The influence of Continuous vs Split training protocols on Endurance Performance

Philip Anthony

Canterbury Christ Church University

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ABSTRACT

Reports of twice daily training being used routinely by elite level endurance runners can be traced back to the 1960s. Coaches and runners have engaged in training protocols conducted during the foundational stage of training, that split the long, low intensity training (LIT) session into two sessions performed twice daily, in order to maintain volume of exercise (aligned with a single, long LIT session). Despite this, few studies to date have explored the acute physiological responses or the long-term (chronic) physiological adaptations to 'twice daily training'. There is an assumption of parallel benefits of once daily training versus twice daily training based on total volume of exercise accumulated, however, this assumption has not been tested. The primary aim of this thesis was therefore to investigate the effects of once daily and twice daily training on factors associated with running performance.

Before addressing this primary aim, a comparison of a 5 km performance TT in both the laboratory and outdoor environments was made. The laboratory is commonly used a testing ground in scientific research, however, there are often questions over the ecological validity of laboratory-based trials and their transferability into a field based competitive environment. Results generated here demonstrate that there are significant performance differences in these environments. However, participants disclosed their discomfort when testing outdoors which drove the decision to limit all testing in Studies 2 and 3 exploring differences in once and twice daily training to the laboratory. Study 1 also derived four prediction equations designed to be used by athletes and coaches. Equations 1 and 2 were to predict laboratory 5 km TT times and 4 and 5 were to predict outdoor 5 km TT times.

Findings from Study 2 demonstrated that in the acute setting, significant differences are seen between once daily training and twice daily training for running economy (RE) (6.4 ± 2.9 $mL \cdot kg^{-1} \cdot km^{-1}$) ($p = 0.033$), respiratory exchange ratio (RER) (-0.05 ± 0) ($p<0.001$) and estimated fat metabolised (12.9 ± 2.4 grams) ($p<0.001$). Furthermore, the twice daily group did not reduce

their velocity over the course of the day to the same degree as the once daily group. These differences provided a rationale for investigating twice daily training as part of a training plan.

Findings from Study 3 demonstrated that when MTRs incorporate once or twice daily training as part of a six week training plan, significant differences were seen between the two groups in RER (-0.06) (p<0.001) and the estimated fat metabolised (13.3 grams) (p<0.001) during the long run.

Study 3 found significant differences in RER and substrate utilization of MTRs who performed either once or twice daily training as part of a six week training plan. The twice daily group used more CHO in the second run when compared with the second half of the once daily group's run. As CHO is the more efficient fuel source for high intensity exercise such as a 5Km runs this will have contributed to the faster speeds observed for this group. Furthermore, while both groups saw significant improvements in a 5 km after performing either once daily (-13 ± 27 seconds) or twice daily (-30 ± 20 seconds) training plans, the group conducting the twice daily training saw significantly greater improvements (p = 0.03).

The findings in this research therefore demonstrate that, rather than previous suggestions that performance typically declines (Svedenhag & Sjodin, 1985) during the foundational stage of training where an increase in volume is achieved, conducting either of the once or twice daily training plans developed in Study 3 for six weeks resulted in improvements in 5 km RP.

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AMPK	AMP-activated protein kinase
ATP	Adenosine triphosphate
°C	Celsius
CaMPK	Calmodulin-dependent Protein Kinase
CHO	Carbohydrate
CO_2	Carbon Dioxide
CS	Citrate Synthase
CV	Coefficient of variation
EE	Energy Expenditure (Kcal)
GPS	Global Positioning System
GXT	Graded Exercise Test
H^+	Hydrogen ion
HIIT	High Intensity Interval Training
hr	Hour
HR	Heart Rate
HR Max	Maximal heart rate
IAAF	International Association of Athletics Federations
km	Kilometres
$km \cdot h^{-1}$	Kilometres per hour
$L \cdot min^{-1}$	Litres per minute
$L.s^{-1}$	Litres per second
LIT	Low Intensity Training
LT	Lactate threshold
LTP	Lactate turn-point
MLSSv	Maximal lactate steady state velocity
m	Metres

