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The Effects of High-Intensity Interval Training on Division I College 800/1500M Runner's

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The effects of high-intensity interval training on Division I college 800/1500m runner's performance

By

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Middle distance runners are always searching for ways to improve performance. This study was conducted to see if high intensity interval training (HIIT) on a cycle ergometer could help improve overall performance within 800/1500m runners. It was hypothesized that HIIT would increase performance, through decreasing 1500m times and increasing time to fatigue. Athletes completed two HIIT sessions every week for four weeks. Pre- and post- performance tests: incremental treadmill test (run to volitional exhaustion) and a 1500m time trial. In addition to performance, athlete's stride length and stride frequency during the 1500m time trial were recorded. No significant changes were seen within performance measures nor stride length and frequency. It was concluded two weekly training sessions of HIIT for four weeks does not significantly increase performance within college Division I 800/1500m athletes.

DEDICATION

This thesis is dedicated to a young athlete, Kaelin Kersh, a teammate and friend, who sadly and tragically lost her life on May 6th 2017. All Bulldog athlete's lost a sister on this day, but we will forever remember and be strong for her.

ACKNOWLEDGEMENTS

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CHAPTER I

INTRODUCTION

Background

Many studies have investigated different interventions to improve athlete performance from nutritional supplementation to different forms of training protocols (Deuster, et al., 1986; Midgley, McNaughton, & Jones, 2007; Saunders, et al., 2006; Paavolainen, Hakkinen, Hamalainen, Nummela, & Rusko, 1999). However, there are limited studies focusing on the effects of high intensity interval training (HIIT) on 800/1500m running performance. It is suggested HIIT may increase performance though increases $\dot{V}O_{2max}$, lactate threshold (LT), and ventilatory threshold (VT) (Astorino, Allen, Roberson, & Jurancich, 2012; Milanovic, Sporis, & Weston, 2015). A higher $\dot{V}O_{2max}$ and improved running economy can improve exercise performance (Astorino, Allen, Roberson, & Jurancich, 2012; Milanovic, Sporis, & Weston, 2015). LT has also been shown to increase when participants have incorporated anaerobic training into their programs (Acevedo & Goldfarbo, 1989; Gist, Fedewa, Dishman, & Cureton, 2014). If the body is more effective at utilizing and buffering lactate, for a further energy source it can help to enhance performance (Brooks, Fahey, & Baldwin, 2005). Lactate threshold has been defined as the onset of blood lactate (OBLA) (Bishop & Skinner, 2014)or occurs when the levels of lactate reach 4mmol within the blood (Bishop & Skinner, 2014). LT and VT are both known as anaerobic thresholds however they measure different physiological events (Cheng, et al., 1992). The VT is the point at which there is a non-linear rise in carbon dioxide (CO_2) as compared to expired air volume (VE). This point represents the athlete's buffering capacity for hydrogen ions. VT is an important factor to improving performance as it helps to assess an athlete's anaerobic threshold (Cheng, et al., 1992). Increasing buffering capacity helps prevent changes in pH occurring from the accumulation of metabolically produced hydrogen ions, which are shown to negatively effect muscle contraction (Fabiato & Fabiato, 1978). It is important to determine if HIIT on a bike can improve running performance in high level athletes.

Purpose

This study aims to investigate an alternative method of training for 800/1500m runners to improve or perhaps maintain running performance. A secondary aim of this study is to investigate the effects of HIIT on stride length and stride frequency. The purpose of this study is to determine is an alternative methods of training can be effective and time efficient.

Hypothesis

The hypothesis for this study is four weeks of HIIT will decrease 1500m times and increase time to fatigue in a graded exercise test. A secondary hypothesis is HIIT will lead to no change in stride length but a increase in stride frequency.

CHAPTER II

LITERATURE REVIEW

Introduction

Various methods have demonstrated the importance in developing economy for aerobic athletes to increase performance, this may be both physiological responses as well as biomechanical (Gist, Fedewa, Dishman, & Cureton, 2014; Frank, Anderson, Ponten, Ekblom, & Sahlin, 2015; Burgomaster, Hughes, Heigenhauser, Bradwell, & Gibala, 2005). Arguments persist regarding efficacy of specific training techniques within sports to increase performance. There are numerous coaching approaches to training 800/1500m athletes, some conventional methods include: long runs (60-120mins), tempo runs, and $\dot{V}O_2$ intervals, that increase aerobic capacity (Conley, Krahenbuhl, & Burkett, 1981) and high intensity track intervals to increase anaerobic threshold (Billat, 2001). Less conventional methods that have been shown to increase athlete economy and performance are strength training and plyometric training (Mikkola, Rusko, Nummela, Pollari, & Hakkinen, 2007; Saunders, et al., 2006). These different approaches occur due to the athlete achieving an elevated aerobic capacity but also the maximizing anaerobic buffering capacity in order optimize performance (Bassett & Howley, 2000).

HIIT has been shown to decrease the impact of lactate accumulation during exercise (Bayati, Farzard, Gharakhanlou, & Agha-Alinejad, 2011). If LT can be altered via anaerobic training, it could help develop race performance, by reducing the onset of fatigue (Esfarjani & Laursen, 2007). Within middle distance running an increased ability to metabolize lactate, means a performer will likely be able to delay fatigue, which could enable athletes to run at a higher intensity for a longer period of time. Not only will the body be acting to buffer the hydrogen ions but it will become more efficient in utilizing oxidative energy systems, therefore helping to increase economy within the athlete and performance (Esfarjani & Laursen, 2007).

Economy

Running performance can be effected by many different factors, including running economy. Running economy comes from the energy demand of a chosen velocity of submaximal running and can be measured and assessed in numerous ways (Saunders, Pyne, Telford, & Hawley, 2004). There are many factors effecting a runner's economy from different training methods to an athletes anthropometrics, different environments, individual physiology and biomechanical differences (Saunders, Pyne, Telford, & Hawley, 2004). An athlete must use varying methods of training to improve physiological and biomechanical status, thereby increasing economy and developing performance. Biomechanically, 800/1500m runners, rely on stride length and stride frequency to increase economy. If athletes can establish a longer stride and an increased stride frequency they can increase running economy, as they are able to cover a larger distance without expending a linear increases in energy requirements. When extending stride length, athletes must be able to maintain maximum power output and speed to increase running economy (Elliot & Ackland, 1981).

