Master's Thesis

The Effect of Short High Intensity Intermittent Training on Pain Tolerance and Self-Paced Cycling Performance

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31/09/2018

This thesis is submitted in partial fulfilment of the requirements of the award of MSc by Research

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Abstract

Introduction

Pain tolerance has been identified as a potential factor attributable to an athlete's success. Previous studies have reported that high intensity intermittent training (HIIT) can increase pain tolerance and exercise capacity. However, it is unclear if short HIIT programs are effective at increasing pain tolerance and self-paced exercise performance. Consequently, we investigated the effect of a short HIIT intervention on pain tolerance and 5 km time trial (TT) cycling performance.

Methods

Participants (n=18) were randomly assigned and completed either three (Ex-1; n=9) or six HIIT sessions (Ex-2; n=9). HIIT involved participants cycling at RPE=15 (6x5mins interspersed by 1mins recovery). Participant's pain catastrophizing (PCS), anxiety (PASS-20), ischemic pain tolerance test and 5 km TT performance responses were assessed at baseline and three or six HIIT sessions

Results

No changes in power output, heart rate or RPE were observed across subsequent HIIT sessions. Pain tolerance and threshold remained unchanged after HIIT. Participant's PASS responses remained unchanged after HIIT but PCS responses did decrease following HIIT ($p=0.002$, $d=0.56$) with no difference between groups. 5 km TT performance remained unchanged although HR decreased after HIIT with no difference between groups ($p=0.031$, $d=0.27$).

Conclusion

Self-paced HIIT was ineffective at increase pain tolerance and cycling time trial performance. This is likely due to the current protocols inefficiency to get participants to exercise to their tolerance and not eliciting the necessary metabolic demands to promote aerobic physiological adaptations respectively. Therefore, future research should consider this and design self-paced HIIT protocols that do not compromise training intensity. Furthermore, research focusing on other psychological measures (e.g. self-efficacy and pain management strategies) should also be considered when assessing the effect of any exercise training on pain tolerance to better understand why any changes in pain tolerance occur.

Acknowledgements

Dr John Jakeman and Dr Adam Bibbey

Special thanks to my supervisors John and Adam for providing me with invaluable support.

Rick Varnham (MSc), Stuart Cocksedge (MSc by Research) and Christopher Deeley (BSc)

Without the support and dedication of Rick, Stuart and Christopher much of this project would have been made impossible. They were instrumental in the supervision and organisation of participant visits. I cannot thank them enough.

Janet Hanspal, Roger Hanspal, Ajay Hanspal and Hattie Hanspal

My family throughout the duration of my Masters project have given me constant support and advice. Without their help I would not be where I am today.

James Chacksfield (BSc), Tim Marshall and Callum Ross

My best friends. All have unknowingly helped me through some stressful and tough times. Many thanks to them for providing me with many laughs and much needed respite from my project.

Olivia Smith (LL.B)

My girlfriend for over four years. She has undeniably proved invaluable in the completion of this thesis being there for me through thick and thin. Love you.

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1 Introduction:

1.1 What is Pain?

From the beginning of our lives we are taught that pain serves as a warning signal that something is wrong. It is even capable of facilitating recovery in patients by allowing them to avoid touching a certain injury or performing certain actions that may result in further damage. In this sense pain can be considered as a protective mechanism.

The International Association for the Study of Pain (IASP, 2012) define pain as “An unpleasant sensory and emotional experience associated with actual; or potential tissue damage or described in terms of such damage”. By this definition pain is always a subjective experience and should be interpreted as such. Furthermore, this definition also recognizes that pain can sometimes arise from psychological reasons in the absence of any apparent tissue damage or any pathophysiological cause. For example, most patients with an amputation often experience phantom limb pain whereby they feel pain in their amputated or missing limb (Andoh et al., 2017). The importance of this is that the perception of pain can never always be associated with observable tissue damage and psychological influences should always be considered.

Pain is often classified into two broad categories which are important to distinguish; neuropathic and nociceptive pain. Neuropathic pain affects an estimated 6.9 - 10% of the general population and is a clinical description rather than a diagnosis (Van Hecke et al., 2014). For example, a recent health survey within a US population, conducted by DiBonaventura et al (2017), observed a prevalence rate for neuropathic pain of 10% (95% CI 9.5% - 10.6%). that It describes pain that is caused by a lesion or disease of the somatosensory nervous system. In contrast, nociceptive pain can be defined as “pain that arises from actual or threatened damage to non-neural tissue” and often occurs with a normally functioning somatosensory nervous system (O’Connor and Cook, 1999). In this regard nociception describes the neural process of interpreting and encoding noxious stimuli. The process of nociception is an extremely complicated process and a complete description would not be in scope of this project. Nevertheless, it is important to understand the mechanisms involved and a brief overview is provided

in section 2.1. For a more detailed overview the reader is directed to a paper reviews conducted by O'Connor and Cook. (1999) and Light et al. (2008).

Two common variables measured when assessing a person's pain response are pain threshold and tolerance. These two variables are not one in the same despite being used interchangeably among the general population. For this work pain threshold represents the minimum intensity of a noxious stimulus to be perceived as painful (IASP, 2017). Conversely, pain tolerance will be defined simply as maximum intensity of a noxious stimulus an individual is willing to accept (i.e. tolerate; IASP, 2017).

1.2 Exercise Induced Pain and Effect of Training on Pain Perception

Pain arising from exercise can be referred to as exercise induced pain and is often termed with the denotation "EIP". Briefly, it is primarily caused as exercise itself results in an increase in muscle distortions, noxious metabolites and intramuscular pressure which activate various muscle nociceptors (O'Connor and Cook, 1999; Stevens et al., 2017). Afferent feedback from muscle nociceptors, especially type III/IV nociceptors is then received and interpreted by structures associated with the pain matrix. This not only causes the sensation of pain to occur but also limits the development of further locomotor muscle fatigue by altering central motor drive to exercising muscles to maintain homeostasis (Amann, 2012). This localised perception of pain in the primary exercising muscles with time will eventually spread to other locations such as the chest at the end of exhaustive running (Slapsinskaite et al., 2015).

Exercise induced pain itself has been demonstrated to be directly correlated with exercise intensity and duration in a series of studies conducted by Cook et al. (1997). As acknowledged by Stevens et al. (2017), it is also clear that EIP is important for self-paced exercise. Evidence for this comes from methods designed to inhibit pain mechanisms (Mauger et al., 2010; Foster et al., 2014; Delextrat et al., 2015; Astokorki and Mauger, 2017) as well as observational studies of athletes during competition (Whitehead et al., 2017).

It should be recognized that EIP is a different construct from perceived exertion. Perceived exertion during exercise is often measured as "rating of perceived exertion" using the 6-20 Borg scale (RPE). The RPE scale was originally designed

by Gunnar Borg (1970) with the intention of matching heart rates ranging from 60-200bpm (Borg et al., 1982) and has been widely used since. A study conducted by Astokorki and Mauger (2017) observed that after transcutaneous electrical nerve stimulation (TENS) EIP decreased, whilst RPE did not change, during a time to exhaustion (12% mean reduction). Consequently, exertion and pain should be treated as separate entities.

Exercise induced pain experienced during training may also be responsible for increasing pain tolerance. This is supported by evidence from a systematic review of cross sectional studies conducted by Tesarz et al. (2012), aerobic training (Anshel and Russell, 1994; Jones et al., 2014; O'Leary et al., 2017a) and longitudinal studies (Scott and Gijsbers, 1981; Thornton et al., 2017) which report higher pain tolerances in athletes and after periods of training respectively.

Specifically, a recent study conducted by O'Leary et al. (2017a) observed that high intensity intermittent training was more effective than a traditional continuous training program at increasing pain tolerance and exercise capacity. The authors attribute this difference largely due to HIIT causing greater consistent and frequent exposure to unpleasant sensory experiences. This is supported by "within-training" data (O'Leary et al., 2017b) which demonstrates that whilst participants consistently reported RPE ratings of 19-20 during the last 5min of each HIIT sessions those in the CONT never reported an RPE above 15. Whilst the mechanisms for these observations are still unclear (Stevens et al., 2017), reductions in inhibitory feedback from muscle afferents (Amann et al., 2015) and alterations in psychological variables such as pain specific; anxiety, catastrophizing and self-efficacy have been previously attributed for increases in pain tolerance following periods of aerobic training (Jones et al., 2014; O'Leary et al., 2017a) and for explaining the differences in pain tolerance between athletes and non-athletes (Roebuck et al., 2018; Thornton et al., 2017; Geva and Defrin, 2013; Johnson et al., 2011; Sullivan, 2000). Furthermore, it is uncertain whether shorter HIIT programs would be as effective at increasing pain tolerance.

1.3 What is High-intensity Interval Training?

The nomenclature proposed by Weston et al. (2014) put forward the idea that interval training can be defined as either high intensity intermittent training (HIIT) or sprint interval training (SIT). Despite there being no universal definition for HIIT it is

generally accepted among the scientific community that HIIT refers to repeated sessions of intermittent exercise often performed at an intensity above a steady state approximately 80–95% HR_{max} (MacInnis and Gibala, 2017). On the other hand, SIT refers to brief all out or supramaximal cycling efforts (often at or above intensities that would elicit VO_2max).

The most well-studied SIT protocol is a Wingate type test (Gibala and McGee, 2008) which involves intermittent (6-30s) all out cycling efforts against a resistance equivalent to ~7.5% of the participants body weight interspersed by periods of recovery (Bar-Or et al., 1987). Not only has this approach been shown to be reliable and valid but studies have demonstrated an increase physiological markers and exercise performance after just six SIT sessions (Burgomaster et al., 2005; Burgomaster et al., 2006; Gibala et al., 2006). However, SIT protocols require an extremely high level of physical exertion from the participant. Consequently, it is not uncommon for side effects such as nausea, vomiting and fainting to ensue if they are untrained and do not perform an appropriate warm-up/cooldown (Suroweic et al., 2014). In contrast, HIIT has been shown to be just as effective as SIT at eliciting similar physiological adaptations and enhancing exercise performance across similar time periods (MacInnis et al., 2017) with fewer negative side effects.

Consequently, we investigated the impact of short HIIT interventions on ischemic pain tolerance. Moreover, we also sought to determine the effect of HIIT on self-paced exercise performance rather than exercise capacity as the former has more external validity to endurance performance. Furthermore, we also investigated the impact HIIT had on pain catastrophizing and anxiety. This was to determine whether changes in psychology could be affected by HIIT and if these changes could explain variances in any of the observed outcome measures most noticeably pain tolerance and/or self-paced exercise performance.

2.0 Literature Review:

In sporting performance, when time to completion is the outcome measure, fatigue is the ultimate determining factor of success (Mauger, 2013). In this sense fatigue can be defined as an exercise-induced reduction in the athlete's ability to produce muscle force/power regardless of if the task can be sustained (Mauger, 2013). Whilst previous explanations have considered fatigue from a peripheral perspective (Kent-Braun, 1999) this comes from studies employing task to failure/time to

exhaustion methods. The problem is that almost all sports do not end in task failure and are instead largely self-paced. Therefore, the mechanisms which govern fatigue in task failure and work rate regulation are not necessarily synonymous (Mauger et al., 2013). Instead Noakes (2012) theory of central control suggests that, in conjunction with past experiences and current knowledge, afferent feedback from the periphery is collected and processed to produce the sensation of “fatigue”. One variable of considerable interest is pain experienced during exercise (EIP) as feedback from muscle nociceptors has been previously associated with central fatigue in the exercising muscles (Amann et al, 2012; see section 2.1 for greater detail).

Previous investigations have demonstrated that as exercise intensity and/or duration increases so does the amount of EIP an athlete experiences (Cook et al., 1997; Ljunggren et al., 1987). For example, in a series of experiments conducted by Cook et al. (1997) it was reported that as cycling exercise intensity increases so does EIP originating from the leg muscles. In one of their experiments male subjects (n=11) completed a maximal cycle ergometer test starting at power output of 50 W and continually increasing by 24 W per minute. During the test pain ratings (0-10) were obtained every minute until pain threshold. At this point leg muscle pain ratings were then obtained every 30 s until volitional exhaustion. Results demonstrated that leg muscle pain increased relative to peak power output and VO_2max. Similarly, in a separate experiment exercise intensity was also positively correlated with leg muscle pain, measured via a visual analogue scale (r=0.79-0.94).

Feedback from type III and IV muscle afferents, which are initially responsible for the neural processing of pain, has also been demonstrated to impact exercise performance (Amann, 2012). This was first observed during studies that measured the maximal isometric exercise performance of a single muscle (Amann, 2012). For instance, when central projection of type III/IV muscle afferents is maintained after a 2 min maximal voluntary contraction of the biceps brachii (via inflating a sphygmometer to 300 mmHg to induce ischaemia thereby blocking off blood supply to the brachioradialalis), then central motor neural drive and voluntary muscle activation persist at low levels and do not recover until circulation, and thus firing frequency of the type III/IV muscle afferents, is restored (Gandevia, 1998). These findings were expanded upon by Amann (2008) who observed that blocking feedback from type III/IV muscle afferents, via lumbar intrathecal fentanyl, attenuated the inhibitory effect of these nociceptors resulting in an increased (less

restricted) central motor neural drive. Indeed, during the experimental condition (i.e. blocked afferent feedback) the power output of participants during the first 2.5 km was substantially higher than during the placebo 5 km time trial (i.e. intact afferent feedback). Taken together these studies suggest that type III/IV muscle afferents are responsible for providing feedback to the central nervous system (CNS) which itself exerts a negative influence on the central motor neural drive to the locomotor muscles (Amann, 2012). This is most to occur to prevent the development of excessive peripheral fatigue and thus harm to the organism (Amann, 2012).

In a similar experiment Amann et al. (2010) also demonstrated that when feedback from type III/IV muscle afferents was blocked, via lumbar intrathecal fentanyl, that; minute ventilation (L/min), arterial haemoglobin saturation and breathing frequency were compromised during cycling exercise performed at various workloads (50 to 325 W). This suggests that afferent feedback from locomotor muscles is also important during whole body exercise performance as it prevents premature fatigue by allowing the appropriate ventilatory and circulatory responses to occur.

In summary pain and exercise are closely interlinked. Not only does pain increase with exercise intensity and duration but afferent feedback from muscle nociceptors, that are themselves responsible for the neural processing of pain (see section 2.1), impact exercise performance by adjusting central motor neural drive to locomotor muscles as well as influence the ventilation and cardiovascular responses so that excessive exhaustion and thus harm to the organism is prevented.

2.1 Neurobiology of Pain and EIP

Type III and IV receptors, also known as type Aδ and C receptors respectively, (Mense and Gerwin, 2010), are responsible for transducing and encoding stimuli that have the potential to cause tissue damage (noxious stimuli) as electrical signals across the central nervous system (CNS). Whilst similar, the axons of these receptors have notable differences. For instance, whilst the axons of Aδ receptors are thinly myelinated allowing for a fast conduction velocity (2-25 m/s) the axons of type C receptors are not resulting in a slower conduction velocity (<2 m/s) (Mense and Gerwin, 2010). However, these receptors also share similarities in that their peripheral terminals (free nerve endings) can all be found in the; skin, muscles, joints, bone, tendon, intervertebral discs, periosteum and fascia.

Furthermore, nociceptors originating from different tissues are often activated by different noxious stimuli. For example, cutting the skin would be enough to activate cutaneous receptors whilst cutting the viscera does not necessarily activate visceral receptors (Mense and Gerwin, 2010). This is important as although multiple tests can be used to examine a pain response the mechanisms causing this response are not necessarily synonymous across tests. For example, the cold pressor test (CPT) causes an algesic response by activating nociceptors located on the skin. In contrast, grip contractions performed under ischemic conditions cause a build-up of metabolites which activate deep type C nociceptors located primarily in the muscles and joints (O'Connor and Cook, 1999). The exact mechanisms underlying the pain response during ischemic conditions continue to be determined but may include; reductions in muscle pH as well as increased ATP and nonapeptide bradykinin (BKN) concentration in the blood (Mense and Gerwin, 2010).