min	Minutes
ml	Millilitres
$mL \cdot kg^{-1} \cdot km^{-1}$	Millilitres of O_2, per Kilogram of body weight, per kilometre
$mL \cdot kg^{-1} \cdot min^{-1}$	Millilitres of O_2, per Kilogram of body weight, per minute
MFO	Maximal Rate of Fat Oxidation
mM	Millimolar
mmHg	Millimetres of mercury
$mmol \cdot L^{-1}$	Millimoles per Litre
$m \cdot s^{-1}$	Metres per second
MTR	Moderately Trained Runner
n	Number
N_2	Nitrogen
O_2	Oxygen
OBLA	Onset of blood lactate accumulation
p	Significance level
PCr	Phosphocreatine
PGC-1α	Peroxisome proliferator-activated receptor Gamma Coactivator 1-alpha
PGE	Pulmonary Gas Exchange
PPI	Patient and Public Involvement
PTv	Peak treadmill velocity
PV	Plasma volume
RE	Running Economy
RE12	Running Economy at the velocity of 12 kilometres per hour
RP	Running Performance
r	Correlation coefficient
r^2	Coefficient of determination
SD	Standard deviation
s	Seconds

SWC	Smallest Worthwhile Change
SEE	Standard error of the estimate
t	Time
TD	Total distance (km)
$\dot{V}O_2$	Volume of Oxygen
$\dot{V}O_2peak$	Peak oxygen uptake
$\dot{V}O_2max$	Maximal oxygen uptake
vVT	Velocity at ventilatory threshold
VT1	Ventilatory threshold
VT2	Second Ventilatory Threshold
$v\dot{V}O_2max$	Velocity at maximal oxygen uptake
wk	Week
yrs	Years
*	Multiplied by

Chapter 1 – Introduction

The Guardian (2018) reported that the number of people who have registered with ParkRun has increased from 13 runners in 2004 to 5 million worldwide in 2018. For many, the motivations behind starting a running training plan are the well-publicised health benefits of exercise; it is widely acknowledged that any exercise, but in particular moderate-intensity endurance training, has a number of health benefits (Thompson, Gordon & Pescatello, 2010). Exercise training has the capacity to reduce the risk of cardiovascular disease (CVD), with low cardiorespiratory fitness, a common condition in sedentary adults, associated with an increased risk of CVD (Carnethon, Gulati, Greenland, 2005; Myers, Prakash, Froelicher, Do, Partington, 2002). Furthermore, research supports the benefits of running as a specific form of exercise training, with reductions in CVD risk factors, such as high and low lipoprotein (HDL/LDL) profiles (Williams, 1996), increased functional capacity and mass of skeletal muscle (Campbell, Fediuc, Hawke & Riddell, 2009), and limiting excessive weight gain and associated diseases (Duscha, Schulze, Robbins, Forman, 2008; Tabet, Meurin, Driss, Weber, Renaud, 2009).

The popularity of running has led to the creation of free, weekly, national and local running events such as ParkRun™, with over 1 million runners in the UK now registered with ParkRun (ParkRun, 2017). These events allow individuals to compete weekly either against other competitors or alone in a time trial format over a distance of 5 km. Runners can then compare their times against both regional results and a national ranking system. Once individuals have recorded a performance time, the motivating factor becomes the drive to improve their times (Allender *et al.*, 2006). In their pursuit of this, many moderately trained club level runners choose to follow generic training programmes designed for untrained runners which are easily available online (Bupa, 2016; Galloway, 2016), or follow the training practices of elite and international level athletes (Robinson *et al*., 1991; Billat *et al.*, 2001). Although the use of almost any training programme may indeed lead to performance improvements when compared with an unplanned approach to training, many generic plans will be unsuitable for the

moderately trained runner (MTR), having been developed through observations and with little or no input from scientific research (Robinson *et al.*, 1991; Billat *et al*., 2001). Furthermore, both untrained and elite runners differ from the majority of regular, moderately trained runners (Pollock *et al.* 1980; Lorenz *et al*. 2013) to such an extent that training programmes designed to improve the performance of either group is unlikely to be appropriate.

