, type and intensity of exercise performed (Pearcey, et al., 2015). Exercise induced muscle damage (EIMD) after high intensity exercise disrupts the extracellular matrix and intracellular muscle structure, causing micro-tears in the muscle fibers (Jay, et al., 2014), which leads to the delayed onset of muscle soreness (DOMS) and its associated impairment of soft tissue function (Cheung, Hume and Maxwell, 2003; Pearcey, et al., 2015). A study by Dick (2006) into the cause of athletic injuries for the National Collegiate Athletic Association found that 87.3% of athletic injuries were soft tissue injuries.

Soft tissue dysfunction is initiated by physical microtrauma, overuse and the inflammatory process associated with DOMS, which decreases performance and causes restrictions in the fascia (Cantu and Grodin, 2001; Curran, Fiore and Crisco, 2008). Fascia, described as a soft connective tissue containing numerous nerve endings and mechanoreceptors (Yahia, et al., 1992; Barnes, 1997; Benjamin, 2009), permeates the whole body in a supportive three-dimensional web that transmits mechanical forces between muscles within the myofascia (Findley, et al., 2012). Physical trauma and inflammation triggers the myofascia to tighten and lose its elasticity as a physiologic and biomechanic protective mechanism (Barnes, 1997; Macdonald, et al., 2013). The inelastic myofascia binds to traumatised areas within the myofascial system; causing fibrous adhesions called trigger points (Beardsley and Skarabot, 2015) that prevent normal muscle mechanics and decrease soft-tissue extensibility (Curran, Fiore and Crisco, 2008). As a result the fascial components lose their functional properties and pliability, which inhibits muscle movement, function, strength, endurance and joint range of movement (ROM) (Barnes, 1997; Curran, Fiore and Crisco, 2008).

Massage therapy has been used for centuries to treat soft tissue dysfunction and restrictions (Weerapong, Hume and Kolt, 2005), through a mechanical manipulation of body tissues that increases vasodilation of the arterial system, thereby promoting nitric oxide production (Okamoto, et al., 2014), which increases blood flow to the affected tissues for improved recovery after physical activity (Cafarelli and Flint, 1992; Peacock, et al., 2014). Over the last ten years traditional massage has been supplemented by a new technique to treat the soft tissue called myofasical release (MFR) (Healey, et al., 2014). MFR releases restrictive barriers and fibrous adhesions present within layers of fascial tissue, through the manual application of pressure until a trigger point release is felt (Barnes, 1997). More recently, self-myofascial release (SMR) has enabled individuals to treat soft tissue restrictions without a therapist (MacDonald, et al, 2013), by applying their own pressure to the damaged tissue using a foam roller (FR). Normal tissue extensibility is restored through small undulations that use body mass to place direct and sweeping pressure on the myofascial mechanoreceptors, to stimulate a trigger point release via the nervous system (Schleip, 2003a; Sefton, 2004).

Various authors (Callagan, 1993; Weerapong, Hume and Kolt, 2005; Best, et al., 2008; Arroyo-Morales, et al., 2009) claim numerous physiological benefits are experienced by athletes who use massage before and after exercise, including reduced muscle pain, swelling and spasm as well as increased skin and muscle temperature, blood flow, joint flexibility and ROM. Furthermore, they suggest it decreases muscle tension, stiffness and fatigue in addition to increasing performance and recovery. Hilbert (2003) claims that post exercise massage is commonly used to prevent DOMS, however, there is a lack of studies on the effects of massage on muscle recovery, injury prevention and physical performance (Weerapong, Hume and Kolt, 2005). In contrast, Ogai, et al. (2008) claims that massage applied before exercise will improve exercise performance, despite a lack of empirical evidence supporting its use in this respect (Goodwin, et al., 2007).

SMR is commonly used as a recovery method to preserve physical performance and correct muscular imbalances, improve joint ROM, relieve muscle soreness and improve neuromuscular efficiency (Barnes, 1997; Curran, Fiore and Crisco, 2008; Stevens, 2013; Pearcey, et al., 2015). Although foam rolling is commonly used for recovery there is a distinct lack of quantifiable scientific evidence to support the effectiveness of foam rolling and the perceived benefits are essentially anecdotal (Stevens, 2013; MacDonald, et al., 2014). Foam rolling has become a popular warm up technique to improve muscular efficiency and functioning (MacDonald, 2014), by correcting abnormal joint movement, improving force couple relationships and restoring length-tension relationships within the muscle (Clark and Lucett, 2010). Additional claims suggest that foam rolling before exercise enables athletes to increase their volume of training and decrease the dysfunctions that result from microtrauma of the muscle and myofascia during exercise (Stevens, 2013; Healey, et al., 2014). However, the literature on SMR is rudimentary, with no peer reviewed research investigating whether SMR actually enhances performance when used as a warm up technique (MacDonald, et al., 2014).

3.0 LITERATURE REVIEW

3.1 Physiological Review

Ischemic Compression

Ischemic compression (IC) is a rehabilitation technique that induces a state of temporary ischemia to an area of damaged tissue through the application of localised pressure, which restricts blood flow to the compressed area (Lavelle, Lavelle and Smith, 2007). When released blood flow is increased to the area, which supplies oxygen and removes waste products to stimulate healing of the tissue (Montanez-Aguilera, et al., 2010). Foam rolling is based on the concept of IC, where an individual uses their body weight as pressure to treat restrictions within the soft tissue (Healey, et al., 2014). Despite these claims, it is questionable whether or not foam rolling applies enough force to induce the physiological mechanisms associated with IC (Sullivan, et al., 2013).

Myofascial Release

MFR is classified as an IC technique, where a therapist places direct pressure on adhesions in the myofascia or ‘knots’ in the muscle, known as trigger points. Pressure is continuously applied to the muscle belly until a release is felt (Lavelle, Lavelle and Smith, 2007). It has been suggested that the physiological mechanism behind MFR involves stimulation of mechanoreceptors within the myofascia, which excites both the central nervous system (CNS) and autonomic nervous system (ANS) resulting in a trigger point release, nevertheless, these theories are still to be proven (Mitchell and Schmidt, 2011). In support of such claims, it has been shown that MFR increases flexibility (Beardsley and Skarabot, 2015) and Wiktosson-Moller, et al. (1983) found both an MFR and static stretching warm up increased ankle ROM. However, static stretching increased the ROM of more lower limb extremities, which questions the physiological mechanisms behind MFR when compared to stretching (Weerapong, et al., 2005).

Central Nervous System and Autonomic Nervous System

The CNS and ANS are activated simultaneously when mechanoreceptors are stimulated. In response to localised pressure, the CNS changes the tone of affected muscle fibers and facilitates the trigger point release experienced during MFR (Schleip, 2003a). Lighter MFR pressure is thought to stimulate interstitial type III and IV receptors (Mitchell and Schmidt, 2011), whereas deep sustained MFR pressure excites fascia Ruffini endings (Schleip, 2003a; 2003b; Clark and Lucett, 2010). Various authors (Johansson, 1962; Schleip, 2003a; 2003b; Clark and Lucett, 2010) suggest overall sympathetic tone is lowered and gamma motor neuron activity is increased when the receptors are stimulated, causing intrafascial smooth muscle cells to relax. Furthermore, a trigger point release and its associated improvement in muscle function occur as the ANS modifies fascia viscosity, making a gel-like substance through vasodilation and fluid dynamics (Dalaney, et al., 2002; Schleip, 2003b; Clark and Lucett, 2010). Despite these claims, the smallest surface pressure required to excite interstitial type III and IV receptors has not been reported (Mitchell and Schmidt, 2011). However, Threlkeld (1992) reported it would take a force greater than 24 kg to change the fascia viscosity, which is a prerequisite for trigger point release. Furthermore, Sullivan, et al. (2013) found 13 kg was the highest amount of pressure applied to the fascia during foam rolling, which places doubt over the ability of MFR to provoke a trigger point release by influencing the CNS and ANS.

Trigger Points

Lavelle, Lavelle and Smith (2007) argue that trigger points develop from the microtrauma experienced during daily exercise, which causes muscles to tighten up and attach to the surrounding tissue. As a result the formed trigger points reduce soft tissue elasticity and create a weak inelastic matrix by shortening the muscle (Clark and Lucett, 2010). The overall result is a reduction in athletic performance due to altered muscle length-tension relationships, force-couple relationships, reciprocal inhibition and abnormal joint motion (Gossman, Sahrmann and Rose, 1982; Clark and Lucett, 2010).

Conversely, Simons, Travell and Simons (1998) identified a lack of concrete pathophysiologic research had been conducted on the formation of trigger points, concluding that the mechanisms behind their formation are unknown. These findings undermine the beliefs of various authors (Gossman, Sahrmann and Rose, 1982; Lavelle, Lavelle and Smith 2007; Clark and Lucett, 2010) about the formation of trigger points and their subsequent impact on athletic performance.

Self-myofascial release

SMR is a subset of MFR involving an object, normally a FR and the individuals own body weight to initiate a trigger point release. Foam rolling involves an individual controlling the amount of pressure applied to the trigger point by sitting or lying on a foam cylinder and rolling in a distal to proximal direction (MacDonald, et al., 2012). Ultimately, it is thought that foam rolling can remove trigger points and improve performance by restoring normal muscle function, therefore making it a popular pre-event warm up technique (Clark and Lucett, 2010).