There have been many ways runners have tried to improve running economy biomechanically, through running drills (Azevedo, et al., 2015), stretching (Zourdos, et al., 2012), and plyometric training (Sundby & Gorelick, 2014). Tartaruga et al., (2012) showed an improvement in running economy through the implementation of running drills. They found improvements in biomechanical variables such as stride frequency and stride length (through improving running technique), running drills, and specific technique training can increase running performance. Azevedo, et al., (2015) however, showed more is needed than just running drills to improve performance, as running drills alone were unable to effect running mechanics related to increasing a runner's performance, such as ground reaction force. Increasing ground reaction force helps increase athlete's economy as it increases the push off phase. This increase in the push off phase decreases energy needed to create a longer stride length and helps to increase stride frequency. Similar to Azevedo (2015), an early study conducted by Petray & Krahenbuhl (1985), showed simply working on running technique also may not increase running performance. Petray & Krahenbuhl found no performance imporvements with training technique in development of 10-year-old runners.

Stride Frequency And Stride Length With Cycle Training

Cycling has been shown to incorporate different muscle activity compared to running (Chapman, Vicenzino, Blanch, Dowlan & Hodges, 2008) and therefore may alter or effect an athlete's running economy through their stride length and frequency.

Studies have shown stride length can be negatively effected through cycle training, seen within triathletes, as the cycling elicits changes within the lower limb musculature activity (Chapman, Vicenzino, Blanch, Dowlan & Hodges, 2008; Bonacci, et al., 2010). The change in musculature activity occurs due to cycling using different muscle groups, such as increased muscle activity within the vastus lateralis and biceps femoris when cycling is compared to running, (Bernard, et al., 2007; Bijker, De Groot, & Hollander, 2002). Increase both stride length and stride frequency is important, to enable athletes to run more economically. Improving only stride length may not increase performance, as this could cause a performer to over stride. Over striding decreases economy within athletes as due to more energy being needed to over-come braking forces (Munro, Miller, & Fuglevand, 1987). Therefore, if the body is moving more effectively it can become more economical with oxygen consumption (Saunders, Pyne, Telford & Hawley, 2004).

Chapman et al., (2008) discovered within cycling training, triathletes are able to elicit changes in muscle activity different than those seen in running training. This was found by comparing muscle activity in running and cycling. The participants used within the study were asked to carry out a 30-minute continuous run after cycling and a 30 minute continuous run without cycling, to see if any changes occurred from cycling to running performance. Cycling has been found to activate different musculature compared to running, suggesting that cycling could be detrimental to running performance. However, it is possible using cycling as an alternative mode of training, could increase aerobic ability (Bijker, De Groot, & Hollander, 2002). Bijker, Groot & Hollander (2002) compared the difference within muscle activity and kinematics when people run compared to cycle. The study by Bijker, Groot & Hollander (2002) looked at 11 participants, measuring gastrocnemius, vastus lateralis, and biceps femoris muscle activity, during the first 20 seconds of the 5th minute at each stage of a cycling and running protocol. They discovered running can act as a more economical method of training, as energy from athletes can be lost into the bike as the bike itself is not 100%

efficient (Minetti, Pinkerton, & Zamparo, 2001). Bijker, Groot & Hollander (2002), also suggested cycling can be more muscle fatiguing as compared to running. However being more fatiguing could offer a more intense workout and increase aerobic capacity more so what is seen in running.

Moreover, it has been shown that cycling can be detrimental to running performance, through compromising stride length (Connick & Li, 2015). By reducing stride length a runner must compensate by increasing stride frequency (Huang, et al., 2010). Increasing stride frequency results in increased ground contact time. When an athlete increases time on the ground, velocity decreases, thus decreasing performance within the athlete (Weyand, Sternlight, Bellizzi, & Wright, 2000). Bernard et al., (2003) demonstrated running performance decreases after bouts of cycling compared to just isolated running. However, it was also shown that stride rate and stride velocity are increased the first 500m of a 3000m time trial after bouts of cycling (Bernard et al., 2003). Connick and Li (2015), demonstrated cycling reduces stride length. They revealed 30 minutes or more of cycling, compromised stride length in a subsequent run, which can reduce economy. It could therefore be suggested that if runners were to complete training on a bike the training should be less than 30 minutes, to be able to increase performance without having detrimental effect of a decreased stride length.

Can Anaerobic Training Show Increases In Aerobic Capacity To Increase Performance?

As well as biomechanical economy, it is important to consider how HIIT may affect physiological economy within the athlete's, in relation to the effects on $\dot{V}O_{2max}$, LT, VT. Recent studies have shown HIIT can induce aerobic changes and enhancements

(Astorino, Allen, Roberson, & Jurancich, 2012; Gist, Fedewa, Dishman, & Cureton, 2014). These increases in aerobic ability have been shown in a multiple of physiological changes increasing $\dot{V}O_{2max}$ and mitochondrial density (Astorino, Allen, Roberson, & Jurancich, 2012; Stepto et al., 2012). However, few studies have looked into incorporating how stride length and stride frequency may also be affected through cycle training, instead of simple running training.

What Is $\dot{V}O_{2max}$?

$\dot{V}O_{2max}$ is the maximal oxygen uptake or the maximum volume of oxygen utilized in one minute, measured as milliliters of oxygen used in one minute per kilogram of body weight (Quinn, 2014). $\dot{V}O_{2max}$ is an important factor in distinguishing athlete's fitness levels and determining the economy of the athlete. Studies have shown male runners to be more economical compared to female runners in 800/1500m (Daniels & Daniels, 1992) .