This thesis investigates training practices of moderately trained runners (MTRs). Throughout this Thesis MTRs are defined as runners who have been running for a minimum of 1 year (Williams et al. 1991), have a $\dot{V}O_2max$ with the range of 50-70 $mL \cdot kg^{-1} \cdot min^{-1}$ (Helgerud *et al*. 2007) and have a run a 5km within the range of 15-22 minutes (Haverty *et al*. 1988).

Ultimately the goal of all committed runners is to improve their running performance (RP), which is influenced by the interaction of many variables. These include physiological variables such as maximal oxygen consumption ($\dot{V}O_2max$), lactate/ventilatory thresholds (LT/VT) and Running Economy (RE) (Figure 1) (Midgley, McNaughton & Jones, 2007), and non-physiological variables such as PTv (Noakes *et al.*, 1990) and Velocity at $\dot{V}O_2max$ ($v\dot{V}O_2max$) (Roecker *et al.* 1998; Bragada *et al*. 2011).

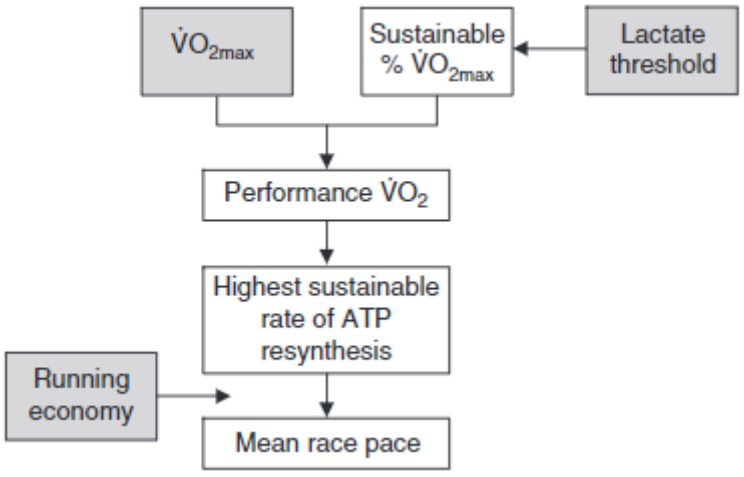


Figure 1.1 Midgley, McNaughton and Jones (2007) Physiological variables known to affect running performance

In the real world, the motivating factor for the runner is not recording a high value for measurements that take place in the laboratory, it is how fast they are able to complete an outdoor event such as 5 km. In addition to this may be the use of running as a method of psychological coping which includes self-esteem building, the maintenance of good health and weight management (Allender *et al.*, 2006; Waśkiewicz *et al*., 2018). Therefore, it would seem logical that researchers ultimately aiming to improve performance should relate research findings to something meaningful for the athlete, such as predicted or actual race finishing time. However, it seems that this is a limitation of a significant proportion of research to date. Common practice is for researchers to adopt a reductionist approach, isolating one of the known physiological determinants of endurance performance: $\dot{V}O_2$max, LT/VT or RE (Costill, 1967; Costill Thomason & Roberts, 1973; Holloszy & Coyle, 1984, Midgley, 2007); they then gauge the success or failure of an intervention on a change to this single measure. In many cases an assumption is then made that positive or negative changes to this single variable will, in turn, result in a change to the athlete's performance in their competitive environment.

While this approach is valuable in helping to gain a better understanding of how each variable responds to exercise mechanistically, it is important to remember that the determinants of endurance performance do not operate in isolation, rather, they are all integrated and the complex interaction between these three factors is far from clearly understood (Midgley *et al*., 2007); therefore, a single isolated physiological variable measured in the laboratory should not be defined or interpreted as performance. It is important therefore not only to monitor predictors of performance, but also to assess changes to predictors and their subsequent impact upon performance. This is one of the aims of this thesis.