3.2 Massage Review

Post-Event

Massage is a frequently used technique to accelerate recovery after exercise as it’s believed to remove accumulated extracellular fluid, reduce swelling and blood lactate through increased blood and lymph circulation (Moraska, 2005; Kargarfard, et al., 2016). Despite its popularity, limited scientific evidence exists to support the use of massage post-event to promote recovery. The majority of massage application used is based on coaches or athletes believing it increases blood flow, reduces neurological excitability or muscle tension, but these claims have little supporting empirical data (Weerpong, Hume and Kolt, 2005). In general, previous studies conducted on massage are criticised for their methodological approach, with limitations including no control group, no information on message techniques, no mention of statistical analysis or an inappropriate study design (Robertson, Watt and Galloway, 2004; Weerpong, et al., 2005; Arroyo-Morales, et al., 2008).

Robertson, Watt and Galloway (2004) reported no significant difference in blood lactate recovery after a Wingate test ($p = 0.82$), or in peak power ($p = 0.75$) between twenty minutes of leg massage or passive rest. The massage trial did, however, record a significantly lower fatigue index ($p = 0.04$). The lack of significant lactate clearance indicates that no change in muscle blood flow or lactate efflux occurred after massage (Robertson, Watt and Galloway, 2004). The subjects' inability to produce more peak power following the message intervention could be a result of reduced neural activation and force-generating capacity due to a change in muscle stiffness (Fowles, et al., 2000). Additionally, the significantly improved fatigue index profile ($p = 0.04$) could also be linked to the impact of massage on reducing muscle stiffness and therefore reducing the muscles force-generating capacity (Robertson, Watt and Galloway, 2004). A limitation of the study is its use of a small male only sample size ($n = 9$) of non-cyclists, which are common design limitations associated with massage studies (Weerpong, Hume and Kolt, 2005).

Ogai, et al. (2008) also found a significant difference in lower limb fatigue ($p < 0.05$), following a study into the effects of a ten-minute leg massage between two bouts of intensive cycling intervals. Despite similar findings a direct comparison of results is not possible due to the different methodology used by each study. Robertson, Watt and Galloway (2004) used a PC interface to calculate fatigue based on power and time, whereas Ogai, et al. (2008) measured the subjects rate of perceived fatigue using a visual analogue scale. Furthermore, Ogai, et al. (2008) used an unsuitable massage time of ten minutes, with research suggesting twenty to thirty minutes is required for an effective massage (Watt, 1999).

Ogai, et al. (2008) also reported a significant increase in total power ($p < 0.01$), concluding that the result proved massage improves high intensity cycling performance. However, these results suffer from a small bias sample ($n = 11$) of female university students (Gratton and Jones, 2010). In contrast, Arroyo-Morales, et al. (2008) discovered MFR significantly reduced the electromyography (EMG) amplitude of the Vastus Medialis (VA) muscle ($p = 0.02$), following a forty-minute massage after a Wingate test. As a result, the authors suggest massage recovery protocols should be avoided before a competition to avoid any negative effects on performance, as the reported drop in EMG amplitude could reduce muscle strength. EMG amplitude has been associated with muscle fiber tension and length, with a stretched muscle experiencing a transient loss of strength, due to a suggested drop in motor unit action potentials and firing rate (Arroyo-Morales, et al., 2008). However, these results can be argued as inconclusive as the study used no direct evaluation of muscle strength during EMG activity. Despite these studies looking at the effects of massage on cycling, neither of them addressed its effects on endurance and further studies into the effects of massage for different events has been recommended (Ogai, et al., 2008).

Pre-Event

Massage is often used before athletic activity as a method of improving performance (Callaghan, 1993) even though there is a lack of empirical evidence to support its pre-event benefits (Weerpong, Hume and Kolt, 2005). Wiktorsson-Moller, et al. (1983) reported lower muscle strength results during isokinetic dynamometry, when measured after fifteen minutes of full-body massage, however, no statistical evidence was reported to indicate if the results were significantly different. Ask, et al. (1987) discovered that a ten-minute massage increased muscle power by 11% during a leg extension test, when compared to passive rest, which highlights a disparity between studies of muscular strength and power. Another study into the effects of pre-event massage using isokinetic dynamometry (Arroyo-Morales, et al., 2011) did report a significant decrease in muscle strength ($p < 0.05$) following a twenty-minute massage. In view of these findings, their validity towards endurance cycling is questionable, due to isokinetic dynamometry not being representative of performance in functional activities (Arroyo-Morales, et al., 2011). Furthermore, the majority of studies investigating the effects of pre-event massage on strength and power have cited either no performance effects or impaired performance (Hunter, et al., 2006; McKechnie, Young and Behm, 2007; Arabaci, 2008; Brummitt, 2008; Fletcher, 2010; Arroyo-Morales, et al., 2011; Arazi, Asadi and Hoseini, 2012). The negative impact of pre-event massage on muscle performance has been attributed to an, "increased parasympathetic nervous system activity and decreased afferent input with resultant decreased motor-unit activation" (Arroyo-Morales, et al., 2011, p.1).

In 1991 two studies (Boone, Cooper and Thompson, 1991; Harmer, 1991) established that massage had no physiological impact during treadmill running or sprinting. Both studies suffered from the same methodological limitations of low subject numbers, no placebo and no control over massage protocols, making the results difficult to apply towards cycling performance. All these factors are commonly identified as limitations in massage studies (Weerapong, Hume and Kolt, 2005). Goodwin, et al. (2007) recommended that massage should not be included as an important part of a warm up routine after discovering that a fifteen minute massage had no significant impact ($p > 0.05$) on subsequent thirty-meter sprint times. Some of the common methodological issues already highlighted for massage studies were addressed, however, Goodwin, et al. (2007) only used male subjects, therefore excluding the effects of pre-event massage on female athletic populations. None of the reviewed studies explored the impact of pre-event massage on endurance cycling and more research is required into the impact of pre-event massage on performance because of the inconsistent methodology and variables used (Goodwin, et al., 2007).

3.3 Foam Rolling Review

Post-Event

Foam rolling is regularly used after physical activity to promote recovery, increase ROM, alleviate muscle soreness, improve neuromuscular efficiency and promote optimal muscle functioning (Barnes, 1997; MacDonald, et al., 2013). However, measureable scientific evidence to corroborate its use as a recovery tool is rudimentary and requires further investigation (MacDonald, et al., 2014). One study into the effects of foam rolling on vascular stiffness and endothelial arterial function does support the theory that foam rolling improves blood flow, by discovering reduced vessel stiffness and improved arterial function (Okamoto, Masuhara and Ikuta, 2013). Despite these findings, the study failed to relate its discoveries to their impact on muscular performance.

Foam rolling is well known for increasing flexibility (Beardsley and Skarabot, 2015) and to date, two studies have examined its acute effects on joint ROM post-event. Roylance, et al. (2013) reported no improvements in joint ROM when foam rolling was used between two sit and reach tests. The study failed to report a P value, an exact time of foam rolling, the use of a control group or the amount of pressure exerted on the FR. Beardsley and Skarabot (2015) imply that higher pressures lead to greater increases in joint ROM, therefore, making these instructions an integral part of methodology for foam rolling studies. In opposition, a study by Skarabot, et al. (2015) found thirty seconds of foam rolling significantly increased ROM ($p < 0.05$) of the planter flexors using a weight-bearing lunge test. The authors encouraged each participant to apply as much pressure as they could but no standardisation was used, nonetheless, a Post Hoc test revealed an increase in ROM was only significant ($p < 0.05$) when foam rolling was combined with static stretching. Therefore, a conclusion as to whether or not foam rolling improves ROM post-event is inconclusive given the vast differences between the study protocols, including volume of foam rolling, applied pressure, ROM tests and muscle groups used (Beardsley and Skarabot, 2015).

A further two studies have explored the effects of post-event foam rolling, MacDonald, et al. (2014) investigated foam rolling as a recovery technique for EMID and Pearcey, et al. (2015) looked at its effectiveness as a recovery instrument for DOMS. MacDonald, et al. (2014) stated that muscle soreness dropped by 98% whilst vertical jump height, ROM and muscle activation all increased by 1%, 13% and 1%, respectively, when compared to rest. The authors hypothesized an increased ROM was due to foam rolling reducing inflammation and muscle soreness, thereby increasing the flow of built up interstitial fluid back into circulation. Likewise, Pearcey, et al. (2015) found foam rolling compared to rest reduced DOMS at twenty-four hours post exercise (74%) and forty-eight hours post exercise (94%). The results of both studies are limited due to poor samples, MacDonald, et al. (2014) used solely male subjects (n = 20) and Pearcey, et al. (2015) recruited low numbers (n = 8). Additionally, both studies used an insufficient rolling time of forty-five seconds, with sixty to ninety seconds having been suggested as the correct amount of time required for a trigger point release to be felt (Paolini, 2009).

Each study implemented a different rolling technique, with MacDonald, et al. (2014) working from the proximal aspect of the limb to the distal end and Pearcey, et al. (2015) rolling from the distal end to the proximal end. Stevens (2013) suggests the most effective technique is to role the limb in a distal to proximal direction as it matches the flow of lymph and venous return. Foam rolling should begin with long light rolls and finish with short, intense movements (Stevens, 2013). In comparison, neither study adopted these techniques with MacDonald, et al. (2014), employing small undulating movements and Pearcey, et al. (2015) using a set cadence of fifty beats per minute. In conclusion, neither study researched the impacts of foam rolling after endurance events and further research is required into the specific benefits of foam rolling (Stevens, 2013).