During dynamic exercise the concentration of noxious chemicals, amount of mechanical pressure and metabolic disturbance either directly stimulate or sensitize type III and IV nociceptors located primarily in the muscle and joints (Pickar et al., 1994; Adreani et al., 1997; Light et al., 2008). Most of these noxious stimuli are summarised in a review paper published by O'Connor and Cook (1999; see table 1).

During exercise the nonapeptide BKN is a potent nociceptive stimulus (Mense and Gerwin, 2010). BKN is produced in response to tissue damage and other common homeostatic disturbances that occur during exercise such as increased metabolic acidosis and hypoxia (Langberg et al., 2002; O'Connor and Cook, 1999). Furthermore, it is capable of not only directly activating and sensitizing Aδ and C nociceptors but is also responsible for the synthesis and release of potent prostaglandins (e.g PGE_2). Prostaglandins themselves are significant tuning chemicals that are correlated with increased muscular pain and decreased pain threshold (Hedenberg-Magnusson et al., 2001). Finally, BKN has also been previously demonstrated to be a regulator of blood flow by causing vasodilation (Wilson and Kapoor, 1993; Langberg et al., 2002) and thus promote the action of other vaso-neuroactive algesics.

Substance	***Primary effect on afferent fibres***
Bradykinin	*Activation**
Histamine	*Activation**
Potassium	*Activation**
Serotonin	*Activation**
Leukotrienes	*Sensitization*
Hydrogen ions	*Sensitization*
Hypoxia	*Sensitization*
Substance P	*Sensitization*

*Table 1: An adapted table from O'Connor and Cook (Page 122, Table 5.1, O'Connor and Cook; 1999). * = Activation of type IV and sensitization of type III afferent fibres.*

High intensity exercise also causes the accumulation of hydrogen ions/protons (H^+) and adenosine triphosphate (ATP). At rest ATP is already at high concentrations in the muscle and is required for muscular contraction. During high intensity exercise ATP molecules are released from the muscle cells as trauma and/or inflammation causes significant damage to the cellular membrane (Mense and Gerwin, 2010). Once released, ATP molecules bind to purinergic membrane receptor P2X3 which opens an ion channel increasing the permeability to small cations such as Na^+ (Cook and McCleskey, 2002). Additionally, small increases in the H^+ ion concentration are known to sufficiently stimulate type IV muscle receptors by binding to local acid-sensing ion channels (ASIC1 and 3). Indeed these protein channels are sensitive enough to detect small pH changes, for example pH 7.4 to 7.1 (Mense and Gerwin, 2010). The vanilloid receptor TRPV1 also responds to increasing H^+ ion concentration as a tissue pH of 6.3 will allow this nociceptor's activation threshold for temperature to decrease from 39ºC to 26ºC (Mense and Gerwin, 2010).

Whilst previous studies have demonstrated that individual injection of metabolites can produce a pain (Sluka et al., 2001; Mørk et al., 2003; Pollak et al., 2014) the evidence is not consistent and typically in isolation these metabolites only cause a algesic response when administered at exceedingly high concentrations (Reinohl et al., 2003; Hanna and Kaufman, 2004; Light et al., 2008; Pollak et al., 2014). Rather, a combination of them are required to evoke a muscular pain response in both animals (Light et al., 2008) and humans (Pollak et al., 2014).

Specifically, Pollak et al. (2014) reported that increasing concentrations of lactate, ATP and H^+ in a metabolite solution increased the pain response as measured on a visual analogue pain scale (VAS) and through various pain adjectives including sensations of aching and hot at the site of injection; the base of the thumb. Indeed, at concentrations similar to vigorous exercise, all subjects (n=10) reported more and stronger sensations of pain. Consequently, this provides evidence that higher levels of noxious stimuli, as produced in HIIT, cause a markedly greater algesic response. However, some subjects reported sensations relating to mechanical movement including; pressure (n=8), flowing (n=1), vibration (n=1) and heavy (n=3) despite the absence of a mechanical stimulus (Pollak et al., 2014). This suggests that the metabolites are somewhat capable of activating mechanoreceptive neurons. F

However, as the authors were “unsure of the potential intensity of the evoked sensations” metabolite solutions were administered in ascending series. Consequently, subjects were not randomized or blinded to solution infusion which should be considered a major limitation. Additionally, the site of injection’s muscle is highly vascular and neurologically innervated (Pollak et al., 2014). Therefore, the activation characteristics for sensations of fatigue/pain for other skeletal muscles are likely different. Together, these limitations mean the results should be interpreted with caution.

Once a sufficient combination of noxious stimuli are present, type III and IV receptors are activated and sensitized, increasing the spontaneous discharge of the nociceptors from the periphery to the lumbar dorsal horn of the spinal cord (Amann, 2012). Here the nociceptive and non-nociceptive afferents converge and release both amino acid and peptide-based neurotransmitters that propagate the impulse from the spinal cord along ascending pathways (spinothalamic, spinoreticular and spinomesencephalic) to various brains structures (O’Connor and Cook, 1999).

Studies measuring regional cerebral blood flow (rCBF) have observed that the insular cortex is important at processing pain in isolation (Casey, 1999) and when induced by exercise (Williamson et a, 1997). Other cortical and subcortical areas have also been identified to respond to the presentation of a noxious stimulus and include the; the bilateral thalamus, secondary somatosensory cortex (SII), premotor cortex, anterior cingulate cortex and cerebellar vermis (Casey, 1999; Peyron et al., 2000; Friebel et al., 2011; Cauda et al., 2014). Together these areas are referred to as the “pain matrix”, “neuromatrix” or “salience matrix” and are responsible for the

sensory processing of pain among other functionalities (Iannetti and Mouraux, 2010). However, this evidence largely comes from innocuous stimuli such as electrical stimulation and temporal summation. Therefore, caution should be applied when interpreting and applying these results to an exercise setting. In contrast, studies employing methods, such as hypertonic saline injection and ischaemia, should be considered to have greater construct validity as these produce conditions which are more representative of the etiology of exercise

Nevertheless, exercise-induced or not, pain perception is a complex process being interpreted at various brain structures and not just at a singular site (Cassey, 1999). Adding to its complexity, pain can also occur in the absence of any tissue damage or obvious pathophysiological cause (Nikolajsen and Jensen, 2006). For example, Andoh et al. (2017) reported that patients suffering from phantom limb pain exhibited increased activation of the SI, SII and intraparietal sulci (IPS). Additionally, the anticipation of pain alone is also associated with pain processing (Porro et al., 2002) and actual clinical pain experienced by fibromyalgia and osteoarthritis patients (Brown et al., 2014). These findings are important as they demonstrate that psychological factors should always be considered as a potential algesic/analgesic influence independent of any observable tissue damage.

2.2 Exercise Induced Hypoalgesia (EIH) and Athletes vs Non-Athletes

A term that is often referenced in literature, whereby exercise alters pain perception, is exercise induced hyperalgesia or EIH. Studies often measure EIH by comparing differences in pain threshold before and after exercise (Nauger et al., 2012). EIH is well documented following aerobic, isometric and dynamic resistance-based exercise in healthy individuals (Nauger et al., 2012; Nauger et al., 2016).

Specifically, aerobic exercise has been demonstrated to produce moderate to large EIH as measured by adjusted effect sizes. Indeed, a meta-analytic review by Naugle et al. (2012) reported moderate effect sizes when regarding the hypoalgesic effects of aerobic exercise in relation to pain threshold (d=0.68) and pain intensity (d=0.64). Furthermore, Naugle et al. (2012) also reported a dose-response relationship when regarding EIH in that high intensity (>75%VO_2max) and longer (>10mins) periods of exercise produced the largest effect sizes. Since then studies have reported EIH in adults (Naugle et al., 2014; Naugle et al., 2016) and

adolescents (Stolzman and Bement, 2016) further supporting the hypoalgesic benefits of aerobic exercise.

Despite this evidence, the mechanisms underpinning EIH are poorly understood although much of the literature focuses on both opioid and non-opioid mechanisms. Exercise-induced release of opioids at the peripheral, spinal and/or central sites has been previously associated with pain modulation and thereby EIH (Thoren et al., 1990). Indeed, opioid antagonists, naloxone and naltrexone, have been previously demonstrated to attenuate the analgesic response after exercise (Mogil and Belknap, 1996). However, neurotransmitters such as, norepinephrine and serotonin (Bobinski et al., 2015) have been identified as potential modulators of EIH providing evidence for non-opioid mechanisms. Similarly, there is evidence suggesting the involvement of *N*-methyl-D-aspartic acid subtype of excitatory amino acid receptors (NDMA; Price et al., 2000).

There is also evidence which demonstrates that athletes have a higher pain tolerance than non-athletes. Tesarz et al. (2012) conducted a meta-analysis of cross-sectional studies comparing athletes to non-athletes. After a sensitivity analysis it was concluded that pain tolerance was indeed higher in athletes with a large effect size (Hedges'g=0.93, CI 0.52–1.34; I^2=73%) although differences did exist between sport categories. For example, pain tolerance in endurance athletes was characterized by a moderate effect size but low heterogeneity (Hedges'g=0.65; CI 0.42-0.88; I^2=6%) whilst in game sport athletes effect size and heterogeneity were high (Hedges'g=0.98, CI 0.40-1.57; I^2 =86%). This suggests that whilst pain tolerance maybe higher in game sport, versus endurance athletes, the population is not homogenous which is typical of game sports as they often involve clusters of athletes with a variety of psychological and physical profiles.

In contrast, the effect on pain threshold was less profound than pain tolerance (Tesarz et al., 2012). Whilst five studies reported higher pain thresholds, others either showed no difference, an effect size in the opposite direction (Ord and Gijsbers, 2003; Hedges'g=-0.57) or a "questionably high" effect size (*d*=2.22; Granges and Littlejohn, 1993; Tesarz et al., 2012). Moreover, a sensitivity analysis did not support the assumption that athletes have a higher pain threshold compared to normally active controls. This is because whilst pain tolerance is influenced by a variety of psychological and psychosocial factors such as self-efficacy and pain acceptance (Baker and Kirsch, 1991; Motl et al., 2007), pain threshold is stable and

unchanging (Tesarz et al., 2012). Furthermore, since pain threshold is not predicated by athletic status this means that the aforementioned findings, on pain tolerance being higher in athletes, are unlikely to be due to EIH. However, due to the nature of cross sectional studies it is uncertain to ascertain whether this observed difference is largely due to higher physical activity/exercise training levels or if athletes inherently possess higher pain tolerances thereby predisposing them to higher levels of physical activity. Consequently, interventional studies, with structured exercise training programs, would provide further insight to determine if exercise training can influence pain tolerance and at what intensity and/or duration.

2.3 Effect of Exercise Training on Pain Tolerance

To the author's knowledge there are only three interventional studies that have examined the effect of exercise training on pain perception in humans (Anshel and Russell, 1994; Jones et al., 2014; O'Leary et al., 2017a). Despite these studies having variable outcomes what they all have in common is they measure and distinguish between pain threshold and tolerance (see section 1.1 for definitions).

Anshel and Russell (1994), examined the effect 12 wks of exercise training had on pain tolerance and appraisal measured by profile of mood states. Participants (n=48) were unfit but otherwise healthy adults and randomly allocated into three exercise conditions; aerobic, resistance or combined aerobic and resistance exercise training in addition to a control (no exercise) group (n=12x4). Only those in the aerobic and combined exercise training increased their pressure pain tolerance to the upper ($p<0.05$). In contrast, resistance training alone, and no training, did not increase pressure pain tolerance.

However, during their study the effect exercise training had on pain threshold was not recorded and pain tolerance was measured as the peak force rather than the duration that the stimulus could be endured (Anshel and Russell, 1994). Secondly, the volume and intensity of exercise performed were not accurately quantified. Consequently, it is impossible to determine the importance of exercise intensity and/or duration interpreting the results. Finally, no measures of maximal aerobic power were conducted and thus the influence of aerobic capacity on pain sensitivity could not be determined. Nevertheless, Jones et al. (2016) did investigate the impact of maximal aerobic capacity on pain sensitivity and observed no relationship between VO_2 peak and pressure pain threshold or ischemic pain tolerance.

Therefore, Anshel and Russell (1994) provides some evidence that aerobic exercise training can increase pain tolerance within a healthy non-athletic population

Jones et al. (2014) investigated the effect of aerobic training on pain sensitivity. In their study 24 healthy participants were assigned to either a control (n=12) or exercise group (n=12). Those in the training group performed 17-18 aerobic training sessions spread evenly over six weeks. Each session consisted of 30 min of cycle ergometry exercise performed at 75% HR reserve after a 5 min warm up at 35 W. Pressure pain threshold (PPT) was measured on four muscular sites on the right side of the body (trapezius, biceps brachii, rectus femoris and tibialis anterior) and ischemic pain tolerance via a modified submaximal ischemic tourniquet test (IPTT). Pain tolerance was defined as the total time participants could tolerate the handgrip exercise under ischemic conditions.

After six weeks of aerobic training Jones et al. (2014) reported that, ischemic pain tolerance increased in >80% of participants by ~20% ($p=0.036$) but remained the same for participants in the control group (-3.75%; $P=0.44$). The duration of ischemic pain tolerance was not associated with any changes in VO_2 peak in either the exercise ($r<0.0001$; $p=0.99$) or control group ($r=0.18$; $p=0.17$) as expected (Jones et al., 2016). However, when both groups were combined a weak association between the variables was found ($r=0.21$; $p=0.02$). This was explained due to how the groups were clustered in that there was little change in VO_2 peak and pain tolerance in the control group but more significant changes in these variables in the exercise group. Pain threshold remained unchanged, after six weeks, in both groups in either the upper or lower body thus providing preliminary evidence that aerobic training increases pain tolerance but not pain threshold.

However, as acknowledged by the authors (Jones et al., 2014), group allocation was not randomized and those in the exercise group received more attention as they were supervised for an additional 18 exercise sessions. This means that behavioural artefacts can not be ignored and must be considered as a potential cofounding factors to the observed increase in pain tolerance. Secondly, training occurred at 75%HR reserve. Although this is better than not prescribing an intensity at all (Anshel and Russell, 1994) this method has been criticized to cause variances in both perceptual and metabolic stress between individuals (Mann et al., 2013).

O'Connor and Cook (1999) proposed that by regularly approaching the limits of performance in training, such as during HIIT, pain tolerance can be vastly improved. Indeed, HIIT causes significant metabolic disturbances as indicated by the increased cardiovascular and perceptual response compared to a typical continuous training model (CONT; O'Leary et al., 2017b). Moreover, HIIT has been reported to be more effective at increasing exercise capacity than CONT (Daussin et al., 2008; Seiler et al., 2013), despite causing similar improvements in markers for aerobic fitness (i.e. VO2max and/or lactate threshold [LT]) (Daussin et al., 2008; Edge et al., 2006; Poole and Gaesser 1985). Additionally, just six to seven sessions (~2wks) of HIIT has been demonstrated to increase markers for mitochondrial biogenesis. This includes but is not limited to an increase the in maximal muscle activity of; PGC1-a (↑30-40%), citrate synthase (↑20-39%), COX IV (↑24%) and acetyl CoA (↑32%) (Perry et al., 2010; Talanian et al., 2006; MacInnis et al., 2017; MacInnis and Gibala, 2017). Furthermore, studies employing HIIT protocols over similar periods of time have also observed an enhancement to maximal aerobic capacity (↑13% VO_2 peak; Talanian et al., 2006), peak work rate (↑8.67%; MacInnis et al., 2017) and time trial performance (↑1.1-2.7%; Garcia-Pinillos et al., 2017) similar to or greater than CONT.