Following an acute bout of exercise training, the body experiences a temporary disruption in homeostasis. In order to maximise physiological adaptation and the remodelling process, the body must be exposed to repeated bouts of training to induce physiological stress (Hawley, Myburgh, Noakes, Dennis, 1997). The rationale for training is, therefore, to repeatedly disrupt homeostasis within the body to optimise adaptation and thus improve performance.

Typically, the ways in which athletes achieve progressive adaptation are to manipulate the duration or intensity of training. It is customary for endurance training plans, whether they are intended for the off season or race season, to devote a large proportion of weekly training time to low intensity training (LIT). In the sport of endurance running, this is typically achieved by including one long run as part of a weekly training plan alongside other high intensity interval training (HIIT) sessions. Although initially, inclusion of LIT may have been based upon a trial and error approach to training and its effects on performance, evidence suggests that during prolonged periods of LIT essential neuromuscular, biomechanical, anthropometrical and physiological adaptations occur. Generally, however, research on LIT is limited not least because the time required to see its benefits is relatively unknown, and there is often a high dropout rate from research studies by athletes because of the extended time commitments required for such training (Hawley, 1997). In spite of this lack of research and science in training prescription, it appears that runners still devote extended periods of time in the off season to purely LIT (Galbraith, 2014).

Research in this field for endurance athletes is weighted towards HIIT or the addition of HIIT to a foundation of LIT training (Seiler, 2010; Lindsay *et al*. 1996; Londeree, 1997; Stepto *et al*. 1999; Weston *et al*. 1997; Billat *et al.* 1999; Smith *et al.* 1999; Smith 2003; Laursen & Jenkins, 2002). Furthermore, research in the HIIT area has focussed on training protocols, intensity, volume, repetition of intervals, and recovery. Professional elite athletes, who have long periods of time to dedicate to training, often report performing large volumes of both HIIT and LIT training in an effort to boost performance (Seiler, 2010; Billat *et al*. 2001; Billat *et al*. 2003). It is reasonable to hypothesise that club-level athletes have greater time constraints that real life presents due to work and other commitments, and thus effective information on the structuring of the LIT is important to consider.

Advances in exercise prescription have explicitly targeted the well documented barrier of ‘time commitments’ associated with engaging in regular physical activity. Training prescription has been aligned with ‘fitting in’ with daily routines to enhance engagement and adherence.

Coaches and runners have engaged in training protocols that split their long run, performed at low intensity, into two shorter runs of equal length; one session performed in the morning and the second session performed in the evening for these same reasons. There is increasing speculation that twice daily training may be more effective than once daily training in promoting adaptation (Croft et al., 2009; Hansen et al., 2005; Hulston et al., 2010; Yeo et al., 2008). However, the research conducted so far has not been based on training performed at low intensity (LIT), with at least one of the split sessions being at high intensity (HIT). In addition to this, LIT has received very little attention from researchers in general, this is despite its frequent use by coaches and its long established place as a fundamental part of training. Therefore, it is warranted to investigate the effects of splitting training when performed at low intensity.

Therefore, the primary aim of this thesis was to compare 'once daily' and 'twice daily' training strategies with two different groups of MTRs. However, before comparing the two different strategies it was deemed necessary to investigate specific differences in indoor and outdoor running performance as measurements were to be made by the researcher in the laboratory while most training by participants was to be conducted out of doors, and it had to be ensured that results obtained in the laboratory were transferable to running out of doors. In essence, an investigation of the differences of running indoors and out of doors formed Study 1, which is detailed with the research questions at the end of the Literature Review.