Pre-Event

MFR has commonly been used as a post-event therapeutic technique to aid recovery from exercise. More recently, SMR using a FR has become a popular pre-event technique to treat the soft tissue dysfunctions associated with exercise-induced microtrauma and enhance performance (Peacock, et al., 2014). Alternatively, claims suggest a SMR foam rolling warm up will improve performance by increasing mobility and neuromuscular efficiency (Healey, et al., 2014). However, there is limited clinical data to support such claims (Curran, Fiore and Crisco, 2008). To date, four studies have investigated the effects of a foam rolling warm up on performance.

A study by MacDonald, et al. (2013) reported a foam rolling warm up significantly increased knee joint ROM (p = 0.001) by 12.7%, without decreasing quadriceps activation, evoked or maximum voluntary contraction (MVC) force under isometric contractions. Furthermore, a significant ($p < 0.01$) negative correlation between subjects' ROM and force production no longer existed after the sixty second foam rolling quadriceps warm up compared to a non-foam rolling control. These findings are not without limitations and can only be taken as estimation, due to the ROM testing method. Accurate tests for measuring knee flexion are difficult due to some individuals being able to flex the knee until the heel contacts the gluteus muscle group (MacDonald, et al., 2013). In this case four out of the eleven subjects touched their glutes, preventing a true ROM measurement. Additionally, it is debatable if these results can be interpreted for dynamic movements and cycling, as they are based on a static ROM test and a test of isometric force production.

The discovered increase in ROM was explained by a change in fascia thixotropic (fluid-like form) property. Under normal conditions the fascia has a gel-like form, repeated stress and overuse causes the fascia to form scar tissue and become more viscous and solid, therefore, restricting ROM. Foam rolling is thought to break down the scar tissue and return fascia back to its gel-like form (Threlkeld, 1992; Stone, 2000;). Additionally, the pressure placed on the muscle by foam rolling is of major importance (Sullivan, et al., 2013) and could cause the golgi tendon organ to detect a change in muscle tension and stimulate the muscle spindles to relax (Miller and Rockey, 2006).

Another study (Sheffield, 2013) reported foam rolling had significantly increased flexibility, however, a direct comparison between the two studies is limited by different methodologies. Sheffield (2013), found a foam rolling warm up increased hamstring flexibility when tested by the active knee extension test (AKE) before a football training session. The study used a female only sample (n = 15) that performed foam rolling from the origin of the hamstrings to the posterior aspect of the knee. Subjects were instructed to roll up and down three times and hold on any tender areas for thirty seconds. No instructions were provided on the amount of pressure to place on the foam roller. Despite the generic conclusion that foam rolling significantly improved hamstring flexibility, the results show that only the left leg values were significant ($p = 0.04$) and that the right leg values were not significant ($p = 0.08$). Furthermore, the study neglected to disclose any information on the statistical analysis used. The study also fails to cater for male football players, the previously discussed direction of foam rolling (Stevens, 2013) and the correct time of foam rolling required for a release to be felt (Paolini, 2009).

Improvements in vertical jump ($p = 0.01$), thirty-seven meter sprint ($p = 0.002$), and pro-agility tests ($p = 0.001$), were reported for a combined foam rolling and dynamic stretch warm up compared to a dynamic warm up (Peacock, et al., 2014). The implication of these results and their application to the mainstream population are limited as only males took part ($n = 11$). Using a bigger mixed gender sample would provide a better representation of the wider population and lead to a more robust statistical analysis (Thomas, Nelson and Silverman, 2011). Further weaknesses of the study included no use of a control group, a short foam rolling time (30 Secs), no information on rolling technique used and the use of a Bio-Foam roller (BFR). It has been suggested that the design and material of foam rollers can affect the level of pressure exerted on the soft tissue, with a Multilevel rigid roller (MRR) applying significantly ($P < 0.01$) more pressure than the used BFR. The higher pressure results in greater myofascial release and treatment of soft tissue adhesions (Curran, Fiore and Crisco, 2008). The significance of these results towards endurance cycling is limited due to its tests of speed, power and agility.

The physiological rationale behind the lower body power improvements shown in the vertical jump test can be partly explained through the improved fiber pattern recruitment linked to MFR (Sucher, 1993). In this case, SMR could have improved lower body power through the increased neural stimulation linked to foam rolling and its associated increase in motor unit firing rate (Peacock, et al., 2014). In contrast, Healey, et al. (2014) found no significant differences across a series of athletic tests, including vertical jump height ($p > 0.05$) between a foam rolling warm up and planking control group, bringing into question the physiological rationale behind the significant vertical jump improvements reported by (Peacock, et al., 2014). Conversely, the vertical jump improvements reported by Peacock, et al. (2014) were based on a combined foam rolling and dynamic warm up, which questions if the results would be the same for a foam rolling protocol. The results of Healey, et al. (2014) are limited by numerous foam rolling weaknesses. The foam rolling time (30 Secs) fell short of the sixty seconds recommended by Paolini (2009), the subjects rolled against the direction of lymphatic flow and venous return (Stevens, 2013) and no set pressure was applied (Beardsley and Skarabot, 2015). The study was also conducted over two days, which could have led to a possible learning effect or treatment effect influencing the results.

Healey, et al. (2014) reported significantly less ($p < 0.05$) post exercise fatigue levels for the foam rolling group compared to the control group. Fatigue was measured using a standard 11-point Likert scale, with subjects rating their perceived levels of fatigue after the foam rolling warm up and testing schedule. Various authors (Mori, et al., 2004; Ogai, et al., 2008) theorise the lower perceived level of fatigue often associated with massage is linked to an increased blood flow to the muscle speeding up lactic acid removal. On a psychological level, massage has been reported to have a positive effect on mood state, with decreases in tension, fatigue and depression (Weinberg, et al., 1988). Massage has also been shown to lower saliva cortisol levels and stimulate parasympathetic activity (Weerapong, Hume and Kolt, 2005). The significant reduction in fatigue levels may result in the subjects feeling they can push harder and as a result enhance their performance (Healey, et al., 2014).

Despite its growing popularity as a pre-event warm up technique for treating the soft tissue dysfunctions associated with exercise-induced microtrauma (Peacock, et al., 2014), there is a lack of empirical evidence to support the benefits associated with a foam rolling warm up (Curran, Fiore and Crisco, 2008). Furthermore, none of the reviewed studies investigated the impact of pre-event foam rolling on endurance cycling and further research is required into its effects on endurance performance (Weerpong, Hume and Kolt, 2005).

4.0 HYPOTHESES

4.1 Aim

The aim of this study is to investigate the effects of a self-myofasical release (SMR) warm up on the endurance performance of athletes, using a ten-kilometre cycling time trial.

4.2 Hypotheses

H_i 1 - A SMR warm up will significantly reduce the time taken to cycle ten kilometres.

H_o 1 - A SMR warm up will not significantly reduce the time taken to cycle ten kilometres.

H_i 2 - A SMR warm up will significantly increase peak power measurements during a ten-kilometre cycle.

H_o 2 - A SMR warm up will not significantly increase peak power measurements during a ten-kilometre cycle.

H_i 3 - A SMR warm up will significantly reduce blood lactate measurements during a ten-kilometre cycle.

H_o 3 - A SMR warm up will not significantly reduce blood lactate measurements during a ten-kilometre cycle.

H_i 4 - A SMR warm up will significantly reduce fatigue during and after a ten-kilometre cycle.

H_o 4 - A SMR warm up will not significantly reduce fatigue during and after a ten-kilometre cycle.

H_i 5 - A ten-minute SMR warm up will significantly increase hamstring and quadriceps flexibility.

H_o 5 - A ten-minute SMR warm up will not significantly increase hamstring and quadriceps flexibility.

5.0 MATERIALS & METHODS

5.1 Subjects

Following ethical approval from Anglia Ruskin University, twelve club level cyclists (n = 12) from Peterborough Cycling Club, Fenland Clarion Cycling Club, Yaxley Riders and Stamford Chain Gang, volunteered to participate in the study. The twelve cyclists consisted of nine males (Age = 40.0 ± 1.9 yrs; Height = 180.6 ± 2.7 cm; Weight = 77.4 ± 2.6 kg) and three females (Age = 33.3 ± 3.7 yrs; Height = 163.1 ± 5.8 cm; Weight = 57.8 ± 4.7 kg). Study inclusion criteria were participant age range (25 to 50 yrs) and weekly cycling distance (>50 miles). Subject characteristics are presented in table 1.

5.2 Equipment and Apparatus

Seca Scales were used to measure weight (kg) and a Seca 213 Stadiometer was used to measure height (cm). A Polar F6 heart rate monitor was selected to record resting and real time heart rates (HR). Subjects performed warm ups and time trials on a Wattbike. Wattbike Expert Software was used to record time (min & sec), power (W), distance (m) and cadence (rpm). A true angle goniometer was chosen to measure hamstring and quadriceps flexibility based on its accuracy ($=1^0$), as reported by MacDonald, et al. (2013). The Borg (1998) scale was used to measure subjects rate of perceived exertion (RPE) and a visual analogue scale (VAS) was used to measure fatigue due to its high user reliability (r = 0.94) (Kim, et al., 2010; Hawker, et al., 2011). Blood lactate (Bla) measurements were taken using an ACCU-CHEK lancing device and Lactate Scout+. An Escape Fitness MRR was used, as it applies significantly more pressure on the soft tissue compared to a BFR (Curran, et al., 2008).

5.3 Procedure

Each participant attended a familiarisation session at the university centre Peterborough (UCP) sports laboratory seven days prior to testing. A physical activity readiness questionnaire (PARQ), informed consent form, introduction to testing equipment, apparatus, procedures and individual bike geometry set up were completed. Following the procedure adopted by Robertson, Watt and Galloway (2004), participants were issued a 24-hour food log, 48-hour exercise log and instructed to complete both forms before test one. Subjects were then informed to replicate both logs to prevent any extraneous influences on their test two performance. Additionally, subjects were told not to exercise for twenty-four hours prior to each test.