Consequently, O'Leary et al. (2017a) designed a study whereby participants were randomly assigned (1:1) into either a 6wks of HIIT or CONT group (n=10x2). The HIIT protocol was adapted from Weston et al. (1997) consisting of 6-8x5 mins exercise (interspersed by 1 min rest) intervals on a cycle ergometer at an intensity halfway between LT and VO_2 max. In contrast, the CONT protocol involved continuous cycling at 90%LT. These protocols were designed as such to address the previous limitation (Jones et al, 2014) of prescribing training based on HR reserve. After 6 wks TTE improved similarly in both groups but ischemic pain tolerance only increased following HIIT (39±29%; $p<0.001$) and not after CONT (4±16%; $p=0.72$). Since the pain tolerance test was performed in the arm, which was not involved in the training, and consisted of occluding blood flow it is unlikely that any changes to the nociceptor stimuli are responsible for this observation. Additionally, a reduction in pain sensitivity is an unlikely mechanism as no changes to pain ratings were observed during studies conducted both by Jones et al. (2014) and O'Leary et al. (2017a). Instead, within training data (O'Leary et al., 2017b) suggests that regularly approaching the limit of exercise tolerance during training was responsible for the increased pain tolerance. Indeed, participants in the HIIT

group always reached an RPE = 19 or 20 during the last 5 min of each sessions whereas participants in the CONT group never exceeded an RPE = 15.

However, there are some limitations that exist with their study (O'Leary et al., 2017a). The most prevalent was that performance was assessed by a time to exhaustion task halfway between LT and VO_2 max. Whilst not necessarily a limitation in of itself (useful to determine exercise tolerance) it has limited external/logical validity to endurance performance (Currell and Jeukendrup, 2008). In the field of exercise physiology most interventions and mechanisms are explained using TTE tasks and/or exercises at a fixed exercise intensity. However, it is very rare for an athlete to exercise to volitional fatigue at a single exercise intensity (Currell and Jeukendrup, 2008). In other words, in the endurance sports performance is often entirely self-paced (Mauger et al., 2013; Mauger et al., 2014). Nevertheless, when comparing TTE to time trials of the same duration, Passfield and Coakley (2014) found no difference in average power output at 100 or 105% VO_2max. Therefore, whilst it has been demonstrated that TTE tasks can be reflective of endurance performance caution should still be taken when interpreting these results when as the mechanisms which govern task failure and work rate regulation are very different constructs (Mauger et al., 2013).

Indeed, whilst previous studies have attributed increased self-paced exercise performance to increased aerobic physiological markers it may also link to an improvement in the regulation of EIP. In self-paced endurance tasks, EIP allows the athlete to evaluate the relative "strain" of exercise on the body which can then be interpreted to make a conscious decision to increase or decrease exercise intensity (Mauger et al., 2013; Mauger et al., 2010). This has been demonstrated by Mauger et al. (2010) who gave participants (n=13) a 1.5 g of placebo (dextrose) or acetaminophen (ACT or paracetamol) 45 min before a 16.1 km time trial. Paracetamol is as an analgesic and its primary function is to inhibit the action of cyclooxygenase which itself is responsible for the production of prostaglandins that sensitive nociceptors (Mauger et al., 2010). Consequently, it relieves pain by elevating the pain threshold. Since its pharmacokinetics are unaffected by exercise and it has minor peripheral effects, any changes to exercise performance that are induced by ACT are likely to be attributable to changes in pain perception (Mauger et al., 2010). Indeed, results demonstrated that in the ACT condition 16.1 km TT performance increased by 2% and remained unchanged in the placebo condition. This was associated with an increase in mean power output and no change in EIP.

Therefore, EIP was demonstrated to be important in the regulation of exercise as ACT enabled participants to exercise at a greater intensity for the same level of perceived pain. This is supported by similarly designed studies (Foster et al., 2014; Delextrat et al., 2015) which also reported that ingestion of ACT in repeated sprint cycling performances can increase mean and/or peak power output with no changes to EIP.

Astokorki and Mauger (2016) also highlighted the importance of EIP. In their study EIP was correlated with endurance performance and could accurately predict a 16.1 km cycling time trial ($r = -0.83$, $p<0.01$) and accounted for 7.5% of the variance after other factors for endurance performance were considered ($p=0.002$). Moreover, Whitehead et al. (2017) reported that, during an outdoor 16.1 km cycling TT, sensations of fatigue and pain were reported more frequently in earlier stages but reduced towards the final quartile of the race. The author attributes this to a variety of factors which include; perceived importance of the event, greater stress response during the initial portion of the race and participants employing specific coping strategies as the event progresses. Additionally, similar observations were made about verbalisations relating to the monitoring/alteration of pace indicating that the riders use sensations of pain and/or discomfort as a tool to appropriately plan their pacing strategy (Whitehead et al., 2017). Thus, these studies demonstrate that not only can tolerance of EIP be a predictor of endurance exercise performance but also that during “real world” scenarios athletes use sensations of pain during exercise to alter their pacing strategy.

It is also uncertain how much HIIT is needed to elicit improvements to pain tolerance. Participants in O’Leary et al. (2017a) exercised for a combined total of 18 HIIT or CONT sessions equating to approximately six weeks in duration. To the author’s knowledge, no study to date has investigated whether pain tolerance or self-paced exercise performance can increase following a short period of HIIT. Consequently, not only is it unclear whether a short period of HIIT could increase pain tolerance but also if subsequent training sessions further this effect.

Finally, it is also unclear why pain tolerance increases following HIIT. Whilst previous studies have attributed this to alterations in the signalling response to afferent signals from nociceptors (Jones et al., 2014), this is unlikely as pain threshold remains unchanged after period of aerobic exercise training (Jones et al., 2014; O’Leary et al., 2017a; Stevens et al., 2017). Instead, it is more likely

psychological factors such as; pain catastrophizing (Sullivan et al., 2000), anxiety (Geva and Defrin, 2013; Roebuck et al., 2018) and self-efficacy (Motl et al., 2007; Johnson et al., 2011), are important at regulating this response as indicated by cross sectional (Tesarz et al., 2012) and training (Anshel and Russell, 1994) evidence. Specifically, Anshel and Russell (1994) observed that after 12wks of aerobic exercise training pain appraisal, as measured by profile of mood states, improved (increase in vigour as well as decrease in tension and depression). However, the POMS has been criticized in the past (Leunes and Burger, 2000) and does not necessarily provide a complete psychological profile as intended.

Therefore, the purpose of the current study was to determine if three or six HIIT sessions had any effect on ischemic pain threshold, tolerance and ratings. The impact of HIIT on self-paced exercise performance as well as pain catastrophizing and anxiety was also investigated. The reason for not employing more HIIT sessions or a control group was due to the scope of the project. Additionally, past studies have observed increases in self-paced exercise performance, exercise capacity and physiological aerobic capacity markers following HIIT (Perry et al., 2010; Talanian et al., 2006; MacInnis et al., 2017; Garcia-Pinillos et al., 2017) further justifying this decision.

2.4 Hypotheses

Firstly, it was hypothesized that three and six sessions of HIIT would increase ischemic pain tolerance, 5 km TT performance and decreased pain catastrophizing and anxiety. Secondly, it was hypothesized that six HIIT sessions would produce a markedly greater response in the aforementioned variables than three HIIT sessions. Finally, it was hypothesized that a training effect would occur only following six HIIT sessions reflected by an increase in power output for the same heart rate response.

3 Methods

3.1 Participants

In total 18 healthy adults (11 males, 7 females) volunteered to participate in the two-arm parallel group. The study was approved by the institutional ethics review board and conducted in accordance with the Declaration of Helsinki. All participants were

recruited in Oxford, UK through advertisements placed on billboards/study tables throughout the campus, posts to social media, word of mouth and emails to coaches of local sports clubs (hockey, triathlon, cycling and cricket). The eligibility criteria were: 1) Healthy with no history of chronic disease or chronic pain; 2) not taking any pain or pain-related medication; 3) between the ages of 18–55yrs; and 4) not currently diagnosed with depression (Thompson et al., 2016). All participants were required to complete a PAR-Q form and provide informed consent before taking part in the study. After completing baseline assessments participants were randomly assigned into one of two exercise groups: three (n=9, Ex-1), or six HIIT sessions (n=9, Ex-2).

3.2 Experimental Procedure

All participants completed experimental trials before and after three or six HIIT sessions depending on their group allocation (see figure 1). All testing and training sessions were separated by at least 24 hrs and lasted no longer than an hour. For the initial baseline assessment instructions were given to each participant telling them to arrive 2 hrs postprandial having already abstained from exhaustive exercise (48 hrs), alcohol (24 hrs) and caffeine (12 hrs). Participant's anthropometric measures and response to the PCS and PASS-20 questionnaires were firstly assessed. This then was followed by measuring their maximal voluntary grip contraction (MVC) and ischemic pain tolerance (see section 3.3). A VO_2max test was conducted to determine maximal aerobic capacity to establish general aerobic fitness and determine the linear factor for training (see section 4.5.1). The second visit involved a 5 km time trial the details of which are provided in section 4.5.2. On subsequent assessment days the following measures were obtained in order; resting HR, PCS and PASS-20 questionnaire responses, MVC, IPTT and 5 km time trial.

3.3 Ischemic Pain Tolerance Test (IPTT)

Before commencement of the IPTT participants were required to establish their MVC so that the required force needed to be produced by isometric contractions could be set (30% MVC) . This consisted of three maximal grip contractions using a handgrip dynamometer (Takei, T.K.K 5401, Japan). Each contraction was separated by 1min and participants were instructed to bend the elbow whilst keeping their arms at their side but not touching the body. Standardized verbal

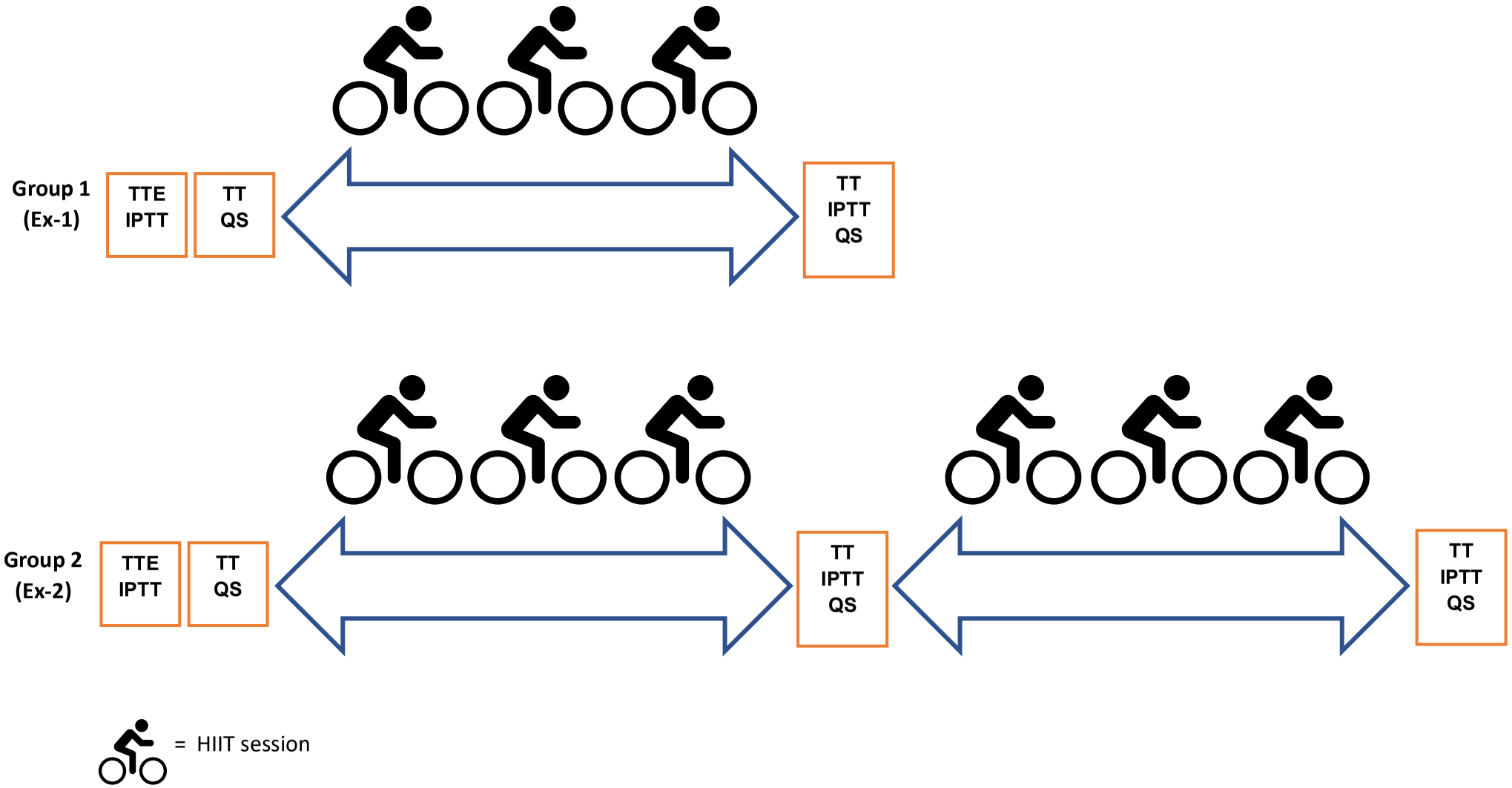


Figure 1 - Overview of the design for study 1. Tests displayed were conducted in a bottom-up order in that those placed below were done first. QS = Questionnaire responses (pain catastrophizing and pain anxiety symptom score) IPTT = Ischemic pain tolerance test. TT = 5 km Time trial. TTE = VO_2max test (time to exhaustion). HIIT = High intensity interval training. Each visit was separated by approximately 48-72hrs.

encouragement was given throughout this test and the best of the three measures was determined as their MVC.

After the participant's MVC was determined they then completed an IPTT. The IPTT is a modification of the ischemic exercise test and the IPTT protocol used for this study is the same as previously described (Jones et al., 2014; O'Leary et al., 2017a).

Throughout the duration of the IPTT participants were seated and a cuff was placed around their upper dominant arm. Subjects were first instructed to raise this arm above their head for 60 s to cause exsanguination. After 60s the sphygmometer was rapidly inflated to 200 mmHg to ensure complete arterial occlusion before the participant lowered their arm to commence the test. The IPTT consisted of a series of 4 s isometric contractions, at 30%MVC, using the previously described force grip dynamometer and software (4.3.1), with visual feedback of the grip force displayed on a nearby computer screen (Toshiba, Satellite Pro, L670-170). Each contraction was separated by 4 s of rest. The test lasted until the participant could no longer continue. A separate PC monitor (Dell, Ultrabook, Latitude E7470) was also positioned adjacent to the grip force visual feedback monitor and displayed a presentation of slides which switched between green (contraction) and red (relaxation) accompanied with an auditory tone.

Prior to assessment participants were asked to note when sensations of discomfort became painful. This was determined as their ischemic pain threshold whereas the total time participants could sustain handgrip contractions was defined as ischemic pain tolerance. Subjective ratings of pain (PPI) were also obtained every 30s from pain threshold. Pain ratings were recorded using a 11-point numeric pain rating scale (NRS-11; figure 7) with three anchor points; 0="No pain, 5="Moderate Pain" and 10="Worst possible pain" and participants were told they could rate their pain in increments of 0.1. Systematic reviews (Williamson and Hoggart, 2005; Hjermstad et al., 2011) have demonstrated that the NRS-11 has significant correlations and agreement levels with the 100mm VAS (r=0.84-0.94). Moreover, the NRS-11 is argued to be superior primarily due to its high compliance and ease of use (Hjermastad et al., 2011). Furthermore, to blind participants of elapsed time, PPI was obtained at random intervals although these data were not recorded. Finally, during the test HR was also obtained every 30 s using online telemetry (T31, Polar, Finland; FT1, Polar, Finland).