Once Study 1 had been conducted and the researcher was confident that results achieved in the laboratory were transferable to running out of doors, the researcher was in a position to compare selected effects of once and twice daily training on performance. This was effected in Studies 2 and 3 which are detailed at the end of the Literature Review. In essence, Study 2 compared the impact of once and twice daily training in an acute setting, or after only a single day of training in this manner (in other words no sustained training programme was conducted under Study 2). Study 2 involved two groups of MTRs, one of which performed a single, continuous run, at low intensity, while the second group completed a run of the same distance, also performed at the same low intensity, but split into two equal parts on the same day. For this twice daily training

group the first part of the split run was performed in the morning and the second in the evening, following 6-8 hours of recovery in between. The physiological variables of runners in each group (the once daily and twice daily training groups) were measured and compared to examine whether differences emerge after a single day's training. The results were used to form the rationale for Study 3 which investigated the effects of incorporating either once daily or twice daily training as part of a six week periodised training plan during the foundational stage of training, and during which an increase in training volume was also performed.

For Study 3 a new group of runners were recruited and allocated to two groups which tied them either to once or twice daily training. A run in the laboratory similar to that conducted for Study 2 was carried out in order to collect baseline data. The participants then conducted a six-week training plan that included four days per week of LIT, with two of these days conducted as either twice daily or once daily training, and one of HIIT. After the six week training period the participants returned to the laboratory and completed another test in the same format as the test conducted before the six week intervention, this yielded results for Study 3. An assessment of the impact of conducting once daily and twice daily training over a sustained period on the physiological variables and exercise performance of the runners was then made.

Chapter 2 – Literature review

Runners of all levels are constantly striving to improve their running performance (RP) by adopting effective training strategies (Midgley *et al*., 2006) and monitoring variables known to affect performance. As the development of training programs for moderately trained runners (MTRs) is central to this thesis, this review begins by providing a classification of Untrained, Moderately trained and Elite level runners (Table 2.1).

Within the scientific literature, the classification of runners is based on a wide range of variables (Table 2.2), but in essence, runners can still be classified into three general groups. These include, the untrained, the moderately trained and the highly trained or elite runner. Table 2.1 provides a summary of these classifications.

Throughout this thesis MTRs are therefore defined as:

- Runners who have been running for a minimum of 1 year.
- Have a V̇O2max with the range of 50-70 $mL \cdot kg^{-1} \cdot min^{-1}$.
- Are able to run a 5km within the range of 22-15minutes.

Table 2.1. Classification of Untrained, Moderately Trained and Highly trained/Elite runners

Category	Untrained	Moderately trained	Highly trained/ Elite
Training and race status			
5 km TT (minutes)	>22	22-15	<15
Years running	0	>1 year	>3 years
Weekly volume (km)	0	40-80	>90
$\dot{V}O_2$max range ($mL \cdot kg^{-1} \cdot min^{-1}$)	<50	50-70	>71

(Summary of information presented in Table 2.2)

Table 2.2. Supporting Literature for classification of untrained, moderately trained and highly trained/elite runners

Training Status	Race distance	Race time (min)	Years running	Weekly volume	$\dot{V}O_2$max range ($mL \cdot kg^{-1} \cdot min^{-1}$)	n	Reference
Untrained			0		43.9 ± 6	17	Stratton *et al.* 2009
Untrained			0		37.9 ± 6.3	81	Kemmler *et al.* 2014
Untrained			0	0	34.7 ± 5.1	10	Moore *et al.* 2012
Untrained			0		38.5 ± 2.4	7	Bergman & Brooks, 1999
Untrained	10km	>45	0		49.2	9	McGregor *et al.* 2009
Untrained			0		40.9 ± 9.3	24	Weltman *et al.* 1992
Untrained			0		48 ± 2	12	Johnston *et al.* 1997
Untrained			0		27.8-46.9	8	Tonkonogi *et al.* 2000
MTR	5 km	15-21	1		61.58 ± 5.5	20	Anthony, Unpublished study1
MTR	5 km	19-20	2-4	5-7 hours	59.8 ± 5	37	Anthony, Unpublished study2
MTR	5 km	18-20	2-4	5-7 hours	60 ± 5	42	Anthony, Unpublished study3
MTR	10 km	38-45	1		-	10	Williams *et al*. 1991
MTR	-	--	4	25-70 km		21	Kemmler *et al*. 2009
MTR					50-67	40	Helgerud *et al*. 2007
MTR			2-3	38 ± 4 km	51.6 ± 2.7	17	Esfarjani & Laursen, 2007
MTR	10 km	38.5 ± 3.3		>20 km	53.9 ± 7.4	14	Lum *et al.* 2016
MTR	2 miles	12.5 ± 1.5			59 ± 6	12	Tolfrey *et al*. 2009
MTR	5 km	15-21			49.9-65.3	11	Haverty *et al*. 1988
MTR	5 km	18-19	7-8		67.7-62.8		Paavolainen *et al*. 1998