In addition to differences in gender, differences in VO_{2max} testing protocols (i.e., mode of testing) have also been recorded. Evidence has shown cycling tests can show a reduced $\dot{V}O_{2max}$ reading compared to tests carried out on a treadmill (Wicks, Sutton, Oldridge, & Jones, 1978). It is suggested these changes occur as cycling puts a greater strain on the lower limbs, meaning that the perceived exhaustion of the performer occurs sooner than on treadmills, and the differences in the kinematics of cycling prevent the performer from producing higher $\dot{V}O_2$ results (Roecker, Striegel, & Dickhuth, 2003; Fairshter, et al., 1982).

Anaerobic vs Aerobic Training On $\dot{V}O_{2max}$

$\dot{V}O_{2max}$ has been reported to be a vital factor in middle distance running as athletes must be able to utilize oxygen, as it is related to improving the bodies ability to utilize oxygen and produce ATP (Brockman, Berg.K, & Latin, 1993) and therefore can delay the onset of fatigue. It is therefore important for athletes to increase their $\dot{V}O_{2max}$ to increase performance. There have been mixed results from a number of studies reporting how both aerobic endurance training and anaerobic interval training can demonstrate increases an $\dot{V}O_{2max}$ (Brenda, et al., 2015; Brockman, Berg.K, & Latin, 1993). Astorino et al., (2012) showed high-intensity interval training can have positive effects on cardiovascular function, demonstrating an increase in $\dot{V}O_{2max}$ after just 2-3 weeks of HIIT. This study found six sessions of four repeated Wingate tests with four minutes recovery produced significant improvements in $\dot{V}O_{2max}$. However, many other studies have provided evidence demonstrating aerobic training provides greater increases in $\dot{V}O_{2max}$ (McGawley, Leclair, Dekerle, Carter, & Williams, 2012). A meta-analysis showed endurance training elicited the greatest increase in mitochondrial density compared to intense interval training (Gist, Fedewa, Dishman, & Cureton, 2014). Even with this difference, it was reported interval training showed little changes in $\dot{V}O_{2peak}$ let alone $\dot{V}O_{2max}$ compared to aerobic training. It was hypothesized HIIT may have inhibited aerobic adaptations and $\dot{V}O_{2max}$ would not be effected and may contribute to detrimental effects to endurance athletes; however, this was not the case. Matsuo, et al. (2014) reported high intensity aerobic training to provide the greatest increases in $\dot{V}O_{2max}$ (22.5% ± 12.2%) compared to sprint interval training (16.7% ± 11.6%) and continuous aerobic training (10.0% ± 8.9%). It is important to note the difference in HIIT and sprint interval training; sprint interval training would have a higher aerobic content, being both part aerobic and anaerobic, whereas the HIIT would be mostly anaerobic training (Bayati, Farzard, Gharakhanlou, & Agha-Alinejad, 2011; Milanovic, Sporis, & Weston, 2015). The changes were seen in healthy but not sedentary male participants. It is likely this level of effect will not be seen within highly trained athletes, as $\dot{V}O_{2max}$ will be high and therefore difficult to increase more (Daniels, Yarbrough, & Foster, 1978). However, one study has shown an increase in $\dot{V}O_{2max}$ over a six-week aerobic training period, within thirteen untrained male participants (Walter, Smith, Kendall, Stout, & Cramer, 2010). This simply suggests time to fatigue may not be purely linked to $\dot{V}O_{2max}$ but may also have a number of other limiting factors such as: VT, movement economy, and LT.

It is also important to highlight for most studies reported, $\dot{V}O_{2max}$ was unchanged, with some increases in $\dot{V}O_{2peak}$. This, can lead to suggestions time to exhaustion is increasing but not necessarily an increase in $\dot{V}O_{2max}$ of the performer.

Anaerobic vs Aerobic Training On Ventilatory Threshold (VT)

The VT is an important fitness factor and can effect an athlete's performance at submaximal intensities, as it indicates changes in metabolic pathways and substrate utlization, that occurs prior to LT (Acevedo & Goldfarbo, 1989). Increasing VT therefore helps the body to become more economical with the oxygen usage meaning there is an improvement of fat and glycogen utilization, also including the buffering of hydrogen ions (Wasserman, Cox, & Sietsema, 2014). The VT is measured through detection of carbon dioxide expenditure, which the body tries to get rid of through increased respiratory rate (Wasserman, Cox, & Sietsema, 2014). Studies show training the body at (or above) the VT can help improve a middle distance athlete's performance, as the intensity of the training forces the body to meet the increased demands of oxygen utilization (Hill, Cureton, Grisham, & Collins, 1987). However, there are mixed views on which methods of training promotes the highest VT (Londeree, 1997; Hill, Cureton, Grisham, & Collins, 1987). Some studies show aerobic training may increase $\dot{V}O_{2max}$, but has very little effect on VT (Ulbrich, et al., 2016). This factor suggests anaerobic exercise would be more likely to increase VT. This is supported by early studies that reported increased intensity of training as associated with improvements in VT (Poole & Gaesser, 1985). These changes were noted within 10km runners, and participants $\dot{V}O_{2max}$ also demonstarted an increase, which suggests HIIT could be more beneficial than just continuous aerobic work within middle distance athletes. Poole and Gaesser (1985) compared the effects of continuous training and interval training, they reported although both, continuous and interval training showed increases, interval training showed the greatest increase. This study was comprised of an eight-week intervention where participants were required to train on a cycle ergometer 3 days/week (Poole and Gaesser, 1985). Although the training was not fundamentally HIIT due to the efforts being 10 x 2 mins, the training demonstrated interval training resulted in greater improvements compared to continuous training. Therefore, it is crucial within the current study to look into whether similar changes occur when athlete's work at a high intensity. A study more recently conducted discovered HIIT can produce these desired effects, such as increases in VT, although the study was comprised of an overweight female population. The study showed greater increases in VT within the HIIT group compared to the moderate intensity group (Sijie, Hainai, Fengying, & Jianxiong, 2012). The intervention used within the study, Sije, Hainai, Fengying and Jianxiong, (2012) consisted interval exercises at a heart rate of 85% heart rate maximum. However as the participants are not working at 100% maximum heart rate it is hard to determine, whether this truly is HIIT. Furthermore, Sijie et al., (2012) does not specify which exercises were used, and therefore the reliability of this study is questionable, as the testing is not repeatable (Sijie et al., 2012).