Participants had complete control over the start and cessation of the test. They pressed a button to inflate and deflate the cuff, starting and terminating the test respectively. A 10 min time limit was set but not known to the participants who were only told to sustain handgrip contractions for as long as possible (no participant reached this time limit). The investigator also terminated the test if the participant themselves requested or they failed to reach 30%MVC.

3.4 Exercise Tests

All exercise tests were conducted on an electromagnetically braked cycle ergometer (Corival, Lode, Netherlands) at a self-selected cadence above 60 rpm. HR was measured using online telemetry (Polar HR sensor, H1) and RPE was determined using the 6-20 Borg scale (figure 9) with 6="No exertion at all" and 20="Maximal exertion". All tests were conducted by the same investigator.

3.4.1 Maximal Aerobic Capacity and Linear Factor Assessment

To assess for maximal aerobic capacity a VO_2max test, to volitional exhaustion, was conducted at baseline using a step protocol, previously used in our laboratory (Jones et al., 2017). The step protocol was chosen over a ramp protocol due to the former providing more valid measurements for gaseous exchange threshold data used for subsequent linear factor assessment (Zuniga et al., 2014).

Specifically, the protocol first consisted of participants resting for 2 min, followed by a warm up at 50 W for 5 mins at a self-selected cadence. Thereafter, the resistance progressively increased until volitional exhaustion occurred using a step protocol (25 W every 3 mins). The test was terminated by the investigator if either a cadence of 60 rpm could not be maintained for 5 s or when the cadence fell below 60 rpm three times (O'Leary et al., 2017a). Inspired and expired gases were collected and recorded using online breath-by-breath analysis (Cortex Metalyzer 3B, Leipzig, Germany). Measures of HR and RPE were obtained every minute and at exhaustion. Data for VO_2 was averaged over 10 s periods with the highest 30 s average value representing VO_2max. Peak work rate was defined as the highest work rate achieved during the step test.

Gas exchange threshold (GET) was determined by using three main criteria previously described by Baily et al., (2009). The criteria were to identify either: 1)

The first disproportionate increase VCO_2 when visually inspecting the plots of VCO_2 vs VO_2; 2) Increase in expired ventilation (VE)/$VC0_2$ with no increase in inhalation (VE)/VO_2; or 3) Increase in end-tidal O_2 tension without a decrease in end-tidal CO_2 tension (V-slope method; Beaver et al., 1986). From this the VO_2, VCO_2 and work rate (W) at GET was then determined by using the closest data point as a reference. The same investigator was responsible for interpreting all the data obtained.

Prior to all VO_2max tests the gas analyser and volume transducer were calibrated in accordance with laboratory standard operating procedures and manufacturer guidelines. The gas analysers were calibrated using a gas standard (Cranlea, 110 L Calibration Gas, 5%CO_2 and 15%O_2) and the volume transducer with a 3L calibration syringe (Hans Rudolph, Series 5530).

From the VO_2max test each participant's linear factor was determined so subsequent tests (3.4.2) and training sessions (3.6.1) could be conducted in linear mode. This ensures specificity in how the work rate responds to changes in pedal rate instead of the load being constant independent of the pedalling rate of the subject (hyperbolic mode). Consequently, participants can pace themselves to an RPE = 15 by adjusting their pedalling rate and the brain of the participant, not the experimenter, becomes "central command" or pacemaker of the exercise the importance of which is discussed further in section 3.6.1 (Noakes, 2011). The linear factor allows for adjustment in work rates as described by Driller (2012):

$$W = L \bullet (RPM)^2$$

Figure 2 – Equation which describes how work rate adjusts for changes in cadence (Driller, 2012). W = Work rate, L = Linear factor (constant value), RPM = Cadence.

The linear factor was calculated from the VO_2max test by obtaining the: average cadence, peak work rate, VO_2max and work rate at GET as previously described. Furthermore, a desired delta was determined to calculate the linear factor. The desired delta is a percentage value that represents the equivalent work rate value between the VO_2GET and VO_2max. For example, if a desired delta of 50% is chosen then the VO_2 value 50% between the VO_2GET and VO_2max will be selected and the corresponding work rate is used to determine the linear factor (Bergstrom et al., 2012). For the present study a desired delta of 70% was agreed upon by the investigators to ensure participants exercise above a steady state. Thus, the linear

factor was calculated using the equation described in figure 2 (Osterberg et al, 2007; Jeukendrup et al, 1996).

$$L = (GET+70\%\Delta) / (AC)^2$$

Figure 3 – Equation which describes how linear factor was calculated for the present study. L = Linear factor. GET = Work rate at gas exchange threshold. 70%∆ = 70% Delta. AC = Average Cadence

3.4.2 5 km Time Trial

After a period of 48-72hrs participants completed a 5 km time trial (TT) designed to assess self-paced exercise performance. The resistance during each participant's 5 km TT protocol was based on their linear factor and ran on the software Lode Ergometry Manager, V.9. Not only have previous studies reported improvements in 5km TT performance following similar periods of time (Hazell et al., 2010) but the 5 km TT was also chosen for its high relative and (ICC > 0.95) absolute reliability (coefficient of variation < 3%) with various endurance performance variables (Dantas et al., 2015).

Before test commencement participants were instructed to warm-up for 5min at a self-selected cadence against a low manual resistance (20-30 W). During the warm-up instructions for RPE and perceived pain (EIP) scales were provided using similar instructions (see appendix section 8.8) adapted from Borg (1998) and Cook et al. (1997). Both scales were attached to a 178 cm stand approximately 50 cm directly in front of the handlebars. Participants then briefly stopped cycling until the flywheel went to a complete stop.

Once the flywheel stopped the investigator counted down from five and the test started on “go” upon which participants were instructed to complete the 5 km TT as fast as possible. All participants were blinded to the elapsed time but knew their distance completed and remaining. Providing distance feedback this way has been previously shown to be preferred by as well as maximising TT pacing and performance in novice cyclists (Boya and Micklewright, 2016; Boya et al., 2017).

Every 0.5 km measures of PO, RPE, HR and EIP (0-10) were obtained alongside how quickly, in seconds, the participant completed the 0.5 km. In all instances measures were obtained during the last 50 m of each 0.5 km with RPE obtained first followed by EIP then HR. Standardised verbal encouragement, unrelated to time, was given during the 5 km TT. To ensure all data were collected accurately values

for time completion and PO were obtained after the test from the exported excel data sheet provided by the software.

3.5 Questionnaires

All participants completed the questionnaires described in the following section. In all instances the questionnaires were completed in silence and away from the influence of the investigators. They were always completed before commencement of any exercise test.

3.5.1 Pain Catastrophizing Scale (PCS)

The PCS (figure 6; Sullivan et al., 1995) consists of 13 items, each with different statements asking the participants to rate their thoughts and feelings when they are in pain. An example of one of the items is: “When I’m in pain…I feel I can’t go on.” Participants rated each statement on a 0-4 scale where: 0=“not at all”; 1=“to a slight degree”; 2=“to a moderate degree”; 3=“to a great degree”; and 4=“all the time”- to produce a maximum possible score of “52”. The internal consistency and validity of the PCS has been demonstrated by Osman et al. (1997) in healthy individuals and also reported a high test-retest correlation (r=0.75) across a period of 6 weeks for the same individual.

*3.6.2 Pain Anxiety Symptom Scale short form 20 (PASS-*20)

The PASS-20 (figure 7; McCracken et al., 1996) consists of 20 items, each of which is a statement relating to the participants anxiety towards pain. For example, “I can’t think straight when in pain”. Participants rated each statement on a 0-5 frequency scale with two anchor points where 0=“Never” and 5=“Always,” to produce a maximum possible score of 100. As the name preludes the PASS-20 is a short version of the original PASS which consisted of 40 items (McCracken et al., 1992). The internal consistency, reliability and construct validity of the PASS-20 has been previously demonstrated in both chronic pain patients (McCracken and Dhingra, 2002) and healthy individuals (Abrams et al, 2007).

3.6 Training

3.6.1 Exercise Sessions

All exercise training sessions were completed on a cycle ergometer in linear mode (Excalibur, Corival Lode, Netherlands) and the HIIT protocol was adapted from O'Leary et al. (2017a). This consisted of 6 x 5 min exercise bouts interspersed by 1 min recovery periods. However, to provide more external validity, participants were instructed to complete these exercise bouts at an RPE = 15 (i.e. "hard") instead of exercising at a fixed exercise intensity halfway between lactate threshold and VO_2max (O'Leary et al., 2017a). This is based on the anticipatory central governor model (Noakes, 2011) in which participants pace themselves based on various psychological (e.g. motivation, previous experience and self-efficacy) and physiological factors (fuel reserves, hydration status and heat accumulation) that occur before and during exercise.

Measures of HR and PO were obtained every 60 s during each exercise bout. Before commencing each HIIT session participants warmed up against a 20-30W load for 5mins. Depending on group allocation participants either completed 3 (Ex-1) or 6 (Ex-2) HIIT sessions with at least 24 hrs separating consecutive sessions.

3.7 Anthropometric and Heart Rate Data

3.7.1 Height

Participant's height was recorded at baseline (Harpenden, Stadiometer, Crymych-Wales). Participants were instructed to stand straight with their back against the wall with their eyes facing forward.

3.7.2 Body Composition

Bioelectrical impedance analysis (BIA) was conducted at baseline (BC-418 Segmental Body Composition Analyzer, Tanita, Tokyo Japan) before any exercise tests to assess for body fat %. For each assessment the mass of clothes was estimated using a visual guide.

3.7.3 Resting Heart Rate

To obtain resting HR participants were instructed to lay down on a clinical laboratory bed and relax taking deep breaths in and out. Screens were set-up to separate the participant from the investigator and resting HR was determined as the value obtained after 60s although participants were not told this. HR values were obtained using online telemetry (Polar HR sensor, H1).

3.8 Statistical Analysis

All statistical analysis was conducted in SPSS (v.25, SPSS Inc, USA). Data were tested for homogeneity using the Levene's Test for equality of variances and are presented as mean ± SD in text, tables and/or figures.

Firstly, to compare baseline values between groups independent t-tests were conducted. Additionally, 2 x 2 ANOVAs were conducted to determine if any significant time interactions occurred and thus if HIIT had any effect on pain tolerance and threshold, average 5 km TT performance and questionnaire responses. Following a significant time interaction one-way ANCOVAS were also implemented to assess the differences between each group's post training values with the baseline values used as a covariate. Changes in PO and HR variables during training were assessed using a series of 1 x 3/6 (group [Ex-1 or Ex-2] x time [HIIT Sessions 1-3 or 1-6 respectively] ANOVAS. Whenever the assumption of sphericity was violated, GreenHouse-Geisser corrections were applied. Confidence intervals (95%) were calculated, wherever appropriate, using the t-statistic (t = 2.11).

The alpha level for significance was accepted as $p<0.05$ and all tests were two-tailed. Wherever appropriate effect sizes were calculated using Cohen's "*d"* for which the following criteria were used; "small, $d = 0.2$", "moderate $d = 0.5$" and "large, $d = 0.8$" (Cohen, 1988).

4.0 Results

4.1 Anthropometrics, Resting Heart Rate and Aerobic Fitness

Table 2 summarises the anthropometric and VO_2max data. Independent t-tests revealed no significant differences between groups in any of the variables. Training

had no impact on resting HR for participants in Ex-1 (Resting HR; Baseline = 67 ± 10 bpm, Post-HIIT = 65 ± 11 bpm; $p > 0.05$) or Ex-2 (Resting HR; Baseline = 64 ± 11, Post-HIIT = 64 ± 9 bpm; $p > 0.05$).

	Ex-1	***Ex-2***	***Total***
Anthropometrics			
Age (Yrs)	*27 ± 10*	*28 ± 12*	*28 ± 11*
BW (kg)	*71.79 ± 8.14*	*71.13 ± 13.14*	*71.64 ± 10.61*
Height (m)	*1.74 ± 0.09*	*1.73 ± 0.12*	*1.74 ± 0.10*
Hours Ex/wk	*6 ± 4*	*7 ± 3*	*6.39 ± 3.26*
Body Fat (%)	*17.86 ± 7.76*	*18.79 ± 7.70*	*18.32 ± 7.52*
VO_2max test			
VO_2max (ml/kg/min)	*48.89 ± 9.32*	*43.22 ± 8.18*	*46.06 ± 8.99*
Time to Exhaustion (s)	*1520.9 ± 549.4*	*1384.9 ± 494.9*	*1452.9 ± 512.0*
PPO (Watts)	*258 ± 53*	*241 ± 70*	*250 ± 61*
Max HR (bpm)	*187 ± 13*	*184 ± 14*	*185 ± 13*
Max RPE (6 – 20)	*19.6 ± 0.7*	*19.7 ± 0.5*	*19.7 ± 0.6*

Table 2 - Anthropometric and VO2max test measures of both intervention groups at baseline. Data are presented as mean ± SD. BW = Body Weight. PPO = Peak power output. RPE = Rating of perceived exertion.
** = Significant difference between groups, $p<0.05$*

4.2 Ischemic Pain Tolerance Test

Data for the IPTT are summarised in table 3 and figures 4 - 7. No significant differences were observed between groups at baseline (Baseline; Pain Threshold CI 95% = 71.92 s to 124.64 s, Pain Tolerance CI 95% = 217.87 s to 293.57 s). Training had no impact on pain threshold, tolerance, pain perception intensity or maximal voluntary contraction.

	Baseline	***Post-HIIT***
Ex–1		
PPI Threshold (0 – 10)	*2.7 ± 1.2*	*3.2 ± 1.6*
PPI Tolerance (0 – 10)	*8.9 ± 0.6*	*9.0 ± 0.7*
MVC (N)	*425.29 ± 100.52*	*424.04 ± 89.37*
Ex–2		
PPI Threshold (0 – 10)	*2.7 ± 1.2*	*2.4 ± 1.6*
PPI Tolerance (0 – 10)	*8.7 ± 1.7*	*9.1 ± 1.2*
MVC (N)	*397.72 ± 102.04*	*396.42 ± 88.56*

*Table 3 – Contraction and pain perception responses for the IPTT. Data are presented as mean ± SD. PPI = Pain perception intensity, MVC = Maximal voluntary contraction. * = Significant difference between groups at baseline.*
*** = Significant difference from baseline ($p<0.05$)*

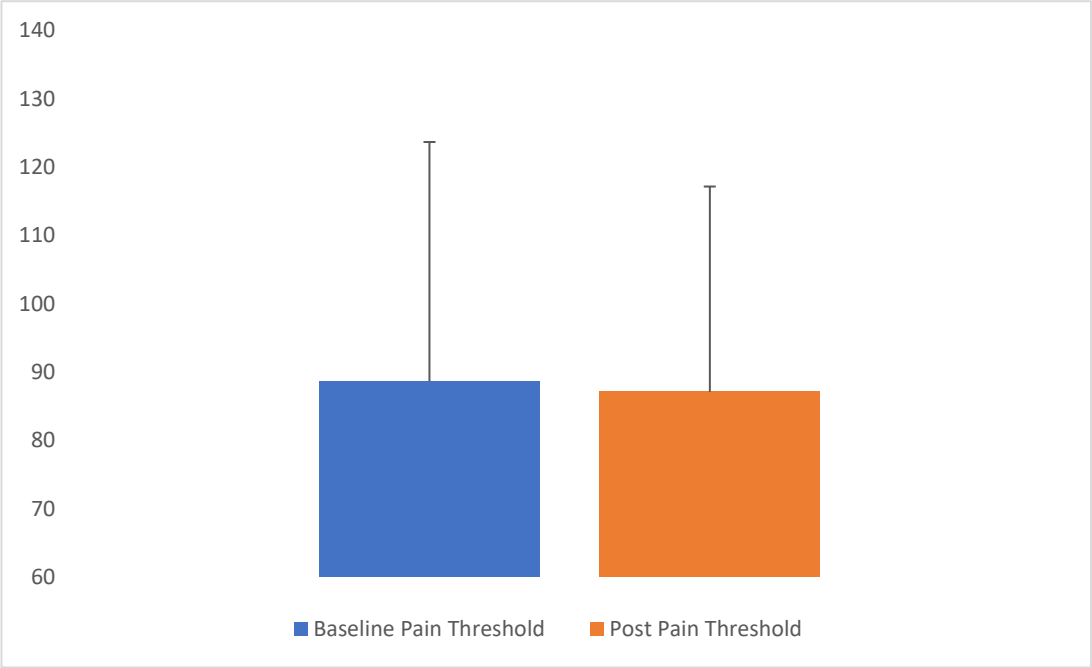


*Figure 4 - Pain thresholds obtained for participants in group Ex-1 at baseline and post training. * = Significant difference from baseline (P < 0.05)*