Participant PARQ forms, exercise and dietary logs were checked at the start of the non-foam rolling protocol. Laboratory humidity (%), temperature (^{o}C) and barometric pressure (Hg) were then recorded. Age, weight (kg), height (cm), resting HR and Bla levels were recorded. Participants were asked to complete a five-minute Wattbike warm up at air resistance 1, maintaining 80 rpm. The straight leg raise (SLR) and active knee extension (AKE) test were completed to assess quadriceps and hamstring flexibility, respectively, using a goniometer. A 10 km time trial was then completed on the Wattbike with the air resistance set at level 3 throughout the test. Time taken (min & sec), HR (bpm), RPE, Bla and fatigue (VAS) were recorded at 2 km intervals. Time taken was recorded using the Wattbike Expert Software, HR was recorded from the Polar F6 receiver mounted on the handlebars. RPE and VAS scales were presented to the participant and Bla was taken from the index finger. Final time (min & sec), minimum power (W), average power (W), peak power (W), average cadence (rpm) and peak cadence (W) were logged from Wattbike Expert Software on completion of the time trial.

The foam rolling protocol used the same initial format until the completion of the five-minute Wattbike warm up. Participants were then subjected to a ten-minute min foam rolling warm up. The lower back, gluteus, hamstrings, gastrocnemius and quadriceps were rolled as per figure 1, for one minute per leg (Paolini, 2009). Each roll began with long lighter rolls leading to short, intense motions in a distal to proximal direction (Stevens, 2013). Foam rolling intensity was regulated using the 11-point numeric pain intensity scale (MacDonald, et al., 2014), with “0” defined as no pain, “5” as moderate pain and “10” as worst possible pain. Hawker, et al. (2011) reported high subject reliability in pain assessment using the scale (r = 0.96). Participants were instructed to apply pressure on each limb equating to a score of 8 out of 10.

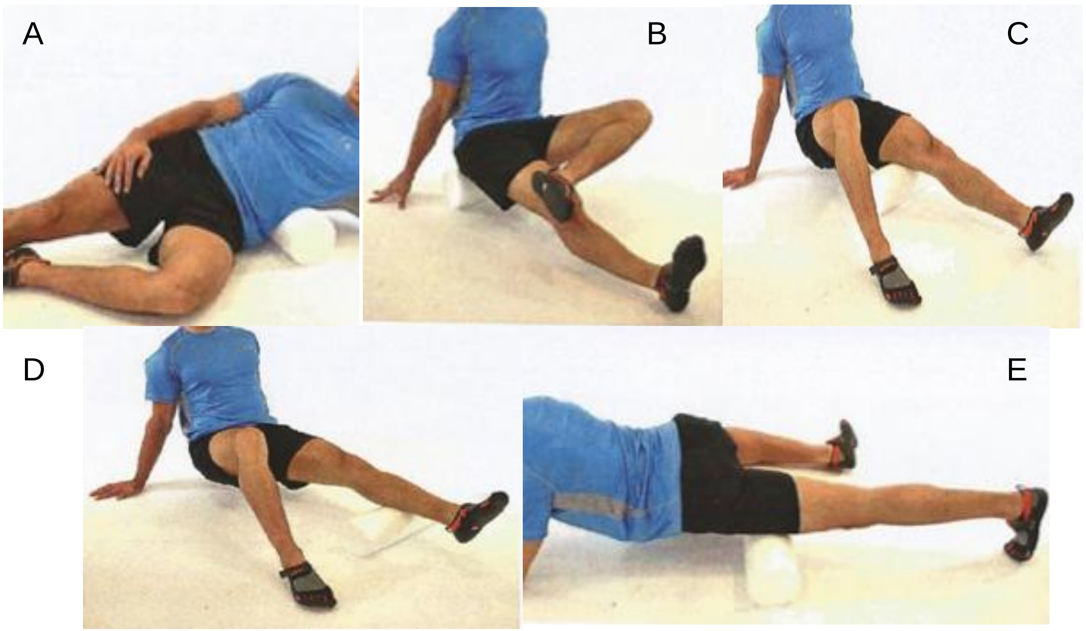

Figure 1. Foam rolling warm up exercises. A) Lower back. B) Gluteus. C) Hamstrings. D) Gastrocnemius. E) Quadriceps.

A counterbalanced, cross over within subjects design was used to provide its own control group (Heppnerm, Wampold and Kivlighan, 2007). Participants were switched between both experimental conditions halfway through the study to reduce bias in the order effects (Heppnerm, Wampold and Kivlighan, 2007; Gratton and Jones, 2010). Protocols were separated by seven days and subjects were randomly assigned to each protocol, a testing timeline is shown in figure 2. During the time trial the watts power output screen was blank to prevent the participants using a pacing strategy and to mask the effects of each condition.

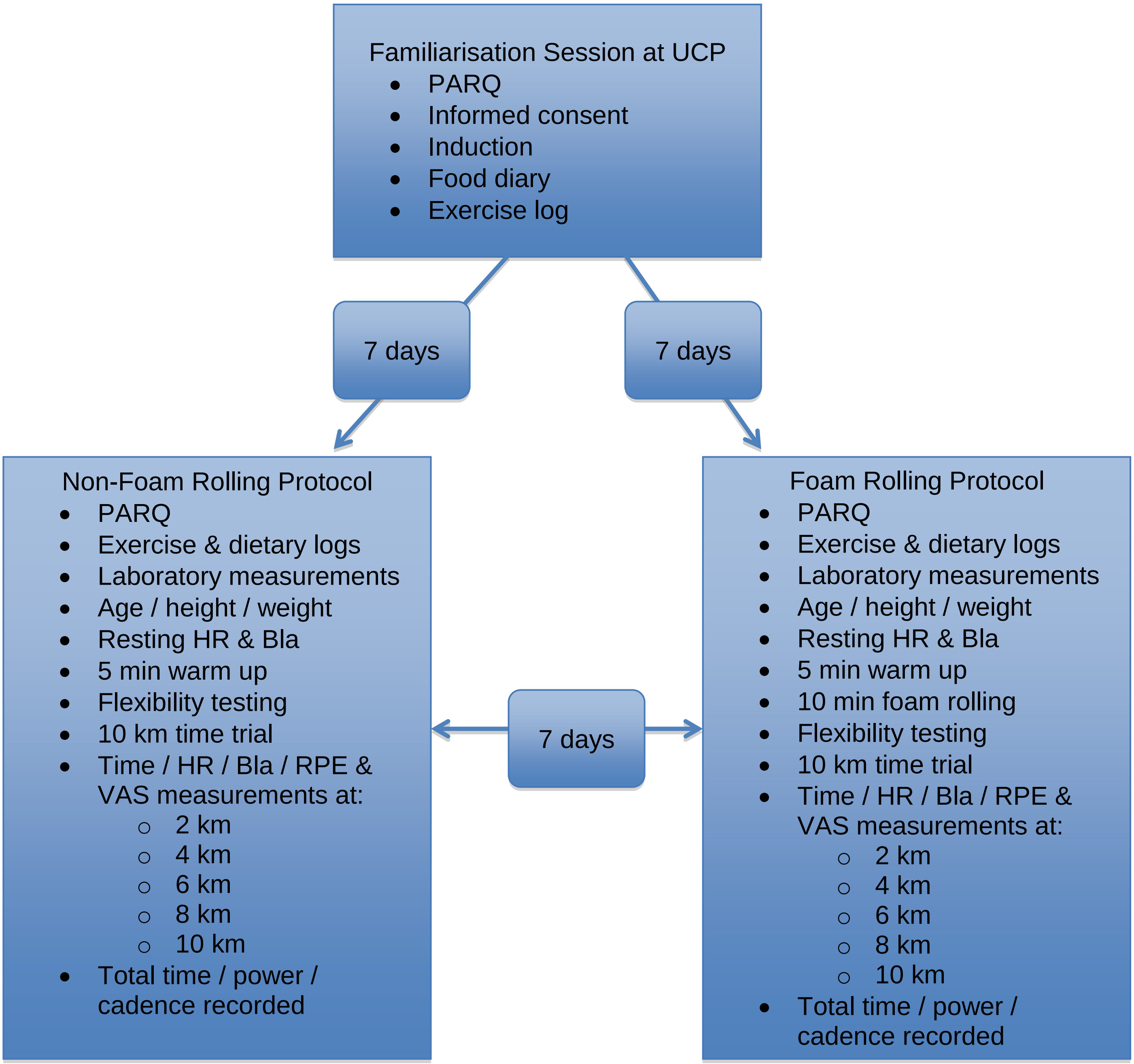

Figure 2. Timeline of testing protocols and procedures.

5. 4 Data Analysis

IBM SPSS for windows (version 20.0) was used to analyse data. Normality of data was assessed using a Kolomogorov-Smirnov test. A parametric paired-samples t-test was used to measure the mean differences between the non-foam rolling protocol and foam rolling protocol. A non-parametric related-samples Wilcoxon signed-rank test was used to compare mean differences when data was not normally distributed. A Levene's test of homogeneity of variance was used to test variance of data when two or more dependent variables were analysed. A One-way ANOVA was used to compare differences between mean data sets at 2 km, 4 km, 6 km, 8 km and 10 km intervals between each protocol. A non-parametric Kruskal-Wallis test was used to compare mean differences at 2 km, 4 km, 6 km, 8 km and 10 km intervals when parametric assumptions were not met. A p value of <0.05 was accepted as significant for all tests.