Anaerobic vs Aerobic Training on Lactate Threshold

LT has been closely linked with VT in that both can be used to estimate a point at which an athlete has reached anaerobic threshold and moves from predominantly aerobic pathways to anaerobic pathways. It is equally important to increase LT as it is to increase VT, as increasing LT will in turn increase VT, although these factors are not the same they are very closely linked (Loat & Rhodes, 1993). Therefore, increasing LT has been shown to require similar training to that of VT, in that interval training shows greater increases in LT. Increasing LT can increase time to fatigue. Ziemann et al. (2011) discovered six weeks of 90 second cycle bouts at 80% $\dot{V}O_{2max}$, with a recovery of 180 seconds three times a week can elicit an increase within LT (and $\dot{V}O_{2max}$). However, it is possible diffeences in fitness level could lead to differences in results. A study carried out by Bayati et al. (2012) saw HIIT over a four-week period can increase LT. The protocol used three different groups to compare different volumes of HIIT (Group 1: carried out 3-5 repeated Wingate tests at 125% $\dot{V}O_{2max}$ with 4 min recovery; Groups 2: 6-10 repeated Wingate tests at 125% $\dot{V}O_{2max}$ with 2mins recovery; Groups 3- control group/ no training). The study used 24 young active males, with group 1 demonstrated the greatest increases in LT as well as an increase in time to exhaustion compared to group 2 and 3. The study revealed a longer recovery could be the key to increasing aerobic adaptations when conducting HIIT, as the recovery places a longer aerobic duration within the repeated intervals (Bayati et al., 2012). Bayati et al., (2012) demonstrates less repetitions can cause a greater adaptation, which to some extent suggests shorter training sessions could show greater benefits, making it a more time efficient method of training. A more recent study demonstrated not just the effect of intensity of cycling training on LT but also the different pedaling rates (therefore not concentrating on resistance) (Hirano, et al., 2015). Hirano, et al., (2015) discovered cycling at a lower rate did not raise the participants $\dot{V}O_2$ or heart rate sufficiently, however pedal force was higher at a lower revolution per minute (rpm) (frequency of pedaling used 35rpm and 75rpm). The study therefore suggests a higher rpm would be more applicable within the proposed study as $\dot{V}O_2$ may provide a greater increase in performance than the athlete improving pedal force (Hirano, et al., 2015). This would be essential information for athletes and coaches, reducing time pressures on training sessions and time constraints within the day. By imporving LT athletes will be able to increase overall performance due to increased buffering capacity and therefore athletes would be able to run at a higher intensity for longer, without performance being negatively effected.

Running vs. Cycling On Lower Limb Strength

Cycling has been shown to increase lower limb strength more than running (Wicks, Sutton, Oldridge & Jones, 1978). Wicks, Sutton, Oldridge & Jones, (1978) revealed this within two separate $\dot{V}O_{2max}$ tests, one conducted on a cycle ergometer and one on a treadmill, the treadmill tests demonstrated lower lower limb strength compared to the cycle ergometer tests. They deduced the increased resistance cycling places on the legs means greater strength must be used from the legs and thus greater adaptations can occur, meaning the participant must use a greater amount of oxygen, when cycling compared to running (Wicks, Sutton, Oldridge, & Jones, 1978). Studies show the legs fatigue before the participant is able to reach their $\dot{V}O_{2max}$ due to the different kinematics required within cycling compared to running as well as, different activations in muscles within running and cycling (Fairshter, et al., 1982; Roecker, Striegel, & Dickhuth, 2003). Raymond et al. (2013), discovered resistance training at progressively high intensities produces greater improvements in lower limb strength compared to lower intensities. They evaluated 21 studies, (912 participants) looking mainly into older adults. If increases can be seen within the older population, then it would be possible this could also occur in athletes.

HIIT vs Aerobic Training In Increasing Mitochondrial Biogenesis

Mitochondrial biogenesis is an important physiological change that can aid endurance performance. Increases in size and number of mitochondria enables cells to utilize oxygen more effectively and produce higher energy levels of ATP (adenosine triphosphate) to be able to continue exercise for longer. Some studies have shown training can increase the production of PGC-1α, which increases mitochondrial gene expression, leading to an increased production in mitochondria (Stepto, et al., 2012). Stepto et al. (2012), reported that HIIT can increase PGC1- α by 11 fold ($p<0.001$). This was seen after just a 10-day intervention in nine untrained participants, which was comprised of four cycle sessions (6 x 5 min). Stepto et al., (2012) shows mitochondrial biogenesis can be increased after just over one week of this training, which suggests a four-week period could have a phenomenal effect of the athlete's performance. IF just one week of HIIT can increase mitochondrial biogenesis the athlete therefore have a greater aerobic capacity and can increase the VT and LT to help improve perofromance. However, it must be noted this study, Stepto et al., (2012) used untrained participants which may evoke these changes more readily compared to highly trained athletes. Stepto et al's training was also more aerobic than the protocol used within this current study, which questioned whether HIIT would have the same changes due to the more anaerobic nature of the intervals, as studies have shown increases in mitochondrial biogenesis in more aerobic interval training that anaerobic (Keating, et al., 2014)Gurd et al., (2010) similarly researched how high intensity aerobic training could increase the activity of mitochondrial enzymes (citrate synthase, β-hydroxyacyl, cytochrome *c* oxidase subunit IV and SIRT1), which in turn helps to indicate and explain any changes in PGC1-α, due to the mechanism in which mitochondrial biogenesis occurs. PGC1-α is dependent on the activity of SIRT1. which activates PGC1-α and leads to a change in gene expression, increasing the production of mitochondria.