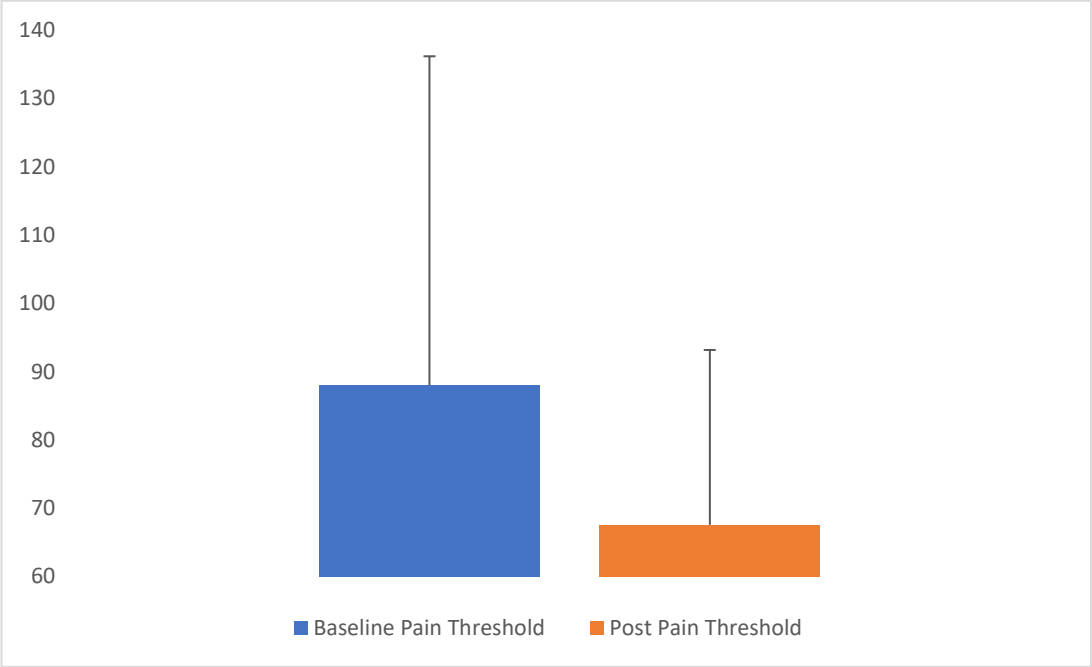


*Figure 5 - Pain thresholds obtained for participants in group Ex-2 at baseline and post training. * = Significant difference from baseline (P < 0.05)*

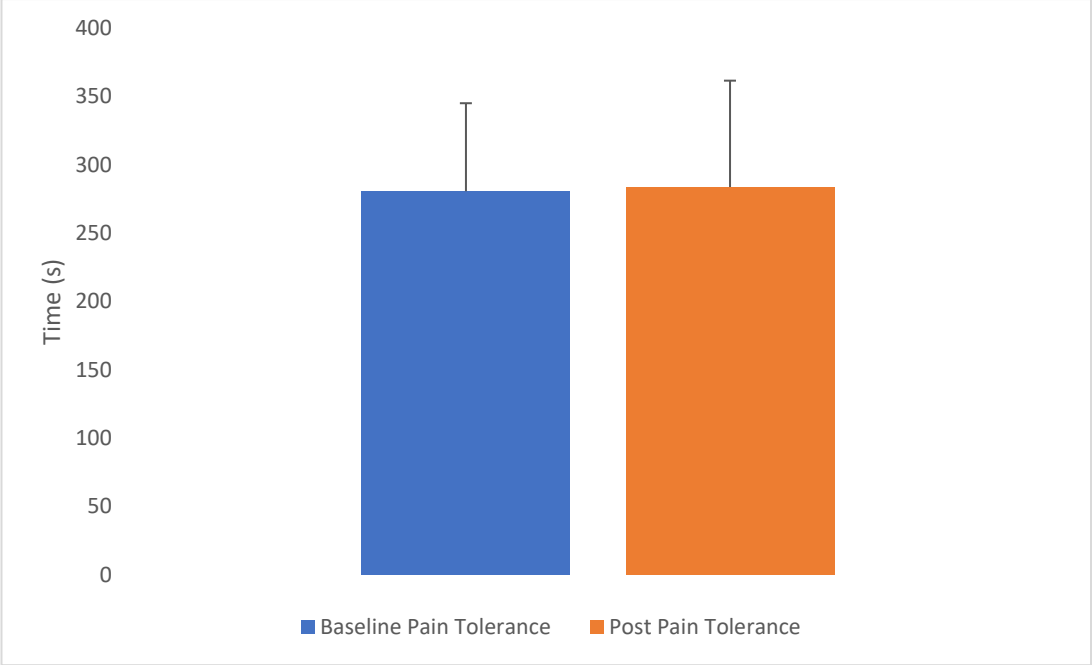


*Figure 6 - Pain tolerance values obtained for participants in group Ex-1 at baseline and post training. * = Significant difference from baseline (P < 0.05)*

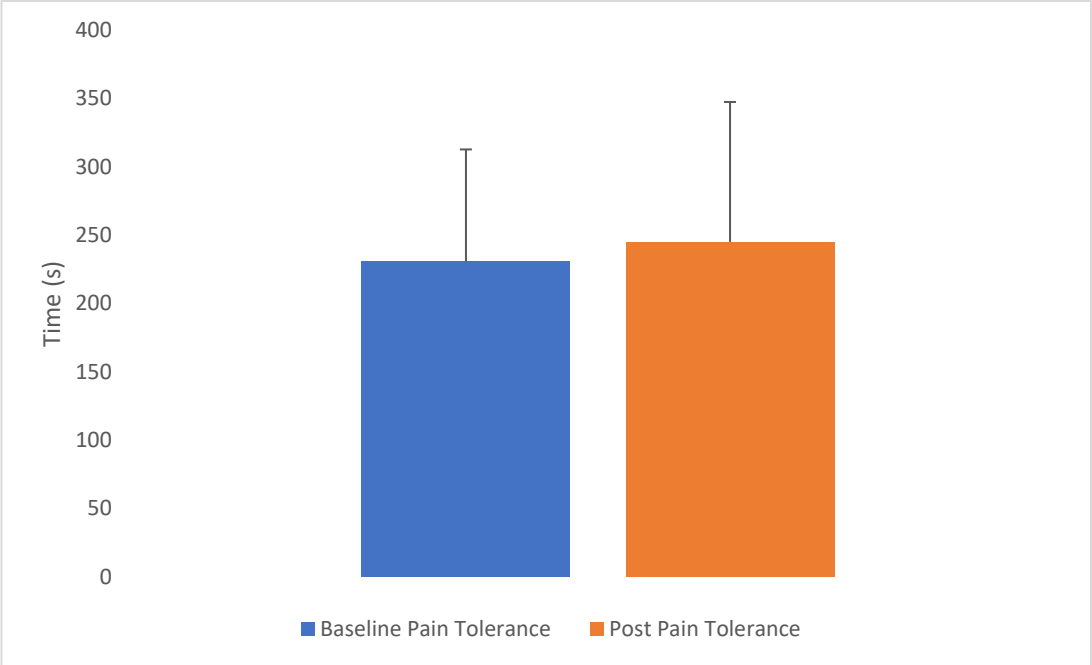


*Figure 7 - Pain tolerance values obtained for participants in group Ex-2 at baseline and post training. * = Significant difference from baseline (P < 0.05)*

4.3 5 km Time Trial

Table 4 summarises results for 5 km TT performances across all tests. No significant differences were observed between groups at baseline. Overall time trial performance (time completion and power output) and psychological parameters (RPE and EIP) did not change after HIIT. The HR response did decrease between tests, for both groups, as indicated by a significant time interaction and small effect size (Average HR; Baseline = 167 ± 13 bpm, Post-HIIT = 164 ± 12 bpm; $F_{[1, 16]}$ = 5.61, p = 0.031, *d* = 0.27). However, an ANCOVA indicated no differences between the groups post values.

	Baseline	***Post-HIIT***
Ex – 1		
Time Completion (s)	*697.8 ± 191.5*	*722.0 ± 255.6*
EIP (0 – 10)	*4.7 ± 2.1*	*4.3 ± 1.9*
RPE (6 – 20)	*15.3 ± 1.1*	*15.3 ± 1.0*
Heart Rate (bpm)	*169 ± 15*	*164 ± 13*
Power Output (Watts)	*236 ± 68*	*237 ± 74*
Ex – 2		
Time Completion (s)	*831.1 ± 277.1*	*780.1 ± 255.3*
EIP (0 – 10)	*5.90 ± 0.88*	*5.4 ± 1.4*
RPE (6 – 20)	*15.2 ± 1.2*	*16.0 ± 1.2*
Heart Rate (bpm)	*165 ± 11*	*164 ± 12*
Power Output (Watts)	*210 ± 77*	*220 ± 82*

Table 4 - Average responses from the 5 km time trial. Data are presented as mean ± SD. RPE = Rating of perceived exertion. EIP = Exercise induced pain.
** = Significant difference between groups at baseline.*
*** = Significant difference across time within the group (p=0.019)*
**** = Significant group x time interaction.*

4.4 Questionnaires

No significant differences were observed between the groups at baseline for PCS (Ex-1 PCS = 25 ± 8; Ex-2 PCS = 20 ± 11, p > 0.05) and PASS-20 (Ex-1 PASS-20 = 14 ± 8; Ex-2 PASS-20 = 13 ± 6, p > 0.05). Overall HIIT decreased pain catastrophizing as indicated by a significant time interaction and moderate effect size ($F_{[1, 16]}$ = 13.98, p=0.002, *d* = 0.56). A one-way ANCOVA revealed no differences in post HIIT values between groups for the PCS (see figures 8 – 9). Training had no impact on pain anxiety as indicated by the PASS-20 responses (see figures 10 – 11).

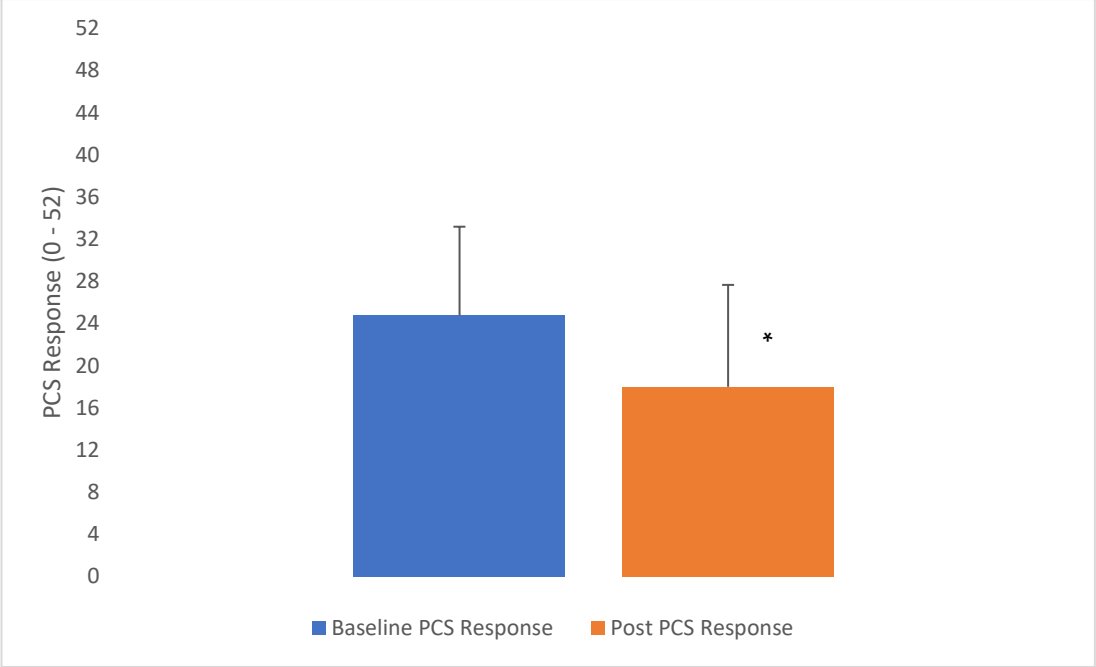


*Figure 8 - Pain catastrophizing scale (PCS) responses obtained for participants in group Ex-1 at baseline and post training. * = Significant difference from baseline (P < 0.05). ** = Significant difference between groups post HIIT values (P < 0.05).*

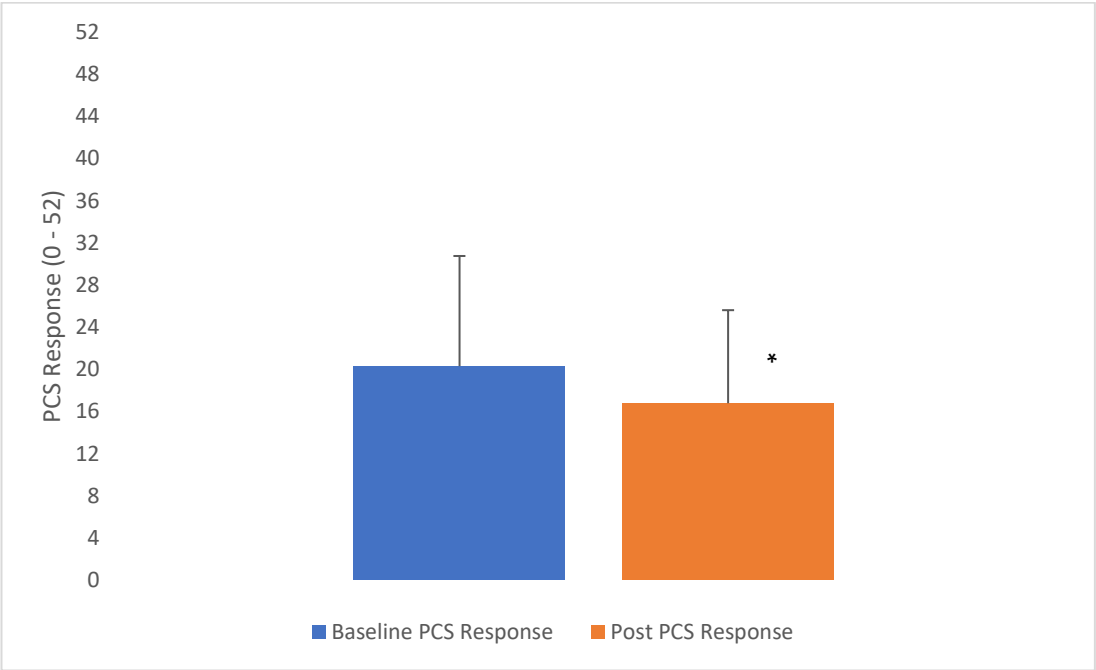


*Figure 9 - Pain catastrophizing scale (PCS) responses obtained for participants in group Ex-2 at baseline and post training. * = Significant difference from baseline (P < 0.05). ** = Significant difference between groups post HIIT values (P < 0.05).*