6.0 RESULTS

6.1 Subjects

All subjects successfully completed both protocols and adhered to dietary and exercise controls.

Table 1. Subject characteristics (n = 12). *

Subjects	Age (yr)	Height (cm)	Weight (kg)
Male (N = 9)	40.0 ± 1.9	180.6 ± 2.7	77.4 ± 2.6
Female (N = 3)	33.3 ± 3.7	163.1 ± 5.8	57.8 ± 4.7

* Reported values are mean ± SD.

6.2 Time Trial Duration

The total time taken for both the non-foam rolling protocol (15.31 ± 0.41), D(12) = 0.12, p = 0.73 and the foam rolling protocol (15.36 ± 0.41), D(12) = 0.20, p = 0.38, did not deviate significantly from normal distribution. A paired-samples t-test revealed no significant differences, t(11) = -0.93, p = 0.37, between the mean time taken for both trials. Mean time can be found in table 2 and figure 3 displays the longer mean time taken for foam rolling compared to non-foam rolling.

6.3 Peak Power

Non-foam rolling peak power (385.92 ± 31.78), D(12) = 0.16, p = 0.57 and foam rolling peak power (384.75 ± 30.21), D(12) = 0.12, p = 0.87, indicated normal distribution. No significant differences in mean peak power were discovered between both trials using a paired-samples t-test, t(11) = 0.04, p = 0.97, as shown in table 2. The main finding was a higher mean peak power for the non-foam rolling trial compared to the foam rolling trial, as shown in figure 3.

6.4 Fatigue Index

Participant fatigue index percentages were calculated using the formula: [(peak power – minimum power) / peak power x 100], by Astorino and Schubert (2014), see table 3. Mean fatigue index for both the non-foam rolling protocol (51.09 ± 5.10), D(12) = 0.13, p = 0.94 and the foam rolling protocol (48.55 ± 4.62) , D(12) = 0.19, p = 0.48, were normally distributed. A paired-samples t-test revealed no significant differences, t(11) = 0.54, p = 0.60, between the two protocols as indicated in table 2. Foam rolling resulted in a lower fatigue index compared to non-foam rolling, as shown in figure 3.

6.5 Flexibility

Mean straight leg raise data of the right quadriceps for non-foam rolling (86.50 ± 3.42) and foam rolling (85.08 ± 2.73) violated parametric assumptions, D(12) = 0.33, p = 0.01. Multiple non-parametric Wilcoxon signed-rank tests found no significant flexibility differences between the non-foam rolling protocol and foam rolling protocol, for left leg quadriceps, Z = -0.51, p = 0.61, right leg quadriceps, Z = -0.58, p = 0.56, left leg hamstring, Z = 0.15, p = 0.88 and right leg hamstring, Z = 0.00, p = 1.00, as seen in table 2. Figure 4 displays a higher mean flexibility measurement for both the left leg and right leg quadriceps during the non-foam rolling protocol.

Table 2. Time trial duration, peak power, flexibility and fatigue index scores for non-foam rolling and foam rolling warm ups.

	Non foam rolling		Foam rolling		P value
	Mean	SD	Mean	SD	
Time trial duration (min & sec)	15.31	0.41	15.36	0.41	0.37
Peak power (W)	385.92	31.78	384.75	30.21	0.97
Flexibility (^{0})					
SLR L*	87.42	4.70	84.75	3.18	0.61
SLR R*	86.50	3.42	85.08	2.73	0.56
AKE L**	146.08	3.80	146.08	4.21	0.88
AKE R**	144.75	4.34	144.75	4.08	1.00
Fatigue index (%)	51.09	5.10	48.55	4.62	0.60

* SLR L = straight leg raise left leg. SLR R = straight leg raise right leg.

** AKE L = active knee extension test left leg. AKE R = active knee extension test right leg.

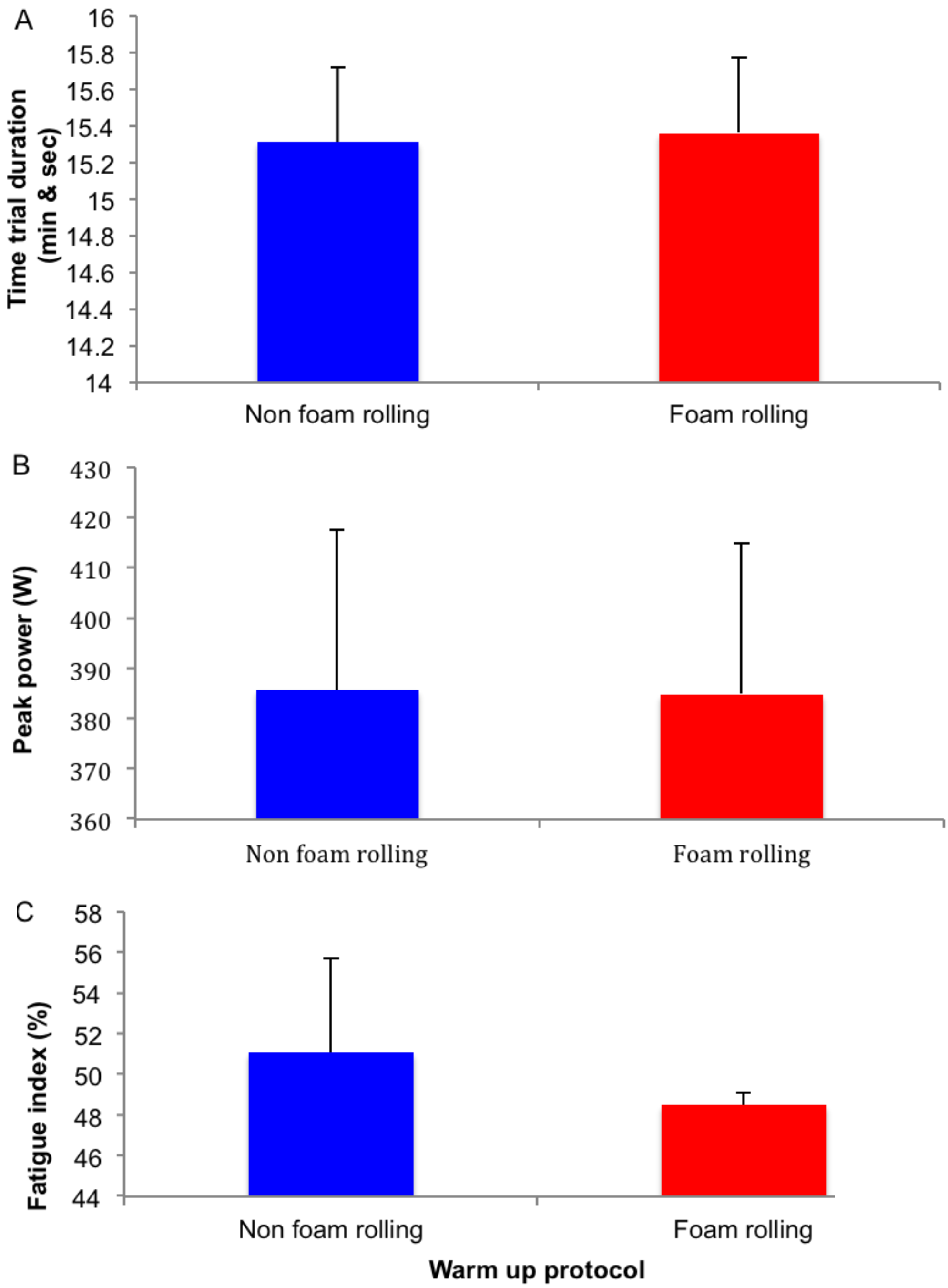

Figure 3. Time trial duration, peak power and fatigue index during the non-foam rolling and foam rolling conditions. A) Total time taken was not significantly different. B) Peak power was not affected by the warm up conditions. C) Fatigue index was lower after foam rolling but not significantly different. Data presented in mean ± SD.

Table 3. Participant peak power, minimum power and fatigue index for non-foam rolling and foam rolling.