MTR	5 km	16 ± .75		90 km	64.4 ± 7.7	20	Tanaka et al. 1986
Highly trained / Elite			5-8		74.2 – 77.4	10	Svedenhag & Sjodin, 1985
Highly trained / Elite				128 ± 27 km	72.8 ± 4.4	22	Saunders *et al.* 2004
Highly trained / Elite	3 km	8.5 ± 0.4		107 ± 43 km	71.7 ± 6	15	Saunders *et al.* 2006
Highly trained / Elite					71 ± 7.7		Conley & Krahenbuhl, 1980
Highly trained / Elite					74.4 – 77.4	45	Daniels & Daniels, 1992
Highly trained / Elite	10 km	28			78.4 ± 2.1	13	Billat *et al.* 2003
Highly trained / Elite				180 ± 27 km	69.8 ± 11	9	Billat *et al.* 2002
Highly trained / Elite	10	28 ± 1.05			68.7 – 80	22	Morgan & Daniels, (1994)

Having defined MTRs for the purpose of this thesis (Table 2.1), the Literature Review turns to training, first the traditional forms and then the growing role of science in training. Next, the literature on twice daily training is explored and following this, the discussion focuses on the scientific assessment of a range of physiological variables influencing training for endurance performance. These physiological variables, including $\dot{V}O_2max$, lactate threshold (LT), running economy (RE) and substrate utilization, are known to drive improvements in performance and thus it is necessary to examine how they can be manipulated through training. The literature on training indoors vs outdoors is explored and this is followed by a review of the literature on predicting athletic, and in particular, running performance. Throughout the chapter it is notable that there is a paucity of published research either on MTRs or on twice-daily training which is relevant to this thesis. This was unexpected owing to the growing popularity of running and the researcher concludes that the work carried out for this thesis is both timely and relevant to the needs of a significant body of athletes and coaches. The chapter concludes with a detailed presentation of the Research Questions.

2.1 Traditional approaches to training

A common trend in running and many other endurance sports is for coaches and athletes to implement training regimens of current world-class performers in their discipline (Hawley, 1995). While these training plans have been effective for a select few elite level runners, many have been developed over many years using a trial and error approach with little reference to science (Wells and Pate, 1988; Hawley, 1995; Hawley *et al.*, 1997; Midgley *et al.*, 2007). Influential coaches of the 1960s and 1970s, Arthur Lydiard and William Bowerman published many books (Lydiard *et al.*, 1962; Lydiard *et al.*, 1978; Lydiard *et al.*, 1983; Bowerman *et al.*, 1979; Bowerman *et al.*, 2009) giving their unique training methods, not based upon research or knowledge of the physiological adaptations that take place with training, but on years of trial and error. These programmes suggested that training should be broken up into macro and micro cycles that incorporate different volumes and intensities within the different stages of the

training programmes (figure 1), however, the *specific level* of intensity a runner should maintain was rarely made clear, and sometimes neglected entirely. Bowerman, for example, was an advocate for not using equipment such as a stopwatch or heart rate monitor (Bowerman *et al.*, 1979). In spite of the lack of evidence on which their training advice was based, the high public profile of these coaches and the success of the athletes they worked with has resulted in many of their methods becoming the basis of much of modern distance running training (Lydiard *et al.*, 2011; Bourne, 2008). At the time, twice daily training did not figure significantly in the training of elite runners and there was little recognition of MTRs

Elite runners are, by definition, different from MTRs who may face different barriers that might prevent them from reaching their potential. For example, research has consistently shown that the principal barrier to exercise is a lack of time (Chinn, 1999; Brown, 2005; Arzu *et al.*, 2006; Schutzer & Graves, 2004), and this is something likely to impact on the way a MTR trains far more than does an elite level runner, as many MTRs have work and family commitments. It could therefore be argued that many 'off the peg' training plans, which have been tailored to elite runners, and which may also lack scientific validity, are of little practical value to the majority of runners.