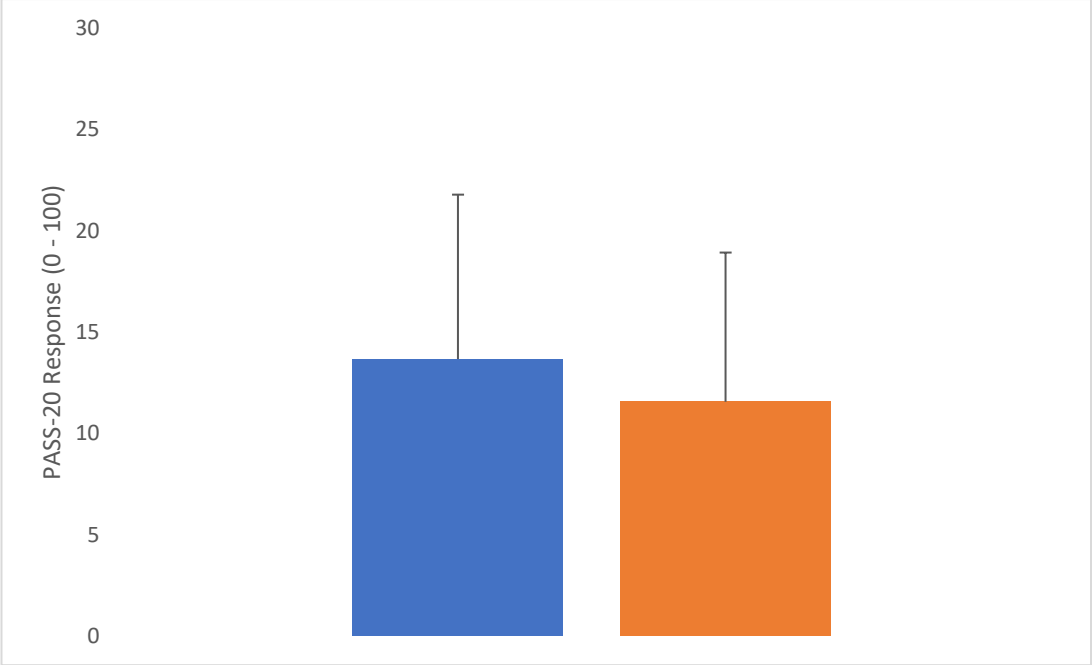


*Figure 10 - Pain anxiety symptom scale short form 20 (PASS-20) responses obtained for participants in group Ex-1 at baseline and post training. * = Significant difference from baseline (P < 0.05). ** = Significant difference between groups post HIIT values (P < 0.05).*

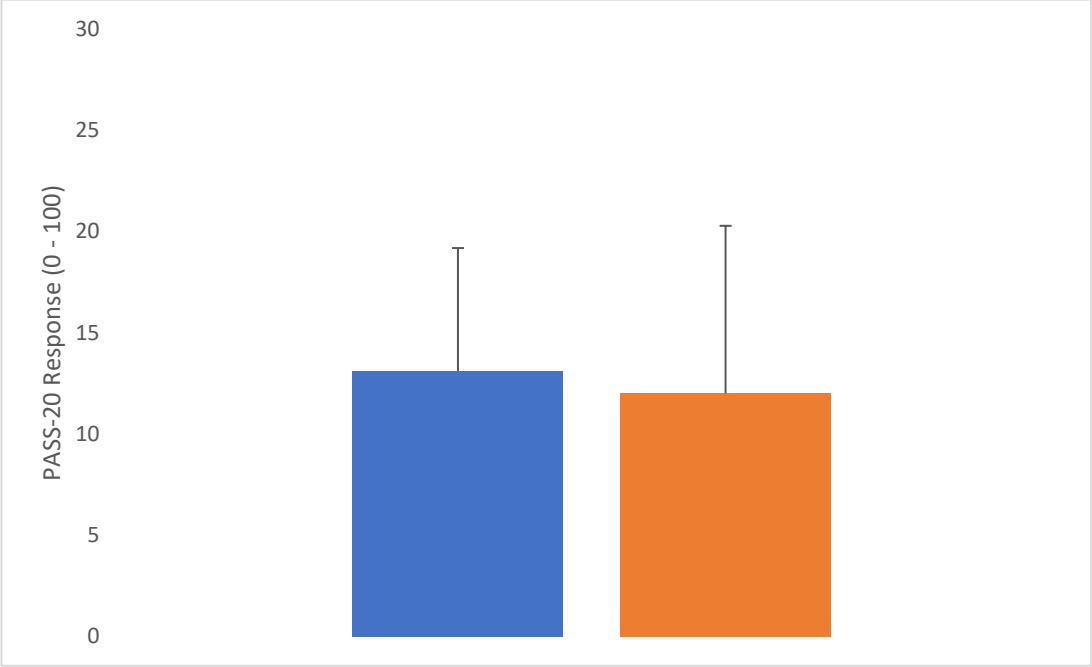


*Figure 11 - Pain anxiety symptom scale short form 20 (PASS-20) responses obtained for participants in group Ex-2 at baseline and post training. * = Significant difference from baseline (P < 0.05). ** = Significant difference between groups post HIIT values (P < 0.05).*

4.5 Training Data

Mean responses for RPE, HR and PO across sessions 1, 3 and 6 are summarized in table 5 and figure 12. No time interaction responses were observed for any of the

parameters. No significant differences were observed between groups from HIIT sessions 1–3.

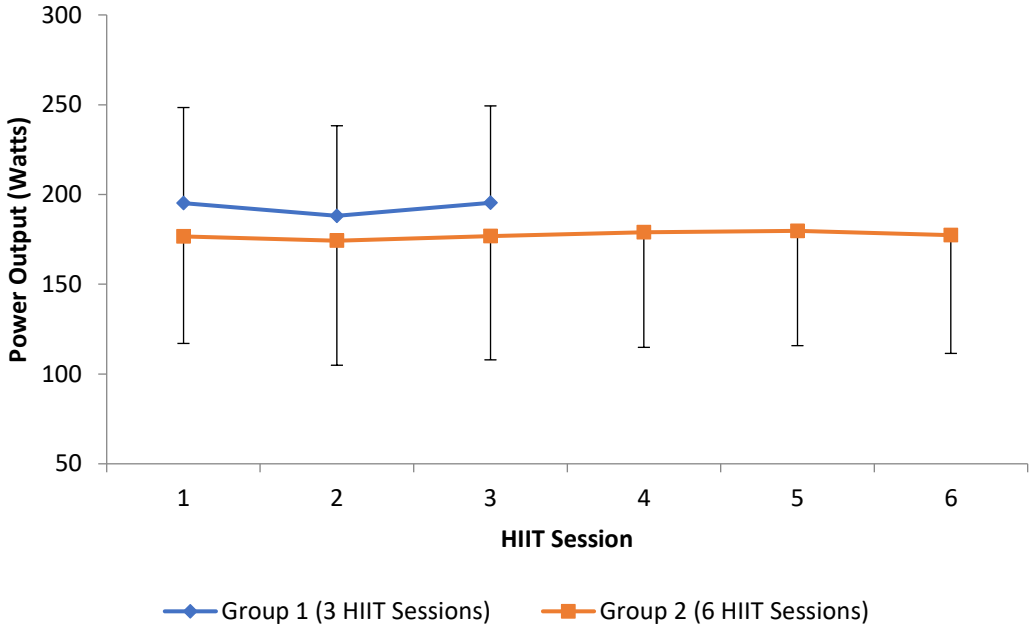


Figure 12 - Mean power output (watts) values obtained for each HIIT session for groups Ex-1 (Group 1) and Ex-2 (Group 2).
** = Significant difference between groups at baseline.*
*** = Significant difference across time within the exercise group.*
**** = Significant group x time interaction*

	HIIT Session		
	1	***3***	***6***
Ex – 1			
Heart rate (%HR max)	*85.29 ± 5.94*	*82.44 ± 5.99*	*N/A*
Heart rate (bpm)	*161 ± 15*	*156 ± 15*	*N/A*
Power Output (Watts)	*201 ± 52*	*199 ± 51*	*N/A*
Ex – 2			
Heart rate (%HR max)	*86.96 ± 6.67*	*84.06 ± 6.32*	*84.99±7.08*
Heart rate (b=pm)	*157 ± 12*	*152 ± 13*	*155 ± 10*
Power Output (Watts)	*177 ± 60*	*177 ± 69*	*177 ± 66*

Table 5 – Data for HIIT Sessions 1, 3 and 6 for both exercise groups. Data are presented as mean ± SD. RPE = Rating of perceived exertion.
** = Significant difference between groups at baseline.*
*** = Significant difference across time within the exercise group.*
**** = Significant group x time interaction.*

5.0 Discussion

Briefly, the present study sought to examine the impact of short HIIT programs on ischemic pain perception, self-paced exercise performance as well as pain catastrophizing and anxiety. Overall, HIIT did not increase ischemic pain tolerance

or 5km TT performance. However, HIIT did decrease pain catastrophizing and average HR obtained during a 5km TT test.

5.1 Ischemic pain tolerance test

Overall ischemic pain tolerance did not change after HIIT. These results are inconsistent with Jones et al. (2014) and O'Leary et al. (2017a) who reported a 20.3% and 39% increase in ischemic pain tolerance after 6wks of aerobic exercise training and HIIT respectively. Furthermore, these results are also inconsistent with longitudinal studies of athletes which have demonstrated pain tolerance to increase over the course of competitive seasons for swimmers (Scott and Gijsbers, 1981) and contact athletes (Thornton et al., 2017).

The reason for this lack of change is likely due to the differences in protocol compared to O'Leary et al. (2017a). In their study participants in the HIIT group always reached an RPE of 19 or 20 during the last 5 min of each exercise session whilst those in the continuous training group never reached an RPE above 15. Since pain tolerance only increased following HIIT, the authors concluded that regularly approaching the limits of exercise tolerance was partially responsible for their observations. On the other hand, participants in our study were instructed to cycle at an RPE of 15 during each of the 6 x 5 min exercise bouts. Whilst this allows for more ecological validity, outside of an experimental setting, it also meant that participants did not approach the limits of their exercise tolerance which may explain the lack of change to pain tolerance.

Furthermore, it is possible that changes in pain tolerance are only detected after a certain period. Indeed, our study was much shorter (3 and 6 HIIT sessions) compared to other training studies conducted by Jones et al., (2014) and O'Leary et al., (2017a) which were 18 aerobic and HIIT training sessions respectively. Additionally, Thornton et al. (2017) reported an effect size, d = 0.28, between participating and non-participating contact athletes after an 8-month season. Thus, even after an extended period of time only a small effect was observed for training that took place outside of a laboratory. However, more research is needed to determine exactly how long is needed to detect changes to pain tolerance using more robust experimental designs.

Nevertheless, increased pain tolerance has been previously attributed to the management of signals from type III and IV afferent fibres. A series of studies conducted by Amann et al. (2012) demonstrated that when feedback from type III/IV afferent fibres was attenuated not only was blood circulation and pulmonary ventilation compromised (Amann et al., 2010) but central motor drive was less restricted resulting in a significantly greater power output during the first half of a 5 km TT (Amann et al., 2008). This allowed the central nervous system to "tolerate" peripheral locomotor muscle fatigue beyond levels measured during a placebo trial (i.e. intact afferent feedback).

Consequently, increased pain tolerance after a period of exercise training has been (Jones et al., 2014) attributed to diminished signalling, in response to nociceptive signals from type III and IV afferent fibres. In theory, this would allow the central nervous system to increase both central motor drive and ventilatory/circulatory responses allowing greater development of peripheral locomotor muscle fatigue for a given exercise intensity. However, if this is the case then a change in pain threshold, in addition to pain tolerance, would be expected after a period of exercise training (Stevens et al., 2017). In contrast, previous evidence has demonstrated that pain threshold stays the same after aerobic exercise training (Jones et al., 2014; O'Leary et al., 2017). This is consistent with cross sectional evidence whereby athletes are demonstrated to have higher pain tolerance but similar pain thresholds to non-athletes (Tesarz et al., 2012). Our findings are in line with these observations whereby pain threshold remained the same after HIIT ($p > 0.05$).

On the other hand, Hakansson et al. (2018) did report an increase in pressure pain threshold ($d = 0.54$) in the rectus femoris and tibialis anterior following 18 sessions of continuous training (30 min at 65-75% peak HR). However, participants in their study were overweight (BMI = 28.2 ± 2.5kg/m^2) compared to predominately normal weighted individuals in Jones et al., (2014) and O'Leary (2017a) (according to BMI; cited Hakansson et al., 2018). Since PPTs have been demonstrated to differ in overweight/obese individuals it is possible that the effect of training may also be differential as a function of body size (Hakansson et al., 2018).

Instead, it has been proposed that the consistent and frequent exposure to unpleasant sensory experiences causes participants to develop psychological coping techniques to tolerate these sensations (Stevens et al., 2017). Indeed, Roebuck et al. (2018) reported that ultra-marathon runners not only had higher cold

pain tolerance, but also lower levels of pain-related anxiety symptoms as measured by the PASS-20 questionnaire. Specifically, mediation analysis revealed that a reduction in pain-related escape and avoidance behaviours (measured by PASS-20) accounted for 40% of the variance in pain tolerance. This behavioural dimension is representative of the extent to which an individual avoids or terminates activities based on the associated pain. Given that ultramarathon runners expose themselves regularly to unpleasant sensory experiences, as demonstrated by pain experienced during training and competitions, these results are not surprising (Simpson et al., 2014).

Specifically, we demonstrated that HIIT decreased pain catastrophizing scores similarly for both groups which was represented by a moderate effect size (d = 0.56). This finding is novel in that, to the authors knowledge, this is the first interventional training study to demonstrate a change in pain catastrophizing in healthy participants. Nevertheless, this evidence is congruent with a three-month physical activity study of fibromyalgia patients conducted by Campbell et al., (2012). In their study not only did they observe a change in pain catastrophizing, but this coincided with a decrease in clinical pain ratings accounting for 14% of the variance (r^2 = 0.14; p = 0.005). However, since no changes in pain perception occurred in this study it is uncertain whether this change in catastrophizing could have an impact on pain perception within a healthy population. Despite this, it has been demonstrated previously by Sullivan (2000) that athletes have lower PCS scores than non-athletes. However, regression analysis revealed that this difference in catastrophizing did not mediate differences in pain perception between athletes and non-athletes. Geva and Defrin (2013) also assessed and compared pain tolerance of athletes and non-athletes. Whilst athletes were observed to have a higher thermal pain tolerance and conditioned pain modulation, pain catastrophizing between the two groups was similar (p = 0.53).

Similarly, a longitudinal study conducted by Thornton et al., (2017) demonstrated that contact athletes who regularly attended training over the course of an 8-month season not only had a higher pain tolerance (p = 0.04; d = 0.28) but also a lower pain catastrophizing score than “non-participating” athletes at the end of the season (p < 0.0001; d = 0.71). However, mediation analysis was not conducted and thus it is uncertain to what extent changes in pain catastrophizing were responsible for changes in pain tolerance. Furthermore, like the present study, measures to quantify participant’s pain specific self-efficacy (SE) or coping/management

strategies were not employed. This is important as these measures have also been demonstrated to influence pain tolerance and tolerance of pain sensations experienced during exercise.

Specifically, Ord and Gijsbers (2003) demonstrated that competitive rowers who adopted high quality pain management strategies had significantly higher mean pain tolerances than the other group members ($p < 0.01$) whereas no difference was observed in the control group. Additionally, qualitative analysis of interview transcripts with ultramarathon runners, by Simpson et al. (2014), revealed that ultramarathon runners, who have a higher pain tolerance than untrained individuals (Roebuck et al., 2018), regularly use mental skills to cope with challenges during their races. They specifically describe the importance of participants using “positive inner dialogue” through difficult moments of the race which is closely reminiscent of positive self-talk. However, since only one participant mentioned using positive self-talk to cope with pain associated with the race it is uncertain if this strategy is indeed effective at managing pain sensations experienced during exercise. Another strategy highlighted by Simpson et al. (2014) was that ultramarathon runners regularly used associative strategies to manage pain. This means that as pain increased during the race participants would increasingly focus on aspects of their run (e.g. putting one foot in front of the other or getting into a rhythm) rather than aspects which are dissociative from the pain (e.g. thinking about unrelated things to distract you). Finally, in a randomized control study, Whitemarsh and Alderman (1993) not only demonstrated that stress inoculation training increased participants pain tolerance (via wall sit task) but this coincided with an increase of relaxation and self-instructional strategies.