Gurd et al. (2010) discovered that six weeks of HIIT (10 x 4 mins) increased PGC1-α by 16% and the activation of SIRT1 by 31%. However, this again is based on more aerobic training, which still questions whether bouts of maximal 30 seconds efforts would elicit a change within particpants. Little evidence was found of any such training within human participants, with only a small number of studies being conducted on rats (Ramos-Filho, et al., 2015). It is therefore important to determine whether shorter anaerobic training can elicit the same increases in PCG1-α activity.

Granata et al., (2015) compared sprint interval training, high intensity interval training and sub-LT continuous training. Granata et al., (2015) discovered training intensity has a large impact on the regulation of PGC1-α. HIIT showed the greatest improvements with sub-LT compared to continuous training and continuous training demonstrated the smallest improvements. However, HIIT within this study required the participants to complete four to seven four minute efforts, yet shorter efforts were used in the sprint interval intervention (4 – 10 x 30 second all out). However, as HIIT shows the greatest increases in LT and VT compared to aerobic methods as well as some increases in aerobic capacity such as $\dot{V}O_{2max}$, HIIT could be more beneficial compared to carrying out pure aerobic training.

CHAPTER III

METHODS

Participants

Twelve 800/1500m track athletes, competing at a Division I collegiate level, were recruited as participants for this study (age: 20.8 ± 2.0, height: 182.0 ± 6.6 and weight: 65.4 ± 7.2). Athletes were asked if they had or were suffering from any injuries prior to testing, those that answered yes were excluded from the research project. All participants were briefed on the study and attended testing and training in appropriate clothing and sportswear to reduce risks of injury and to enable them to perform to their maximum ability.

Performance testing

Athletes were tested pre- and post-intervention to examine if four weeks of HIIT had a significant impact on 800/1500m performance. Performance tests consisted of an incremental treadmill test (run until volitional exhaustion) and a 1500m time trial. A modified Fox/Costill protocol (Kasch, et al., 1999), a Cosmed treadmill (T170) (Waukesha, USA) and harness (for safety reasons) were used for the incremental treadmill test. The participants began at 6.5km/h for three minutes, and increased 1.5km/h every three minutes, until they reached 11km/h. Once at 11km/h the speed remained constant, with the gradient increasing by 2% every minute. The participants completed this protocol until they reached volitional exhaustion and could not continue the test.

During this test, heart rate was taken as well as within the last minute of each incremental stage, using a polar heart rate monitor (FT1) (Kepele, Finland).

Performance was also measured from a 1500m time trial during which, time to completion was measured and recorded (using a stopwatch) to the nearest hundredth of a second. Athletes performed a standardized, dynamic warm up before this time trial to reduce the risk of injury. This consisted of a 2-mile jog followed by 20m of skips, side steps, crossovers and a three minute extended run (an up tempo run). The run was completed on a standard 400m tartan outdoor track (Mississippi State University, USA) as accordance with IAAF facility standards (Wilson, et al., 2008). Runners ran both 1500m time trials at the same time of 08.25 ± 0.25 minutes with a temperature of 9.0 ± 5.0 degrees Celsius.

Stride Length

Stride length was measured during the 1500m time trial. Stride length was measured during the 1500m time trial through setting up a camera and tripod 10.5m on the inside of the track. 10m was marked out along the track, with 10cm increments being marked using a tape measure and chalk.

Stride Frequency

Stride frequency was measured during the 1500m run. A hand held 'clicker' (Coolestone) (Leavenworth, WA) was used to count each stride by the athlete throughout the 1500m run. The number of strides were counted each time the right foot struck the track. The number of strides were then divided by the overall seconds it took for the athlete to complete the 1500m time trial.

Training

Each athlete completed a training intervention which consisted of four 20-second maximal effort sprint (modified Wingate) tests with four minutes of active recovery in between each sprint. Training was conducted twice a week for four weeks. A standardized warm-up was conducted, which consisted of cycling at 50 watts for females and 75 watts for males. The warm-up lasted five minutes. Once participants completed the dynamic warm-up, they began the training protocol. Resistance was set at 7.5% of particpants body weight and particpants were asked to cycle as hard as they could (i.e., maintain maximal cadence) for 20 seconds, while maintaining a seated position. A Velotron bike (Seattle, WA) was used for the Wingate testing, using the Velotron Wingate software (RacerMate) (Seattle, SA). Each participant had a four minute active recovery in between the 20-second repetition (set at 50 watts for females and 75 Watts for males) and completed a five-minute cool down either cycling (35watts) or on a Woodway treadmill (ELG)(4mph) (Waukesha, WI).

Statistical Analysis

SAS version 9.4 (Cary, NC) was used to carry out all statistical analyses. A paired T-test was used to distinguish significant differences between: pre- and post-1500m times, pre- and post-maximum heart rate, pre- and post-maximum RPE, pre- and post-stride length and pre- and post-stride frequency. An 11 X 2 RMANOVA (stage x time) was used to distinguish significant differences between the incremental stages for both heart rate and RPE as well as comparing pre-intervention and post-intervention heart rate and RPE at eleven stages of the incremental treadmill test. A Tukey post hoc was used when significant main effect was found. Significance was set at $p \leq 0.05$.

CHAPTER IV

RESULTS

Six participants completed the study, with six participants dropping out. Four of the six participants, which dropped out, withdrew from the study before pre-testing, two of these four participants, due to time commitments and conflicts of interest and two of these four due to injury. The other two participants withdrew after the second training week due to injury.

Table 1

Descriptive data recorded of participants that completed the study.

Descriptive data	Mean ± SD
Age (years)	20.8 ± 2.0
Height (cm)	182.0 ± 6.6
Weight (kg)	65.4 ± 7.2

Performance

No significant changes were seen within performance: time to exhaustion ($t = 1.759$, $p = 0.139$), 1500m time ($t = 1.356$, $p = 0.23$) maximum RPE ($t = 0.488$, $p = 0.640$), maximum heart rate ($t = 0.869$, $p = 0.449$), stride frequency ($t = 0.294$, $p = 0.780$), and stride length ($t = 2.113$, $p = 0.088$).