Participant (N^o)	Peak power (W)		Minimum power (W)		Fatigue index (%)	
	NFR*	FR**	NFR	FR	NFR	FR
1	200	211	135	140	33	34
2	333	383	259	228	22	40
3	451	441	302	297	33	33
4	503	394	190	200	62	49
5	514	396	170	199	67	50
6	450	321	237	235	47	27
7	289	288	112	152	61	47
8	307	308	151	79	51	74
9	341	336	***	194	***	42
10	542	615	107	239	80	61
11	431	450	220	240	49	47
12	270	474	116	132	57	72

* NFR = non-foam rolling trial

** FR = Foam rolling trial

*** Participant 9 fatigue index data not complete (NFR min power) and removed from statistical analysis.

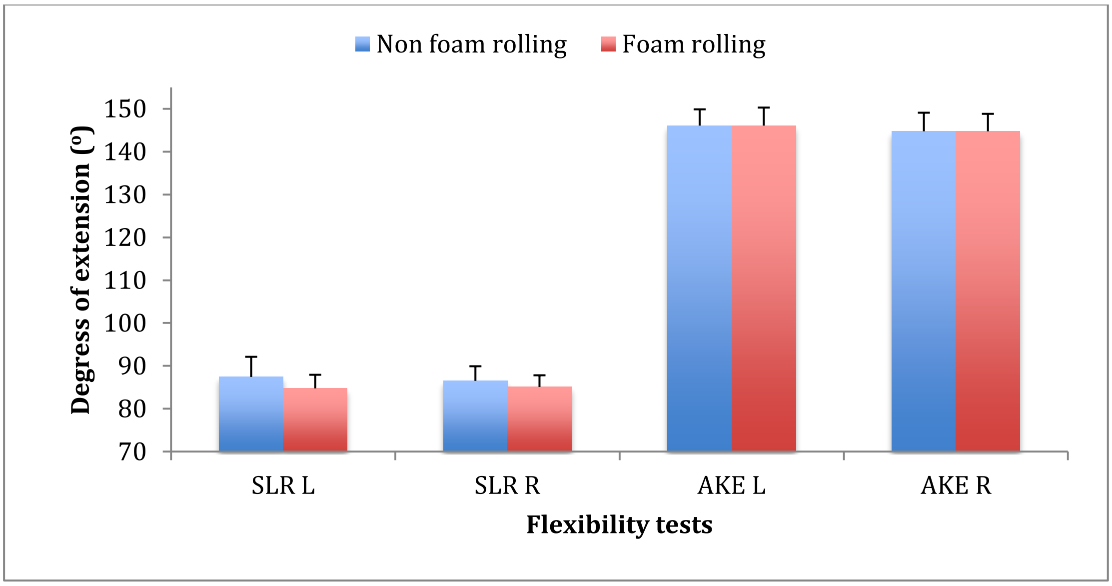

Figure 4. Quadriceps and hamstring flexibility scores for both legs under non-foam rolling and foam rolling conditions. Quadriceps flexibility measured using the straight leg raise (SLR) was higher in both legs under the non-foam rolling condition. Hamstring flexibility using the active knee extension (AKE) test showed no differences. All data presented as mean ± SD.

6.6 Fatigue - Visual Analogue Scale (VAS)

Non-foam rolling and foam rolling mean VAS scores for 2 km, 4 km, 6 km, 8 km and 10 km, were not normally distributed. A non-parametric Kruskal-Wallis test reported no significant differences between both trials at 2 km, H(1) = 0.10, p =0.75, 4 km, H(1) = 0.03, p = 0.86, 6 km, H(1) = 0.20, p = 0.66, 8 km, H(1) = 0.10, p = 0.74 and 10 km, H(1) = 0.63, p = 0.43. Table 4 presents mean VAS based fatigue scores and figure 5 shows foam rolling scores were higher at 4 km, 6 km and 10 km, which contradicts the lower fatigue index scores reported for foam rolling in figure 3.

6.7 Blood Lactate

Blood lactate data at 2 km, 4 km, 6 km, 8 km and 10 km were normally distributed for both non-foam rolling and foam rolling trials. No significant differences were found using a series of one-way ANOVA's between blood lactate levels for non-foam rolling and foam rolling conditions at 2km, F(1, 22) = 0.20, p = 0.66, 4 km F(1, 22) = 0.24, p = 0.63, 6 km F1, 22) = 0.35, p = 0.56, 8 km F(1, 22) = 0.00, p = 0.94 and 10 km F(1, 22) = 0.44, p = 0.51, as shown in table 4. Blood lactate levels can be seen in figure 6, which shows higher blood lactate readings for foam rolling at 2 km, 4 km, 6 km and 10 km intervals.

Table 4. Fatigue and blood lactate scores for non-foam rolling and foam rolling conditions at 2 km intervals.

	Non foam rolling		Foam rolling		P value
	Mean	SD	Mean	SD	
Fatigue (VAS)					
2 km	4.42	0.54	4.25	0.45	0.75
4 km	5.46	0.51	5.59	0.47	0.86
6 km	6.38	0.52	6.58	0.50	0.66
8 km	7.54	0.53	7.42	0.50	0.74
10 km	8.42	0.54	8.75	0.55	0.43
Blood lactate (mmol/l)					
2 km	6.75	1.12	7.46	1.10	0.66
4 km	9.26	1.64	10.30	1.36	0.63
6 km	10.49	1.56	11.71	1.34	0.56
8 km	11.78	1.64	11.67	0.92	0.95
10 km	12.38	1.34	13.50	1.02	0.51

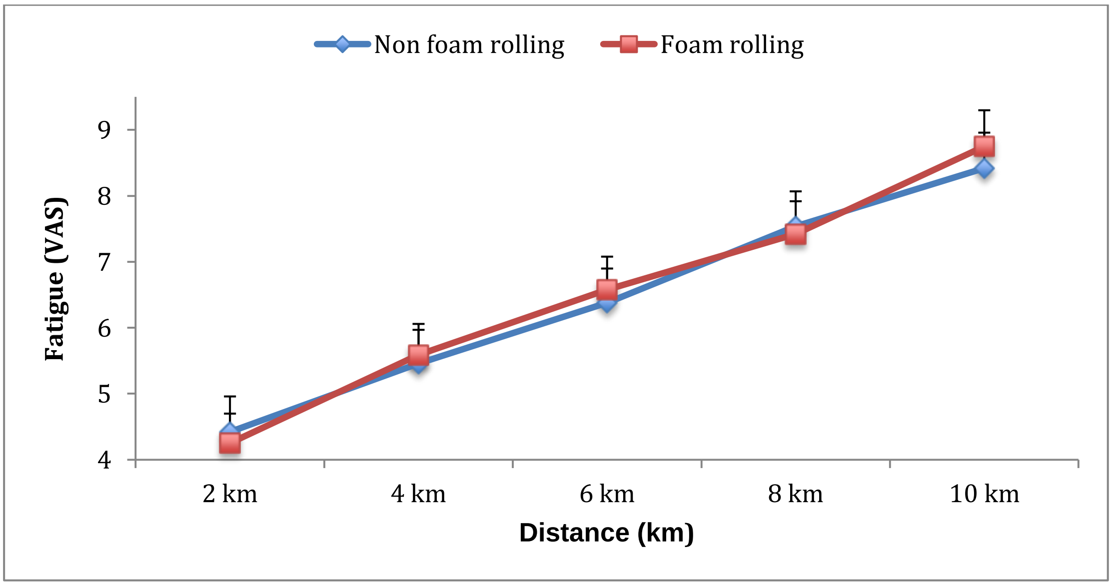

Figure 5. Visual analogue scale scores of fatigue for non-foam rolling and foam rolling conditions at 2 km intervals. Foam rolling fatigue scores were higher at 4 km, 6 km and 10 km. Data presented in mean ± SD.

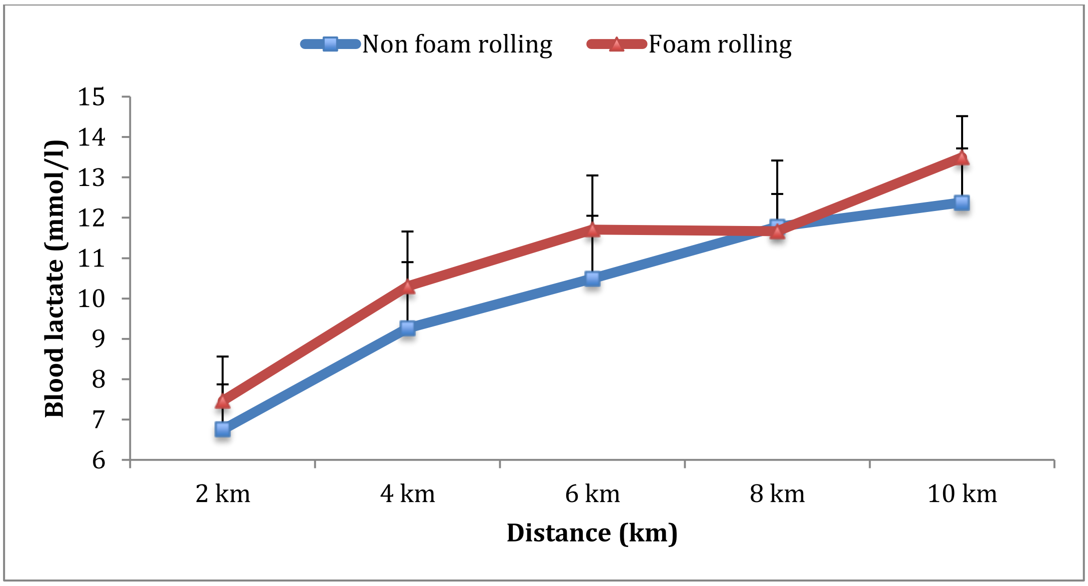

Figure 6. Comparison of blood lactate changes between non-foam rolling and foam rolling protocols at 2 km intervals. Foam rolling blood lactate levels were higher on four of the five intervals. Data presented in mean ± SD.

7.0 DISCUSSION

The purpose of this study was to investigate the effects of a self-myofascial release (SMR) warm up on the endurance performance of athletes, using a ten-kilometre cycling time trial. The results suggest that a ten-minute foam rolling warm up had no significant impact on the time trial performance of cyclists. There was no significant difference in the mean time taken to cycle ten-kilometers for both trials, which accepts the null hypothesis (H_o 1). Peak power scores were not significantly different between each trial and accept the null hypothesis (H_o 2). Blood lactate levels were not significantly different at 2 km, 4 km, 6 km, 8 km and 10 km, between the non-foam rolling and foam rolling trials, therefore, accepting the null hypothesis (H_o 3). The null hypothesis (H_o 4) was also accepted because no significant differences were found between fatigue levels at 2 km intervals throughout both trials, when measured by VAS or at the end of each trial when calculating fatigue index. Flexibility of the quadriceps and hamstring muscle groups were not significantly different between the non-foam rolling and foam rolling trials, these results accept the null hypothesis (H_o 5).