Regarding pain-specific SE, Motl et al. (2007) investigated the effect of pain-specific-SE on muscle pain during moderate-high intensity cycle ergometry. Sixteen participants completed a TTE task followed by a 30 min submaximal bout of cycling exercise (80% VO_2peak). Muscle pain was rated during the test and a SE scale was designed to assess an individual’s beliefs in their capability to tolerate moderate-strong leg muscle pain during cycling without stopping. This scale was modified, from a previously existing scale, so that the SE measured was indeed specific for the study of pain during exercise experienced during the study (Motl et al., 2006). Results demonstrated that SE was inversely correlated with peak muscle pain obtained during the TTE test ($r= -0.45$, $p=0.04$) and muscle pain experienced during the second half of the submaximal test ($r= -0.45$ to -0.69, $p<0.05$). Additionally,

Keefe et al. (1997) observed that patients with higher SE had a higher pain tolerance compared to those with a low SE towards clinical pain (d = 1.69; p = 0.03). Furthermore, a cross sectional study demonstrated that SE accounted for 40% of pain tolerance variance between athletes and non-athletes (Johnson et al., 2011). However, these findings should be interpreted with caution as SE was measured using a non-validated single item questionnaire.

On balance, it is uncertain whether any changes of these psychological variables may have changed in response to HIIT or had an impact on the changes to pain tolerance observed by Thornton et al. (2017). Thus, it is important that future research considers measuring different psychological variables to examine if and how they are impacted by periods of structured training.

Another limitation of this study was that the questionnaires, PCS and PASS-20, were not analysed for each of their respective subscales. This is important as previous studies have demonstrated that differences between athletes and non-athletes can be specific and explained further by analysing certain subscales within a questionnaire. For example, in a study conducted by Sullivan (2000) whilst athletes had a lower PCS score ($p < 0.05$) further analysis revealed this was only true for rumination and helplessness but not magnification. Additionally, a recent study demonstrated that only the escape and avoidance subscale (measured via the PASS-20) was responsible for mediating 40% of the pain tolerance variance between athletes and non-athletes whereas the other subscales (cognitive anxiety, physiologic anxiety and fearful thinking) did not account for this difference (Roebuck et al., 2018).

Furthermore, we did not observe any changes to pain anxiety as indicated by the PASS-20 questionnaire scores. These findings are inconsistent with cross sectional evidence whereby athletes have been demonstrated to have lower pain anxiety scores than non-athletes via the PASS-20 (Roebuck et al., 2018) or fear of pain questionnaire (Geva and Defrin, 2013). Specifically, Geva and Defrin demonstrated that anxiety, measured via fear of pain questionnaire, was negatively correlated with the training hours per week ($r = -0.36$; $p < 0.05$). However, two major limitations must be considered when interpreting these findings. Firstly, training hours cannot be validated as they were self-reported by participants. Secondly, no further information for training was provided other than the number of hours per week and thus the impact of training intensity and/or duration cannot be determined.

The lack of change in pain anxiety is most likely due to our participants already having a low PASS-20 score at baseline when compared to other non-athletic samples (Abrams et al., 2007). Indeed, in a study of 155 healthy but non-athletic people the total score for PASS-20 was 24 ± 13 (95% CI 21.9 to 26.1; Abrams et al., 2007). When compared to our participant's PASS-20 baseline responses in groups Ex-1 and Ex-2 (Ex-1 PASS-20 = 14 ± 8; Ex-2 PASS-20 = 13 ± 6) this difference becomes apparent.

It remains uncertain why participants, in our study, exhibited such low pain anxiety. Whilst, the PASS-20 questionnaire was initially developed for patients suffering from chronic pain it has been validated in nonclinical populations having concurrent validity with related measures such as anxiety sensitivity (anxiety sensitivity index; r = 0.56), fear of pain (Fear of Pain Questionnaire; r = 0.53) and pain catastrophizing (PCS; R = 0.38) (McCracken et al., 1992). Additionally, the PASS-20 questionnaire has been shown to have good internal consistency (α = 0.81) and convergent validity with the original scale consisting of 40 items (PASS-40; Abrams et al., 2007). Consequently, it is unlikely that the questionnaire itself or its use within a non-clinical population would explain these observations. Furthermore, whilst our participants were healthy and active, they were untrained as indicated by their VO_2max and resting HR values (see section 4.1). Therefore, it is also unlikely that training status would explain these observations as would expected of triathletes (Geva and Defrin, 2013) or ultramarathon runners (Roebuck et al., 2018).

Consequently, future research should not only investigate the effect longer HIIT programs have on pain tolerance but also determine if and to what extent pain management/coping strategies (Ord and Gijsbers, 2003), SE (Motl et al., 2007; Ghazaie et al., 2015), self-efficacy, anxiety and pain catastrophizing explain these changes. Finally, subscales of questionnaires, such as the PCS and PASS-20, should be considered and analysed to identify which dimensions of pain perception are responsible for any observed changes in pain tolerance.

5.2 Training and 5 km Time Trial Performance

Overall, 5 km TT performance was not affected by HIIT when considering completion time and power output. Additionally, average RPE and EIP obtained during the 5km TT were not affected by HIIT. Mean HR decreased from baseline

with was characterized by a small effect size (*d* = 0.27). Furthermore, there were no changes in HR and PO responses across subsequent HIIT sessions.

Firstly, the lack of a training effect to participants in Ex-2, represented by no change in PO, is surprising as O'Leary et al. (2017b) demonstrated PO increased when comparing participant's first and last HIIT sessions (202 ± 47 W vs 228 ± 45; $p < 0.05$; *d* = 0.57) using a similar protocol. However, the short duration (three or six HIIT sessions) of the HIIT programs in the present study, compared to O'Leary et al. (2017b), may explain why no change in PO was observed (18 sessions). Furthermore, the lack of a training stimulus may explain these observations. Indeed, when comparing the first HIIT sessions to O'Leary et al. (2017b) on average participant's HR is 10-12bpm lower which is characterized by a small-moderate effect size (*d* = 0.21-0.71) when comparing both studies first and last HIIT sessions. This is likely due to differences in protocols in that the present was self-paced and the one chosen by O'Leary et al (2017b) was prescribed.

More specifically in the study conducted by O'Leary et al. (2017b) participants in the HIIT group were prescribed a fixed intensity (202-228W) halfway between lactate threshold and VO_2max, typical of most HIIT protocols (MacInnis and Gibala, 2017). Therefore, participant's in their study consistently reached the limits of their exercise tolerance as indicated by RPE ratings (RPE = 19 or 20 during last 5 min stage). In contrast, our adapted protocol involved participants cycling in linear mode at a fixed RPE = 15 which allows adjustments in work rate based on the participants cadence (see figure 1). However, whilst this allows participants to set the pace, and thus has more ecological validity outside of an experimental setting, they ultimately exercised at a lower work rate (Noakes, 2011; 177-200W) leading to a markedly decreased HR response.

One explanation for this observation comes from the central governor model (Noakes, 2011) which predicts that behaviour modification ensures that homeostasis is protected. Thus, it is possible that the participant's brains unconsciously chose to exercise at an intensity that they deemed as sustainable for the expected duration of the exercise (Noakes, 2012). Indeed, it has been demonstrated that athletes choose different pacing strategies based upon the actual duration of the race (Tucker et al., 2006). For example, analysis of world record performances shows that, except for the 800m, athletes speed up at the end of longer races which is clearly an example of an end-spurt (Tucker et al., 2006).

However, since our participants exercised at a fixed RPE this reserved energy was not needed and thus participants did not exercise to the limits of their exercise tolerance. Therefore, it is likely that the physiological demand in the current study protocol did not cause sufficient metabolic disturbances to promote aerobic physiological adaptations. However, since HR data at ventilatory thresholds obtained during the VO2max tests, or any other physiological data, were not collected this is cannot be known for certain. On the other hand, the lack of metabolic disturbance and thus physiological adaptations would partially explain the lack of change in 5 km TT performance.

One type of training which has been demonstrated to cause such metabolic disturbances and improve endurance performance is sprint interval training (SIT). Indeed, studies employing SIT protocols over similar periods of time to that of the present study (6-7 sessions) have observed increased sporting performance for both exhaustion (Burgomaster et al., 2005; Hazell et al., 2010) and self-paced exercise tasks (Burgomaster et al., 2006; Hazell et al., 2010; Jones et al., 2017). It has been proposed that due to the increased flux between exercise and rest, SIT protocols may result in greater perturbations to muscle milieu than HIIT (Jones et al., 2017). Furthermore, during SIT, PPO declines which is a primarily due to falling phosphocreatine (PCr) stores in the muscles (Bogdanis et al., 1996). Decreased PCr availability, combined with repeated attempts to generate PPO, stimulates both oxidative phosphorylation and glycolysis the former of which becomes more predominant during successive efforts (Hazell et al., 2010). Therefore, in shorter periods of time (i.e. 6 sessions), SIT is more likely to cause significant metabolic adaptations than HIIT and thus improve endurance performance.

Additionally, the linear factor, and the tests chosen to calculate it, are also factors to consider when regarding the lack of training stimulus. The test chosen for the present study was a VO_2max test which involved participants cycling for 5 min at 50 W (warm up) with the resistance increasing by 25 W every 3mins thereafter until volitional exhaustion (Jones et al., 2017). Consequently, this protocol involved long stages with relatively small increases in resistance. Such protocols have been demonstrated to underestimate VO_2max (Julio et al., 2017) and peak work rate values (Amann et al., 2004) as the energy requirements are significantly higher compared to shorter protocols for any given work rate resulting in greater levels of exhaustion. Considering both variables are crucial to calculating the linear factor (see figure 1) this may of lead to each linear factor being underestimated. On the

other hand, considering the difference in work rate values between the present and O'Leary (2017b) HIIT protocols, a more likely issue is the impact of the cadence to power output ratio in that small variations in cadence result in markedly variable power outputs. For instance, using the equation provided in figure 1, an increase of 5rpm with a linear factor of 0.031 (from rpm = 80 to 85) results in the work rate increasing by over 20 W (~198 W to 224 W). This itself would be enough to account for the PO differences observed between that of the present and the study conducted by O'Leary et al., (2017b). However, data for cadence were not recorded during the present study and thus the impact of varying cadence on power output can not be quantified.

Therefore, whilst this specific self-paced exercise training protocol may have more ecological validity, outside an experimental setting, its inefficient at improving endurance performance over short periods of time (3 and 6 HIIT sessions). Consequently, although future research should consider employing self-paced HIIT protocols, they should not compromise the training stimulus response and should be tested thoroughly before using them in a training study. For instance, future research could consider employing similar protocols to the present but at a higher fixed RPE and adjusting work rate through PO and not cadence. Indeed, Astokorki and Mauger (2016) instructed participants to cycle at a fixed RPE = 16 who could adjust their PO to maintain this perception of effort. However, since the test was terminated if the participant's PO dropped below 70% of their initial PO, the duration of the test was not fixed (TTE = 28:35 ± 13:40 min:s). As a result, future research would need to take this into consideration when adapting this into a training protocol.

Another factor to consider is the 5 km TT test itself. Hazell et al. (2010) reported a 3-5% increase in 5 km TT performance after 2wks (6 sessions). However, this was following SIT and the 5 km TT protocol differed drastically. Firstly, participants in Hazell et al. (2010) were given instantaneous computer video image feedback during their 5 km TT racing against an image of themselves. Furthermore, they were provided additional measurements including; time elapsed, previous best time, current speed and distance behind/ahead of the competitor. Therefore, whilst the 5 km TT has been reported to be sensitive to changes in performance (sensitivity index>1), it is unclear if a longer test (i.e. 40km TT; Stepto et al., 1999) would have been necessary to detect changes in self-paced exercise performance after such

short HIIT programs and to what extent motivation is a cofounding factor (Dantas et al., 2015).

Finally, one observation, regarding the 5 km TT, was that mean HR decreased by ~4bpm with no change to resting HR (see table 4; $p = 0.031$, $d = 0.27$) from baseline. Indeed, previous evidence demonstrates submaximal HR response to decrease following aerobic training by 12-15 bpm with little change to resting HR (McArdle et al., 2014). This is likely due to greater vagal dominance caused by; increased parasympathetic activity, decreased sympathetic discharge and reduced intrinsic firing rate of the sinoatrial node pacemaker (Lee et al., 2003; Schaefer et al., 1992). However, HR variability between tests may also explain this observation as non-significant correlations where reported by Dantas et al. (2015) when comparing relative HR responses from two 5 km TT tests (ICC = 0.21; $p > 0.05$).

6.0 Conclusions and Future Research Directions

On balance, results demonstrated measures for pain threshold, tolerance and anxiety did not change after three or six sessions of HIIT. However, individual's pain catastrophizing did decrease similarly following three or six HIIT sessions as measured by PCS questionnaire responses. However, subscales of questionnaires, PCS (rumination, helplessness and magnification) and PASS-20 (escape avoidance, cognitive anxiety, physiologic anxiety and fearful thinking), were not separately analysed. Furthermore, other psychological variables which have been shown to impact pain tolerance were not measured such as pain-specific SE and pain coping/management strategies. Thus, future research should ensure to analyse subscales of questionnaires and consider the impact of structured training programs, such as HIIT, on other psychological variables in relation to changes in pain tolerance.

Self-paced exercise performance did not change after HIIT, but mean HR did decrease between subsequent tests. The former can be largely attributed to the HIIT protocol employed in this study. Though the self-paced nature of our HIIT protocol has more ecological validity outside an experimental setting, such as a gym environment, the physiological and therefore training response was not as profound as previous "prescribed" protocols. Therefore, when designing self-paced exercise training protocols, future research should ensure that the training stimulus is not compromised. Furthermore, self-paced protocols should allow participants to adjust

their work rate by changes to power output and not cadence as small variations in the latter has the potential to cause significant changes to the training response.

7.0 Appendices

Figure 13 - Typical setup for the ischemic pain tolerance test. Privacy screens (Drive, Panel Privacy Screen, 2006) were set-up to ensure participants performed the test with minimal outside influence

7.1 Physical Fitness Background:

Participant ID: ……

Physical Fitness Background	
Age (yrs)	
Hours of exercise (per week)	
Category of exercise (e.g Cardio, weights etc…)	
How long have you been training within this sport (in months)	

Have you ever had respiratory problems in the past or currently?
Yes/No
If yes then explain: ……

Have you ever had an injury causing you to not perform in exercise before?
Yes/No
If yes then please explain: …….

Have you been ill within the past 4 weeks?
Yes/No
If yes then explain: ……

7.2 Anthropometric and aerobic capacity measures:

Anthropometric Measures		**Metalyzer**
Body Weight (kg)		
Height (cm)		
Body fat (%)		
Aerobic Capacity		
VO_2max (ml/kg/min)		
Time to exhaustion (secs)		

	Elapsed Time (mins)														
	75 Watts			100 Watts			125 Watts			150 Watts			175 Watts		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
HR (bpm)															
RPE (6-20)															
	200 Watts			225 Watts			250 Watts			275 Watts			300 Watts		
	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
HR (bpm)															
RPE (6-20)															

7.3 5 km Time Trial (delete as appropriate): Baseline / Week 1 / Week 2

Participant ID: ……

Laptop number: …… Data entered: …….