Table 2

Pre- and post- four-weeks HIIT training on performance determinants: incremental treadmill tests, 1500m time trial, max RPE, max heart rate, mean stride frequency, and stride length.

Test	Pre-HIIT (mean +/-SD)	Post-HIIT (mean +/-SD)
Time to Exhaustion (mins)	20.1 ± 1.2	19.7 ± 1.3
Max RPE	9.3 ± 1.0	9.5 ± 0.8
Max HR (bpm)	187.8 ± 7.9	183.8 ± 3.1
1500m time (mins)	5.0 ± 0.7	4.8 ± 0.5
Stride frequency (stride/second)	1.5 ± 0.1	1.5 ± 0.1
Stride length (m)	3.2 ± 0.3	3.3 ± 0.3

*Significance $p \leq 0.05$

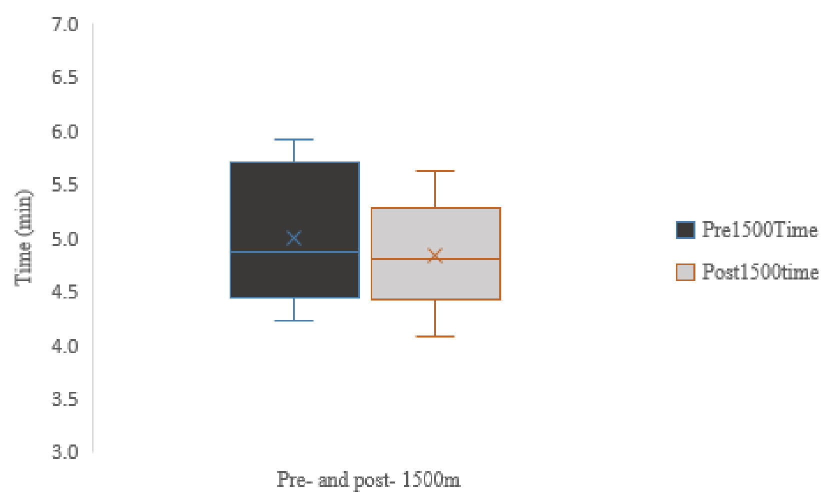

Figure 1. Pre- and post- 1500m times within the participants. Data are shown as mean ± SD. No significant changes were seen.

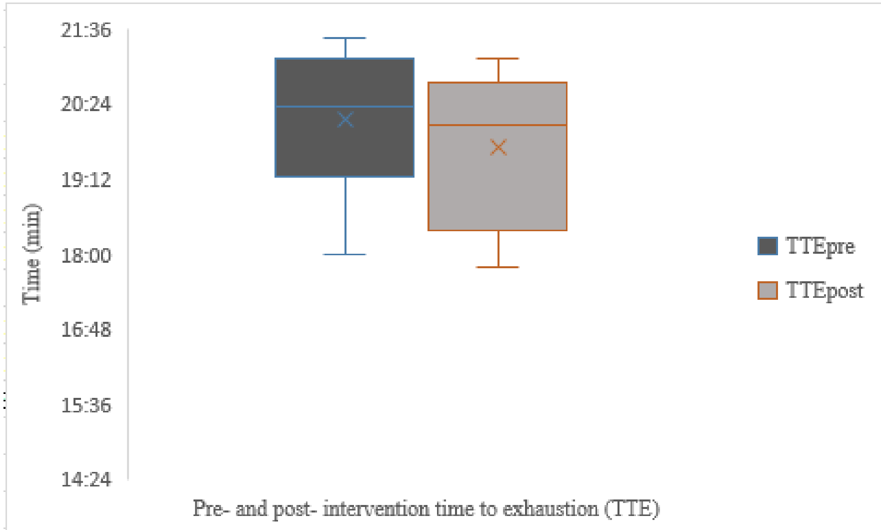

Figure 2. The incremental treadmill time to exhaustion tests pre- and post- four-weeks of HIIT. Data are shown as mean ± SD. No significant difference was found.

RPE

RPE results pre- and post-intervention are shown in Table 3. No significant interactions were found between intervention and stages (F = 0.750, p = 0.671). No significant changes were seen with treatment (F = 0.560, p = 0.455). A significant main effect was seen between stages (F= 26.770, p = <0.001). There were no significant changes between stages 1, 2, and 3 (p > 0.05). There was a significant RPE increase from stage 3 to stage 4 (p = 0.030). There was no significant RPE difference between stages 4 through 7. Stages 7, 8, and 9 were significantly higher than stages 1, 2, and 3 (p < 0.001). There was no significant difference between stages 10 and 11. Stage 10 RPE was significantly higher than stage 7 (p < 0.001) and 8 (p = 0.001). Finally, stage 11 was significantly higher than all stages except stage 8 (p < 0.001)and stage 9 (p =0.0008).

Table 3

Comparison of RPE pre- and post- four-week HIIT intervention between each stage of the incremental treadmill test (time to exhaustion trial).

Stage	Mean pre-RPE ± SD	Mean post-RPE ± SD
1*	1.0 ± 0.0	1.7 ± 0.5
2*	1.0 ± 0.0	1.7 ± 0.5
3*	1.6 ± 0.7	1.9 ± 0.7
4*	2.1 ± 1.0	2.1 ± 1.0
5*	2.5 ± 0.6	3.0 ± 1.3
6*	2.8 ± 0.9	3.2 ± 1.2
7*	3.4 ± 0.7	3.2 ± 1.3
8*	4.4 ± 1.4	3.8 ± 1.6
9*	5.3 ± 2.0	4.8 ± 1.8
10*	6.4 ± 2.0	6.7 ± 2.3
11*	7.5 ± 1.6	7.4 ± 2.1

*Significance $p \leq 0.05$
†Significance $p \leq 0.05$ between pre- and post- intervention

Heart rate

No significant differences were seen between pre- and post-heart rate measures, as reported in Table 3.