7.1 Peak Power

The non-significant differences found for peak power between both protocols suggests that foam rolling had no effect on the muscles ability to produce power. Power was monitored throughout the ten-kilometre time trial using the Wattbike Expert Software, which provided a peak power reading at the end of the time trial. These findings are in agreement with pre-event foam rolling studies by MacDonald, et al. (2013) who reported no decrease in quadriceps power during a MVC under isometric conditions and Healey, et al. (2014) who measured lower limb power using a vertical jump test and found no significant difference. Despite similar findings all three studies used different tests of power and foam rolling techniques. Foam rolling was carried out for sixty seconds in this study, forty-five seconds (MacDonald, et al., 2013) and thirty seconds (Healey, et al., 2014). These differences make a direct comparison of the results questionable due to a lack of methodological standardisation, which is a common weakness in massage literature (Robertson, Watt and

Galloway, 2004). Future research should address these issues and provide detailed information on foam rolling techniques, including time, direction of travel, pressure and type of FR used. Without this information the intervention cannot be evaluated or reproduced (Robertson, Watt and Galloway, 2004).

Laymen’s literature claims that EIMD following high intensity exercise causes micro-tears in the muscle fibers, which leads to DOMS, soft tissue restrictions and myofascial trigger points (Cheung, Hume and Maxwell, 2003; Jay, et al., 2014; Beardsley and Skarabot, 2015; Pearcey, et al., 2015). As a result, the fascial components lose their functional properties and the muscles ability to produce power is inhibited (Barnes, 1997; Curran, Fiore and Crisco, 2008). It has been proposed that foam rolling before exercise enables athletes to decrease the dysfunctions that result from regular exercise and consequently improve performance (Stevens, 2013; Healey, et al., 2014). However, the subjects used by MacDonald, et al. (2013) and Healey, et al. (2014) were college-aged participants (22.3 ± 3.8 and 21.56 ± 2.04 yrs), who were described as recreational trainers and therefore may not have had any soft tissue dysfunctions (Healey, et al., 2014).

In contrast, this study investigated club level cyclists (Age = 40.0 ± 1.9 yrs), who had an average weekly cycling distance of more than fifty miles and were more likely to suffer from soft tissue dysfunctions due to undertaking regular physical exertion (Pearcey, et al., 2015). However, this study failed to assess for any soft tissue dysfunctions prior to both trials. This is a limitation of the current study and future research should investigate the effects of a foam rolling warm up when soft tissue restrictions are present. Furthermore, the results of the current study are limited due to a male biased (n = 9) small sample size (n = 12). Heppnerm, Wampold and Kivlighan (2007) recommend using a minimum of fifteen participants in a counterbalanced, cross over within subjects design to enhance statistical power.

There is a disparity between the effects of pre-event foam rolling and massage on power. Wiktorsson-Moller, et al. (1983) reported lower results for quadriceps isometric force and hamstring isokinetic force following a massage warm up. Two key differences between this study and Wiktorsson-Moller, et al. (1983) were the type of massage (foam rolling versus massage) and massage time (1 minute versus 7-15 minutes). Furthermore, Arroyo-Morales, et al. (2011) found a longer massage (20 minutes) significantly decreased power when measured by isokinetic dynamometry. Therefore, in opposition to short duration foam rolling, longer massage times may reduce muscle power through increased parasympathetic nervous system activity, which reduces afferent input and motor-unit activation (Arroyo-Morales, et al., 2011). Additionally, the pre-event massage opposed to the foam rolling warm up, could have reduced muscle stiffness by increasing muscle fiber length (stretching). An increased muscle fiber length could decrease the muscles length-tension relationship and force-generating capacity (Robertson, Watt and Galloway, 2004; Arroyo-Morales, et al., 2011).

In contrast to the previous findings, MacDonald, et al. (2014) discovered post-event foam rolling improved power, when assessed by the same vertical jump test used by Healey, et al. (2014). The participants (n = 20) were subjected to an EIMD protocol of 10 x 10 squats based on individual one repetition maximum scores, followed by twenty minutes of rest or twenty minutes of foam rolling. Vertical jump height was tested forty-eight hours after the foam rolling treatment. These findings support claims that foam rolling enables athletes to decrease the dysfunctions that result from regular exercise and consequently improve performance (Stevens, 2013; Healey, et al., 2014). In direct conflict to Arroyo-Morales, et al. (2011), the authors proposed foam rolling reduced neural inhibition and increased afferent receptors communication. Therefore, vertical jump height was increased via improved muscle sequencing and recruitment patterns (MacDonald, et al., 2014). The non-significant differences in power found in the current study are incomparable to the results of MacDonald, et al. (2014) based on the current studies inability to expose its subjects to EIMD or recruit subjects with proven EIMD. In conclusion, a ten-minute foam rolling warm up had no significant impact on peak power, however, the proposed benefits of a foam rolling warm up based on its ability to decrease soft tissue dysfunctions and improve performance were not fully investigated.

7.2 Blood Lactate

Blood lactate measurements taken at 2 km, 4 km, 6 km, 8 km and 10 km during the non-foam rolling and foam rolling trials were not significantly different, implying that a ten-minute foam rolling warm up had no effect on blood lactate clearance. In the absence of a significant level of lactate clearance during foam rolling compared to non-foam rolling, it can be suggested that muscle blood flow, lactate efflux or lactate removal from the circulation (Robertson, Watt and Galloway, 2004) were not altered by foam rolling. These findings are in disagreement with Moraska (2005), who proposes that blood flow and lymphatic fluid movement are increased during massage and therefore help the transfer of blood lactate out of the affected tissues into a gluconeogenic organ. Lavelle, Lavelle and Smith (2007) and Montanez-Aguilera, et al. (2010) also support the notion that massage increases blood flow. They theorise that the release of IC applied during foam rolling increases blood flow to the area and the removal of waste products. Furthermore, Okamoto, Masuhara and Ikuta (2013) suggest the discovery of reduced vessel stiffness and improved arterial function found with foam rolling supports the theory that foam rolling improves blood flow. Despite these findings, neither study related its theories to practice.

These theories fail to stand up to scrutiny in practice as demonstrated by Robertson, Watt and Galloway (2004) who reported a non-significant difference in blood lactate concentration between a twenty minute leg massage and passive rest, when measured after a Wingate cycling test. Moreover, Ogai, et al. (2008) found a ten-minute leg massage resulted in no significant differences between lactate levels after intensive cycling intervals. Consequently, in agreement with the non-significant differences found in the current study, these results show massage and foam rolling were unsuccessful in reducing blood lactate concentrations at a speed significantly faster than passive rest (Moraska, 2005). These findings could be attributed to massage and foam rolling having no impact on blood flow, which had previously been considered a possibility (Mori, et al., 2004; Ogai, et al., 2008). However, there is a shortage of corroborating evidence to show that massage or foam rolling has any actual impact on blood flow (Weerapong, Hume and

Kolt, 2005). This study neglected to directly examine the effects of foam rolling on blood flow, which is a limitation when considering its potential relationship to blood lactate clearance. Future research should directly investigate the effects of foam rolling on blood flow, such as venous occlusion plethysmography (Weerapong, Hume and Kolt, 2005). In conclusion, a ten-minute foam rolling warm up had no significant impact on blood lactate concentrations throughout a ten-kilometre cycling time trial and for this reason cannot support the hypothesis that blood lactate concentrations will be lower following the use of a SMR warm up.

7.3 Fatigue

The ten-minute foam rolling warm up had no significant impact on fatigue index compared to the non-foam rolling warm up. However, it is commonly believed that massage will reduce fatigue by decreasing muscular excitability and by inducing relaxation (Healey, et al., 2014). In support of this view and in opposition to the findings of the current study, Robertson, Watt and Galloway (2004) reported a significantly improved fatigue index when measured after a Wingate cycling test. Fatigue index was calculated using a PC interface, which measured the power produced in the first five seconds and last five seconds of the thirty-second test, to produce a fatigue index percentage. In comparison, the current study calculated fatigue index based on the subjects recorded peak power and minimum power throughout the ten-kilometre time trial, using the following calculation [(peak power – minimum power) / peak power x 100] (Astorino and Schubert, 2014). Robertson, Watt and Galloway (2004) also measured fatigue index following a twenty minute lower limb massage applied by a therapist, compared to this study which used the subjects own body weight to foam roll the lower limbs for eight minutes. Therefore, the inconsistency in massage type, time and methodology could explain the differences between the two studies fatigue index calculations, with a longer massage inducing more relaxation (Healey, et al., 2014).

Caferelli and Flint (1992) reviewed the effectiveness of massage when used to enhance the recovery of fatigued muscles and found no physiological effects. Fatigue has often been linked to the muscles ability to generate power; with massage before exercise known to reduce power due to a stretch effect that reduces the muscles force-generating capacity (Arroyo-Morales, et al., 2011). As a result, fatigue is significantly reduced when the muscles are unable to produce the same amount of power or workload as found by Robertson, Watt and Galloway, (2004). The current study found a ten-minute foam rolling warm up had no significant impact on peak power, which given this premise could also explain the non-significant difference found in fatigue index across the two trials.