	Elapsed Distance (kilometres)									
	0.5 km	1km	1.5 km	2km	2.5 km	3km	3.5 km	4km	4.5 km	5 km
Time (mins:secs)										
Heart rate (bpm)										
RPE (6-20)										
PPI (0 - 10)										
Power output (Watts)										

7.4 Ischemic pain tolerance test (delete as appropriate): Baseline / Week 1 / Week 2

Participant ID: ……

Ischemic pain test	
Resting HR (bpm)	
MVC (N)	
Pain threshold (secs)	
Pain tolerance (secs)	

	Time since pain threshold (secs)														
	0	30	60	90	120	150	180	210	240	270	300	330	360	390	420
Pain (0-10)															
HR (bpm)															
	450	480	510	540	570	600		**END**							
Pain (0-10)															
HR (bpm)															

7.5 Training session (delete as appropriate): Week 1 / Week 2 Session 1 / 2 / 3

Participant ID: ……

Laptop number: …… Data entered: …….

	Elapsed Time (seconds)											
	60	120	180	240	300	360	420	480	540	600	660	720
HR (bpm)												
RPE (6-20)												
PO (Watts)												
	780	840	900	960	1020	1080	1140	1200	1260	1320	1380	1440
HR (bpm)												
RPE (6-20)												
PO (Watts)												
	1500	1560	1620	1680	1740	1800	1860	1920	1980	2040	2100	
HR (bpm)												
RPE (6-20)												
PO (Watts)												

7.6 Questionnaires and Scales

PCS

Client No.: _____ Age: _____ Sex: M(__) F(__) Date: _____

Everyone experiences painful situations at some point in their lives. Such experiences may include headaches, tooth pain, joint or muscle pain. People are often exposed to situations that may cause pain such as illness, injury, dental procedures or surgery.

We are interested in the types of thoughts and feelings that you have when you are in pain. Listed below are thirteen statements describing different thoughts and feelings that may be associated with pain. Using the following scale, please indicate the degree to which you have these thoughts and feelings when you are experiencing pain.

0 – not at all **1** – to a slight degree **2** – to a moderate degree **3** – to a great degree **4** – all the time

When I'm in pain …

1. ☐ I worry all the time about whether the pain will end.
2. ☐ I feel I can't go on.
3. ☐ It's terrible and I think it's never going to get any better.
4. ☐ It's awful and I feel that it overwhelms me.
5. ☐ I feel I can't stand it anymore.
6. ☐ I become afraid that the pain will get worse.
7. ☐ I keep thinking of other painful events.
8. ☐ I anxiously want the pain to go away.
9. ☐ I can't seem to keep it out of my mind.
10. ☐ I keep thinking about how much it hurts.
11. ☐ I keep thinking about how badly I want the pain to stop.
12. ☐ There's nothing I can do to reduce the intensity of the pain.
13. ☐ I wonder whether something serious may happen.

…Total

Figure 14 – Pain Catastrophizing Scale developed by Sullivan et al. (1995)

Pain Anxiety Symptom Scale Short Form 20

Please rate each item in terms of frequency, from 0 (Never) to 5 (Always).

Item Numbers	Never Always
1. I can't think straight when in pain	0 1 2 3 4 5
2. During painful episodes it is difficult for me to think of anything besides the pain	0 1 2 3 4 5
3. When I hurt I think about pain constantly	0 1 2 3 4 5
4. I find it hard to concentrate when I hurt	0 1 2 3 4 5
5. I worry when I am in pain	0 1 2 3 4 5
6. I go immediately to bed when I feel severe pain	0 1 2 3 4 5
7. I will stop any activity as soon as I sense pain coming on	0 1 2 3 4 5
8. As soon as pain comes on I take medication to reduce it	0 1 2 3 4 5
9. I avoid important activities when I hurt	0 1 2 3 4 5
10. I try to avoid activities that cause pain	0 1 2 3 4 5
11. I think that if my pain gets too severe it will never decrease	0 1 2 3 4 5
12. When I feel pain I am afraid that something terrible will happen	0 1 2 3 4 5
13. When I feel pain I think I might be seriously ill	0 1 2 3 4 5
14. Pain sensations are terrifying	0 1 2 3 4 5
15. When pain comes on strong I think that I might become paralyzed or more disabled	0 1 2 3 4 5
16. I begin trembling when engaged in activity that increases pain	0 1 2 3 4 5
17. Pain seems to cause my heart to pound or race	0 1 2 3 4 5
18. When I sense pain I feel dizzy or faint	0 1 2 3 4 5
19. Pain makes me nauseous	0 1 2 3 4 5
20. I find it difficult to calm my body down after periods of pain	0 1 2 3 4 5
Total Score	_____

Cont'd▶

Figure 15 – Pain Anxiety Symptom Scale Short Form-20 developed by McCracken et al. (1996)

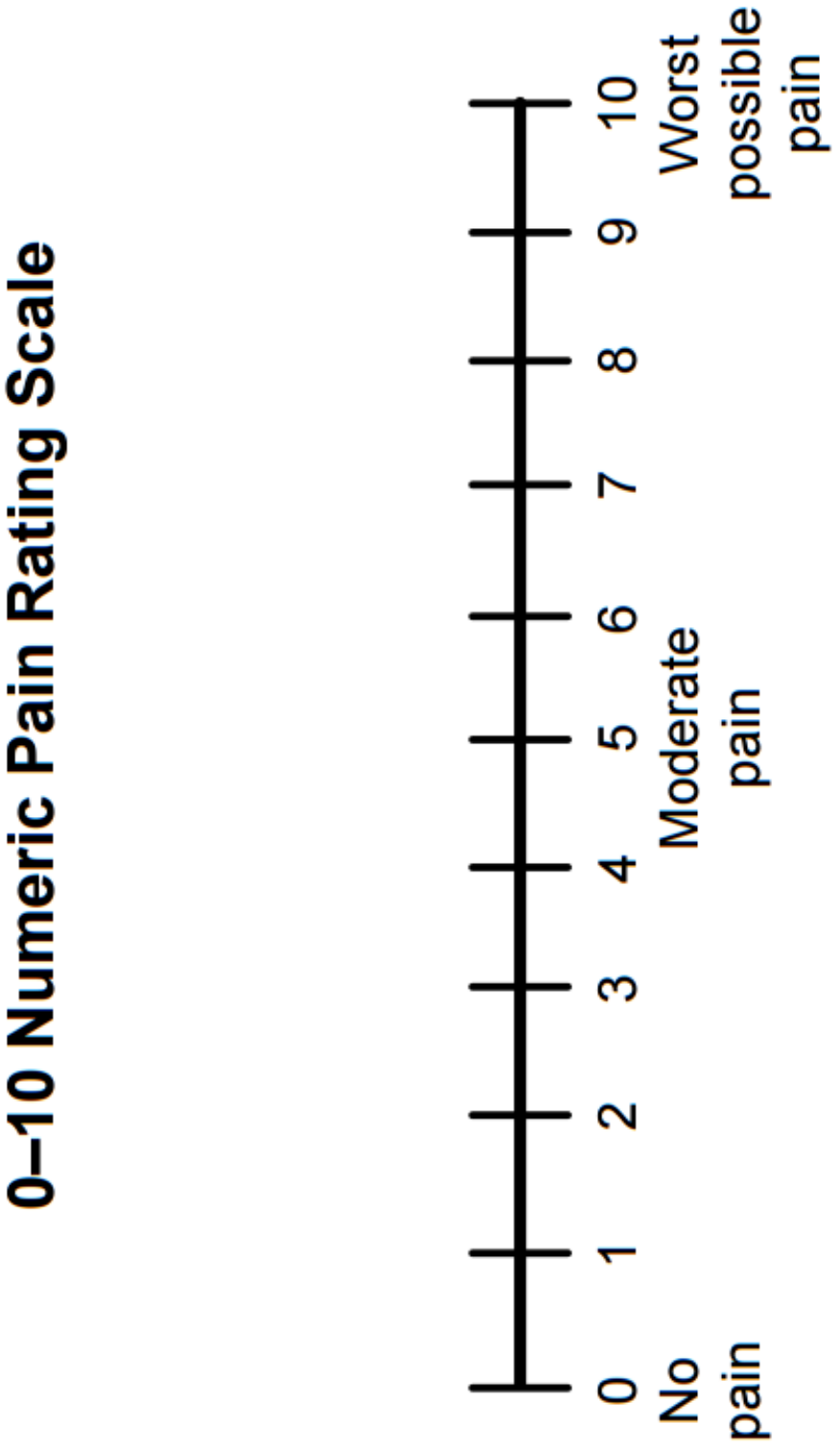
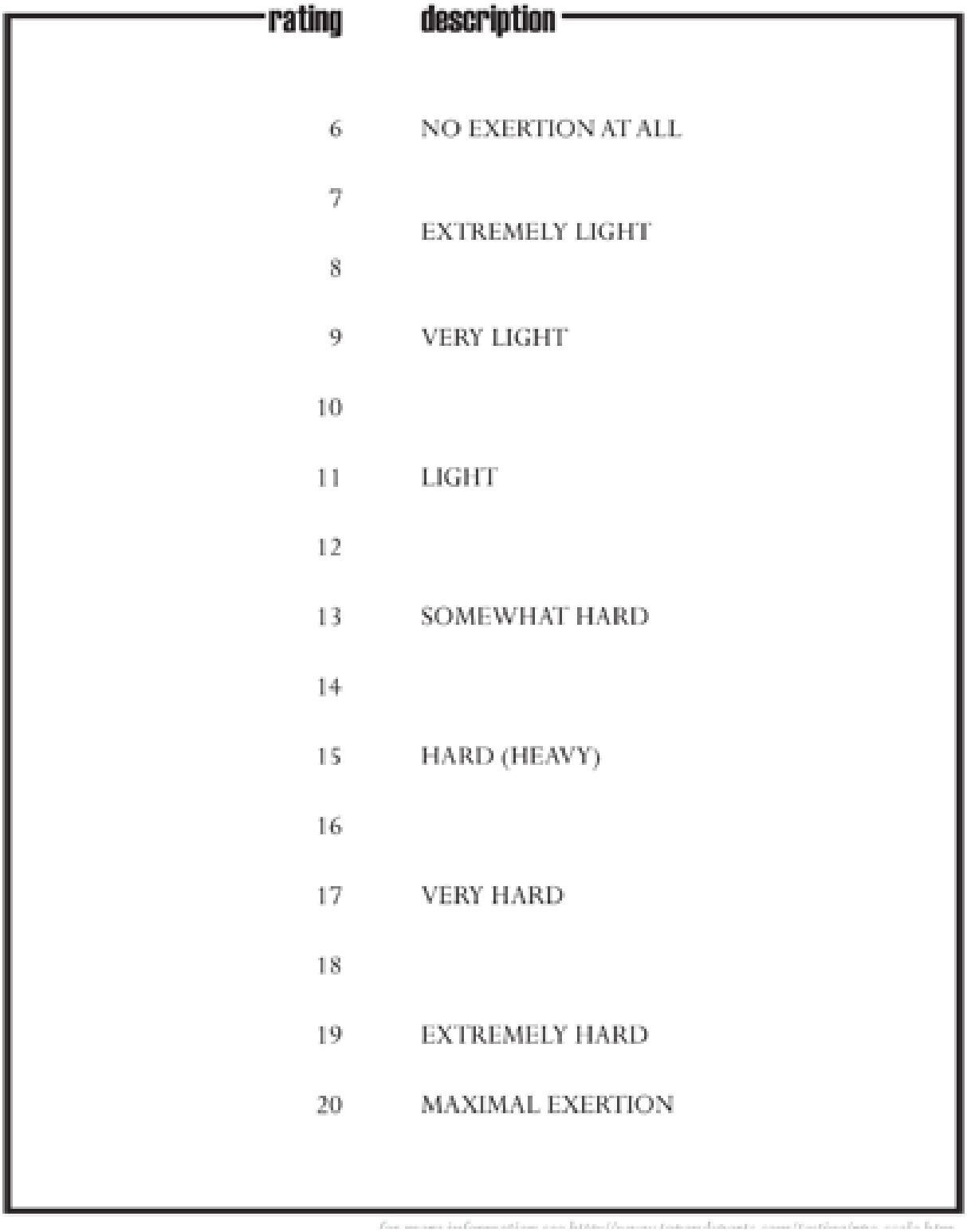


Figure 16 – 11-Point (0-10) Numeric Pain Rating Scale. Used to measure pain perception during the IPTT, CPT and 5 km TT



rating	description
6	NO EXERTION AT ALL
7	
	EXTREMELY LIGHT
8	
9	VERY LIGHT
10	
11	LIGHT
12	
13	SOMEWHAT HARD
14	
15	HARD (HEAVY)
16	
17	VERY HARD
18	
19	EXTREMELY HARD
20	MAXIMAL EXERTION

Figure 17 – Rating of Perceived Exertion (RPE) scale developed by Borg (1970)

7.7 Physical Activity Readiness Questionnaire

OXFORD BROOKES UNIVERSITY

Physical Activity Readiness Questionnaire (PAR-Q)

Exercise and Sports Science Research Group
School of Biological and Molecular Sciences
Oxford Brookes University
Oxford
OX3 0BP

Please read the following questions carefully and answer as accurately as possible.

Medical history	**Yes**	**No**
1. Has a doctor ever said you have heart trouble?	____	____
2. Do you suffer frequently from chest pains?	____	____
3. Do you often feel faint or have spells of dizziness?	____	____
4. Has a doctor ever said you have epilepsy?	____	____
5. Has a doctor ever said you have high blood pressure?	____	____
6. Has a doctor ever said you have diabetes?	____	____
7. Has a doctor ever said you have asthma?	____	____
8. Do you have a bone, joint or muscular problem which may be aggravated by exercise?	____	____
9. Do you have any form of injury?	____	____
10. Are you currently taking any prescription medications?	____	____
11. Have you suffered from a viral illness in the last two weeks	____	____

Adpated from Chisholm, D. M., Collins, M. I., Davenport, W., Gruber, N. and Kulak, L. L. (1975) PAR-Q validation report *British Columbia Medical Journal* **17**.

If you have answered YES to any of the above questions please inform a member of the research team.

If any of the information you have provided changes in any way, you must inform a member of the teaching staff BEFORE you participate in any physical assessment

If, prior to participation in a physical assessment, the answer to any of the following questions is ‘yes’, I will inform a member of the teaching staff

Pre-exercise activity
1. Have you eaten within the last 2 hours?
2. Have you drunk coffee or tea within the last 2 hours?
3. Have you smoked within the last 12 hours?
4. Have you consumed alcohol within the last 24 hours?
5. Have you performed exhaustive exercise within the last 48 hours?

I understand that the information provided above is important, and I will inform a member of staff if I believe there is a medical reason I should not participate in physical assessments. I will also inform a member of staff if any of the above information changes during the course of this module, such that it may affect the completion of any exercise testing

Name Signature

7.8 Exertion and Pain Rating Instructions (5km Time Trial)

While exercising I want you to rate your perception of exertion, i.e., how heavy and strenuous the exercise feels to you. This will depend mainly on the strain and fatigue in your muscles and on your feeling of breathlessness or aches in your chest. Try to rate your feelings of exertion as honestly as possible without thinking about what the actual physical load is. Look at the scale and the expressions and then give a number where 6 means no exertion at all and 20 means maximal exertion.

After rating your exertion, I will also want you to rate your perception of pain on this scale from no pain (0) to the worst possible pain imaginable (10). When rating these pain sensations, be sure to attend only to the specific sensations in your legs and not report other pains you may be feeling (e.g. seat discomfort). It is important that your ratings of pain intensity reflect only the degree of hurt you feel in your legs during exercise and not as an expression of fatigue.

Please provide your exertion ratings first followed by pain ratings and use verbal expressions to help rate your perceptions which I will take every 0.5km. Both scales are provided in front of you on this stand for reference. Don’t underestimate or overestimate the degree of fatigue or hurt you feel when rating your exertion and pain ratings respectively, just try and estimate them as honestly and objectively as possible. Any questions?

“

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