Table 4

Pre- and post-mean heart rate readings of four-week HIIT intervention within each completed stage of the incremental treadmill test (time to exhaustion).

Stage	Mean pre- heart rate (bpm) ± SD	Mean post- heart rate (bpm) ± SD
1*	74.2 ± 13.3	79.3 ± 4.9
2*	101.8 ± 12.4	97.0 ± 6.2
3*	125.5 ± 20.4	118.5 ± 27.8
4*	131.8 ± 21.1	124.8 ± 24.5
5*	140.5 ± 18.9	132.8 ± 19.7
6*	144.0 ± 12.9	139.0 ± 18.2
7*	152.0 ± 12.1	147.0 ± 18.7
8*	158.8 ± 12.5	153.5 ± 14.8
9*	167.5 ± 13.4	163.5 ± 8.1
10*	173.8 ± 10.4	168.5 ± 7.6
11*	178.3 ± 9.2	174.3 ± 7.6

*Significance p ≤ 0.05 between stages
†Significance p ≤ 0.05 between pre- and post- intervention

No significant interaction was found between stages and treatment regarding heart rate (F = 0.360, p = 0.959). No main effect was seen for treatment (F = 1.260, p = 0.265). A main effect was seen for stages (F = 121.380, p <0.001) indicating a change in HR between stages. This pattern was seen within both pre- and post-intervention. Stage 1 HR was found to be significantly lower than stages 2 through 11 (p < 0.001). Stage 2 was significantly lower than stages 4 through 9 (p < 0.0001) and stage 10 (p = 0.0004). Stage 3 was significantly lower than 4 through 10 (p < 0.0001) and stage 11 (p = 0.009). Stage 4 was significantly lower than stage 5 through 11 (p < 0.0001). Stage 5 HR was significantly lower than stage 7 (p = 0.0005) and stages 8 – 11 (p < 0.0001). Stage 6 was significantly lower than stage 7 (p = 0.042), stage 8 (p = 0.001) and stages 9 – 11 (p < 0.0001). Stage 7 was significantly lower than stage 9 (p = 0.002), stage 10 and 11 (p < 0.0001). Stage 8 was significantly lower than stage 10 (p = 0.0005) and stage 11 (p <

0.0001). Stage 9 HR was significantly lower than stage 11 ($p = 0.0002$) and stage 10 was significantly lower than stage 11 ($p = 0.023$).

CHAPTER V

DISCUSSION

Performance

Overall, performance was unchanged after carrying out the four-week HIIT intervention, as time to exhaustion and the 1500m time trials showed no significant differences between pre- and post-testing. However, it is important to note that performance also did not decrease, suggesting this method of training could potentially be used to maintain fitness within 800/1500m runners. Therefore, if athletes are experiencing overuse pain/injury, HIIT can be used to maintain fitness while they are unable to run. Overuse injuries are the most common injuries within running, resulting in stress related injuries, such as stress fractures and stress responses (Daoud, et al., 2012). Cycling is shown to have far less impact than running and therefore can reduce these risks, without costing the athlete a loss in performance (Neiman, et al., 2014; Scofield & Hecht, 2012). These stress related injuries have been shown to inhibit physical performance as the athletes are forced to refrain from any running to recover (Shellock & Prentice, 1985). If an athlete cannot train, they can lose large amounts of conditioning, which will likely make performance progressions more difficult from previous years.

In addition to injury prevention, the current protocol it is far more time efficient, being a total length of 30 minutes compared to completing an hour long run or a two-hour track session. By being more time efficient athletes can concentrate on additional aspects within their training such as: strength training, and plyometric training, which may help further increase performance within distance runners (Saunders, et al., 2006; Mikkola, Rusko, Nummela, Pollari, & Hakkinen, 2007). Making coaches aware of this time component factor of HIIT could increase the uses of HIIT within athlete's training. Additionally, the athletes within this study were able to carry out the HIIT sessions a day before and after hard track sessions. HIIT could help to increase the amount of hard workouts the athlete is able to complete without increasing impact forces on the athlete.

The lack of significant increases in performance could suggest $\dot{V}O_{2max}$ was unchanged after the training period, as increasing $\dot{V}O_{2max}$ has been shown to increase performance significantly (Paquette, et al., 2016). $\dot{V}O_{2max}$ has been seen to be unchanged in similar studies such as, Burgomaster et al., (2005). Six sessions of sprint interval training did not improve $\dot{V}O_{2max}$ significantly, but showed improvements within time to fatigue, suggesting high intensity interval training can help improve performance, even if $\dot{V}O_{2max}$ is unchanged. Further studies have also shown little improvement within $\dot{V}O_{2max}$, however $\dot{V}O_{2peak}$ was increased (Gist, Fedewa, Dishman, & Cureton, 2014). Other similar studies however, have shown significant increases within $\dot{V}O_{2max}$ (Astorino, Allen, Roberson, & Jurancich, 2012; McGawley, Leclair, Dekerle, Cater, & Williams, 2012). One explanation to why this intervention did not increase performance compared to other similar studies (Astorino, Allen, Roberson, & Jurancich, 2012; McGawley, Leclair, Dekerle, Cater, & Williams, 2012; Whyte, Gill, & Cathcart, 2010; Ready, Eynon, & Cunningham, 1981), may be due to the elite level of athlete used within this study. Studies have shown that HIIT can improve $\dot{V}O_{2max}$ within untrained women (six weeks, three sessions per week) (Ready, Eynon, & Cunningham, 1981) and obese males (two weeks, five to six sessions) (Whyte, Gill, & Cathcart, 2010). As the athletes being used within the current study are already at a highly trained stage within their career, it may take longer for these athlete's to produce significant changes within performance. This can be due to their $\dot{V}O_{2max}$ already being at an already high level, as well as their LT and VT levels and therefore requiring a more vigorous training protocol. It could be suggested the athletes in this current study should have been given a more intense workout, due to increased levels of fitness. This could have been done through increasing the duration of repetitions as well as decreasing rest periods.