No significant differences were found for perceived levels of fatigue when assessed by a VAS. In contrast, Healey, et al. (2014) reported significantly lower fatigue results when measured using a VAS. Both studies applied foam rolling pre-event, however, Healey, et al. (2014) measured fatigue after the participants completed four athletic power events compared to a ten-kilometre cycling time trial. Healey, et al. (2014) hypothesised the foam rolling warm up resulted in a significantly lower fatigue index by increasing blow flow to the lower limb muscles, therefore, causing a subsequent improvement in lactate clearance. These findings are only a suggestion as Healey, et al. (2014) failed to measure blood flow or lactic acid during the study. Furthermore, the current study found no significant difference in blood lactate levels between each trial, which disputes the explanation for the significantly lower fatigue scores found by Healey, et al. (2014).

In conclusion, a ten-minute foam rolling warm up had no significant impact on the subjects calculated fatigue index or perceived levels of fatigue, due to foam rolling having no impact on peak power or blood lactate clearance. These results are unable to support the hypothesis that a foam rolling warm up reduces fatigue levels. Despite these findings many authors (Robertson, Watt and Galloway, 2004; Arroyo-Morales, et al., 2008; Healey, et al., 2014) have suggested that the relaxation of massage therapy could give athletes the perception of being able to train harder and longer, thus creating a psychological mindset that is conducive to improving performance. The current study failed to investigate the amount of training each participant felt they could perform following the foam rolling treatment and future research should explore the psychological effects of foam rolling on subsequent mood state, training load, intensity and performance.

7.4 Flexibility

The non-significant differences found for hamstring and quadriceps flexibility between both protocols suggests that foam rolling had no effect on joint ROM. Hamstring flexibility was measured using the AKE test and quadriceps flexibility was tested using the SLR. Both tests were carried out using a goniometer directly after the non-foam rolling and foam rolling warm ups. These findings suggest that a foam rolling warm up does not increase joint ROM by increasing the flow of built up interstitial fluid back into circulation or through reduced muscle soreness and inflammation, as claimed by MacDonald, et al. (2014). Three studies have reported significant differences in flexibility when assessed after a pre-event or post-event bout of foam rolling.

MacDonald, et al. (2013) found a sixty second foam rolling warm up improved quadriceps flexibility, but a true ROM measurement was not found for all subjects due to the chosen flexibility test. The modified kneeling lunge failed to correctly measure quadriceps flexibility for thirty-six percent of the subjects due to the heel contacting the glutes. In contrast, the current study found no significant difference for quadriceps flexibility for all subjects based on the SLR test. Sheffield (2013) reported a significant difference in hamstring flexibility after a foam rolling warm up when using the AKE test, however, only the left leg results were significant. Sheffield (2013) also suggested that flexibility was only significantly different for those subjects who had restricted pre-test hamstring flexibility results ($<65^0$), as they would be suffering from tight muscle fascia. The current study failed to assess for hamstring restrictions, which is a limitation given the possibility that foam rolling will only improve flexibility when restrictions are present (Miller and Rockey, 2005; Sheffield, 2013).

Future research should consider investigating effects of a foam rolling warm up on hamstring flexibility for participants with limited flexibility. Skarabot, et al. (2015) discovered thirty seconds of foam rolling significantly improved planter flexor ROM when combined with static stretching, but no significant difference was found without static stretching. During the foam rolling intervention, participants were instructed to apply as much pressure as they could, but no standardisation was used. In contrast, the current study used the 11-point numeric pain intensity scale to standardise pressure, which could affect the results as higher pressures lead to greater ROM improvements (Beardsley and Skarabot, 2015). Also this study did not combine a foam rolling and static stretching warm up and future studies should look into the effects of a joint foam rolling and static stretching warm up on the flexibility of the hamstrings and quadriceps.

In agreement with the non significant flexibility findings in this study, Roylance, et al. (2013) also reported that foam rolling had no effect on flexibility when used prior to a sit and reach test. The study failed to report the amount of pressure exerted on the FR, which is an important methodological consideration. Despite numerous authors (Barnes, 1997; Miller and Rockey, 2005; MacDonald, et al., 2014) claiming foam rolling improves ROM, a contentious issue is whether or not it supplies enough pressure to stimulate any physiological changes (Beardsley and Skarabot, 2015). To date the minimum pressure required to stimulate Ruffini endings and interstitial receptors (III and IV) during MFR has not been reported (Mitchell and Schmidt, 2011). However, Threlkeld (1992) suggested that it would take a force between 24 and 115 kg to change the thixotropic property of the fascia, which Stone (2000) states is required to break down scar tissue, release trigger points and therefore improve flexibility. Sullivan, et al. (2013) discovered that 13 kg was the maximum force that an individual's body weight and FR could generate and transfer onto the hamstring muscles, thus falling short of the minimum pressure required to change the fascia as cited by Threlkeld (1992).

Therefore, the inability to apply the required force necessary to change the thixotropic properties of the fascia via body weight and foam rolling could be used to explain the non-significant differences found in the current study for hamstring and quadriceps flexibility. In conclusion, based on the inability to apply the required level of pressure needed to release trigger points within the fascia, the current study adds weight to the discussion that a foam rolling warm up has no significant impact on hamstring or quadriceps flexibility in individuals without limited ROM.

7.5 Time Trial Duration

The mean time taken to cycle ten-kilometres following a foam rolling warm up was not significantly different to the mean time taken after a non-foam rolling warm up. Despite being the only study to date to investigate the effects of a foam rolling warm up on the endurance performance of athletes, these findings are not surprising given that the foam rolling warm up had no significant impacts on peak power, blood lactate clearance, fatigue or flexibility when compared to the non-foam rolling warm up. Therefore, based on these discoveries it appears that the foam rolling warm up failed to provide any performance enhancing benefits to athletes and therefore subsequently had no significant impact on the time taken to cycle ten-kilometres. In conclusion, the purpose of this study was to investigate the effects of a self-myofascial release (SMR) warm up on the endurance performance of athletes, using a ten-kilometre cycling time trial. The results suggest a ten-minute foam rolling warm up had no significant impact on the time trial performance of cyclists and may not be beneficial as a pre-event technique for enhancing physical performance.

The non-significant results found in this study also suggest a foam rolling warm up causes no decrements in physical performance. Therefore, future research should investigate the psychological effects of incorporating a bout of foam rolling into an athlete’s pre-event routine, as various authors (Robertson, Watt and Galloway, 2004; Arroyo-Morales, et al., 2008; Healey, et al., 2014) suggest it could create a psychological mindset that is conducive to improving performance.

8.0 CONCLUSION

The main findings of the current study are as follows, peak power scores were not significantly different between the non-foam rolling and foam rolling warm ups ($p = 0.97$). Non-significant blood lactate levels were found between both trials at 2km ($p = 0.66$), 4 km ($p = 0.63$), 6 km ($p = 0.56$), 8 km ($p = 0.94$) and 10 km ($p = 0.51$). Fatigue index scores were not significantly different between the non-foam rolling and foam rolling warm ups ($p = 0.60$) and non-significant fatigue levels were also found between both trials using a VAS at 2 km ($p = 0.75$), 4 km ($p = 0.86$), 6 km ($p = 0.66$), 8 km ($p = 0.74$) and 10 km ($p = 0.43$). Non-significant differences in flexibility were found between both trials for left leg quadriceps ($p = 0.61$), right leg quadriceps ($p = 0.56$), left leg hamstring (0.88) and right leg hamstring ($p = 1.00$) flexibility. The mean time taken to cycle ten-kilometres following a foam rolling warm up was not significantly different to the mean time taken after a non-foam rolling warm up ($p = 0.37$), therefore, these results accept the studies null hypotheses (Ho 1, Ho 2, Ho 3, Ho 4, Ho 5).

MacDonald, et al. (2014) found a foam rolling warm up significantly improved power compared to passive rest. The non-significant differences in power reported by the current study are incomparable to the results of MacDonald, et al. (2014), based on the inability to expose its subjects to EIMD. Future research should investigate the effects of a foam rolling warm up when soft tissue restrictions are present.

The non-significant blood lactate levels found are in disagreement with Moraska (2005), who proposed that blood flow is increased during massage, which increases the movement of blood lactate from affected tissues into a gluconeogenic organ. The current study neglected to examine the effects of foam rolling on blood flow and future research should investigate the impact of a foam rolling warm up on blood flow (Weerapong, Hume and Kolt, 2005).

Robertson, Watt and Galloway (2004) reported a significantly improved fatigue index when measured after a Wingate cycling test, but the study used a twenty-minute massage compared to a ten-minute foam rolling warm up. The current study also found a ten-minute foam rolling warm up had no significant impact on peak power, which could further explain the non-significant difference found in fatigue index across the two trials.

Healey, et al. (2014) reported significantly lower fatigue results when measured using a VAS after a foam rolling warm up, however, blood flow and blood lactate were not measured. Healey, et al. (2004) hypothesised the significantly lower fatigue levels were caused by an increased blow flow to the lower limb muscles, with a subsequent improvement in lactate clearance. The current study found no significant difference in blood lactate levels between each trial, which disputes the explanation provided by Healey, et al. (2014).

Sheffield, et al. (2013) reported foam rolling only significantly improved flexibility for subjects who had restricted pre-test hamstring flexibility results ($<65^0$). The current study failed to assess for hamstring restrictions, which is a limitation given the possibility that foam rolling will only improve flexibility when restrictions are present (Miller and Rockey, 2005; Sheffield, 2013). Future research should consider investigating the effects of a foam rolling warm up on hamstring flexibility for participants with limited flexibility.

8.1 Practical Applications

The SMR warm up using a FR failed to provide any physiological advantages and subsequently had no significant impact on the time trial performance of cyclists, which suggests a foam rolling warm up should not be used as a pre-event technique to enhance physical performance.

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