Stride Length/ Frequency

Performance may not have been affected due to no significant changes within stride length and stride frequency, both shown to effect performance (Anderson, 1996). Increasing stride length and stride frequency has been shown to alter running economy, therefore if stride length and frequency were improved it may have assisted with increasing $\dot{V}O_{2max}$, as the performer could be more economical (Anderson, 1996). Elliot and Aukland (1981) demonstrated as runners' stride length and stride frequency can effect performance. When a runner becomes more fatigued, stride length and stride frequency decrease, decreasing velocity and therefore decreasing performance (Elliot & Ackland, 1981). Therefore, by not altering the stride frequency or stride length of the athletes within the present study performance would not be effected as velocity would not have been significantly affected.

Hue et al., (1997) demonstrated adjusting a runner's stride length can increase demand for oxygen uptake and thereby reduce performance. However, athlete's at a high level are able to self-select stride length (Saunders, Pyne, Telford, & Hawley, Factors affecting running economy in trained distance runners, 2004), suggesting these athletes are highly trained, it could be detrimental and unlikely for their stride length to alter.

Heart Rate and RPE

HR and RPE both showed significant increases from stage 1 compared to stage 11. This was expected as heart rate will increase as intensity of exercise increases. As the athletes increased through the stages the heart rate increases due to larger demand of muscle involvement, which demands greater oxygen and nutrients (Borg, Hassmen, & Lagerstrom, 1987). Heart rate will therefore increase to get more oxygen delivery to the active muscles. This oxygen will be used as a hydrogen acceptor to increase the production of ATP for energy, allowing the athlete to continue to exercise. Furthermore, as the intensity increases carbon dioxide in the form of bicarbonate will beused to neutralize the pH within the blood, as intensity increases the body must start to use anaerobic glycolysis, building up bi-products such as, lactic acid and hydrogen ions (Grassi, Quaresima, Marconi, Ferrari, & Cerretelli, 1999). This is because aerobic glycolysis produces the energy needed too slowly. The build-up of hydrogen ions alters the pH of the muscles effecting contraction mechanisms within it (Nakamaru & Schwartz, 1972; Grassi, Quaresima, Marconi, Ferrari, & Cerretelli, 1999; Hoff, Storen, Finstad, Wang, & Helgerud, 2016). Changes in pH alters the way certain enzymes work within the body, in this case enzymes assisting with aerobic glycolysis (Nakamaru & Schwartz, 1972).

The increases in heart rate can be used to help predict and determine LT and VT which is important for 800/1500m runners (Hofman, Duvillard, & Seibert, 1997). As we exercise heart rate will experience a deflection, this deflection point can indicate an athlete's LT (Conconi et al., 1982). Conconi et al., (1982), demonstrated heart rate and running speed have a linear relationship and by using this relationship heart rate deflection point can identified and thus estimate an athlete's anaerobic threshold. As heart rate demonstrated no significant differences within the current study between pre- and post- intervention stages of the incremental treadmill test, it is suggested that LT and VT were unchanged. However, this technique gives an estimated LT and VT, with many other studies showing inconsistencies within predictions, therefore was the technique was not used to predict LT and VT within the current study(Tokmakidis, Leger, & Pilianidis, 1998; Zacharogiannis & Farrally, 1993; Jones & Doust, 1995). Many other studies evaluating the effects of HIIT demonstrated improvements within LT within untrained populations and soccer players (Helgerud , Engen, Wisloff, & Hoff, 2001; Ziemann, et al., 2011). Ziemann et al (20011) demonstrated cycling training can help to improve LT, however the training protocol used was conducted three times a week for six weeks, suggesting the protocol used within the present study may not have been long enough nor contain a sufficient amount of training sessions per week.

As stages increased RPE increased, showing significant differences within stage 1 and stage 11. This is due to the fact, as the stages increased in intensity, the athletes are forced to work harder therefore, increasing fatigue levels, which would increase level of perceived exhaustion (Marcora, Bosio, & de Morree, 2008).

RPE has been shown as a predictor for exercise intensities (Stoudemire, et al., 1996), as RPE was not significantly different between stages as a result of the training protocol, it can be suggested that the runners ran at the same intensity for both the pre- and post-incremental test. Stoudemire et al., (1996) linked the level of RPE with blood lactate levels, thus suggesting as no differences occurred within the later stages of the run to exhaustion that lactate threshold remained the same for athletes. This would explain why performance was unchanged, as altering lactate threshold can impact performance greatly (Bailey, et al., 2012) (as discussed previously).

Limitations

No $\dot{V}O_2$ readings were used to determine whether athletes had fully reached their maximum effort, although many athletes had reached maximum heart rate towards the end, it is hard to distinguish whether the participants could in fact run for longer, as some participants stopped before reaching an RPE of 10. Furthermore, fatigue may have played a factor within testing weeks, suggesting the participants were not able to perform at maximum levels for the tests. This fatigue may have come from the athletes having to continue with normal training, as well as carry out testing and interventions. Using another group to assess whether the added cycling session effected the progression of performance would have been beneficial. Therefore, if the population were to allow, there should be an added group which only conducts the conventional training given by their coach.

Suggestions Of Use

Although no significant improvements were observed within this study, there is evidence of maintaining conditioning. Therefore, suggesting HIIT on a bike could be used as an alternative method of training for runners. Furthermore, many of the participants were able to carry out HIIT a day before a hard track workout and still perform at a high level, suggesting this method of training can offer an added workout with little risk of stress related injuries and little impact of fatigue on running performance.

Conclusion

It can be concluded two HIIT sessions per week for four-weeks does not elicit changes to Division I college 800/1500m runner performance. It can be suggested a more intense training program may be needed to elicit significant increases in performance. However, this study does show evidence that HIIT can possibly be used as an alternative method of training to maintain performance, with little to no detrimental effect to performance. Further studies would be encouraged to assess what level of intensity of HIIT would elicit increases in performance. Areas to assess would be the number of training days per week to assess whether increasing intensity per week, increasing the period of training, could show increases in performance, as well as, increasing the Watts placed upon the bikes.

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