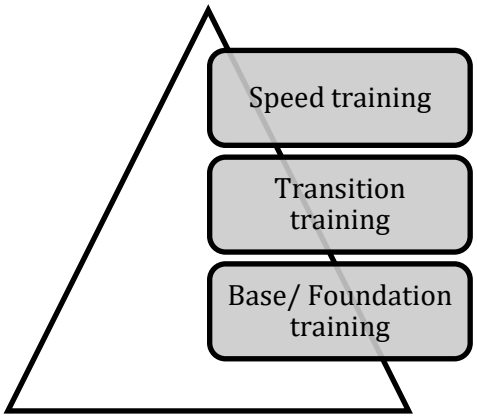


Figure 2.1 Representation of the three phases of training for an endurance athlete (adapted from Hawley, 1995).

Such programmes typically begin with a period of base or foundational stage training where the volume of training, performed at or below the ventilatory threshold (VT1), and defined as low intensity training (LIT) (Seiler et al., 2006), is increased, and then maintained, for a number of weeks or months during the non-competitive period. The goal of this phase is the establishment of a sound endurance base gained through the prolonged (greater than 60 minutes) accumulation of low intensity training sessions. In this period when LIT is increased there is little hint as to how it might be structured, in other words, little reference as to whether the increase in LIT should be completed in one session or whether it might be completed in two daily training sessions. During this phase, it is notable that little or no HIIT is performed (Hawley *et al*., 1997; Esteve-Lanao *et al*., 2005; Galbraith et al., 2014). Throughout this thesis HIIT will be defined as bouts of relatively intense exercise that elicit ≥80% of maximal heart rate, interspersed by periods of lower intensity exercise or rest for recovery (Gibala 2018).

Following the LIT phase is a period that Hawley (1995) terms 'transition training' where the total volume decreases and a portion of the LIT sessions is replaced with bouts of HIIT exercise. Again, there is little advice on the patterning of training during the week / day.

Finally, as the competition date approaches (14-21 days), a speed phase is introduced where the training volume decreases further and more emphasis is placed on HIIT (Hawley et al., 1997; et al., 2005; Galbraith et al., 2014; Garcia-Pinillos et al., 2017). Hawley (1997) recommends that during this phase HIIT should be performed up to three times per week at speeds faster than planned race pace.

2.2 The rise of science behind traditional approaches to training and the importance of LIT

The scientific research into endurance training programmes can be traced to the mid-1920s (Hill, 1924), and while it must be noted that knowledge is still limited regarding the physiological effects of high volume but low intensity endurance training on the human body,

researchers have made advances towards understanding how skeletal muscle adapts to the varying exercise stimuli experienced in each of the stages of training.

During the foundational or base stage where high volumes of endurance training are performed at low intensity, physiological adaptations that take place include: an increased delivery of oxygen (central adaptation) through increased stroke volume (SV), cardiac output (Q̇), plasma volume (PV) and blood flow (Green *et al*., 1990; Green *et al*., 1987; Fritzsche & Coyle, 2000), and increased utilisation of oxygen at the working muscles (peripheral adaptations), through an increase in the number of mitochondria (mitochondrial density) and the efficiency of the mitochondria (mitochondrial capacity) (Holloszy & Coyle, 1984). As central factors such as stroke volume (SV), Q̇ and PV have been reported to plateau relatively quickly (particularly in untrained athletes), a greater stress is required to further disrupt homeostasis, and this can be achieved through an increase in the volume of LIT (Daniels *et al*., 1978; Costill *et al*, 1988). Whether the stress disrupting homeostasis needs to be greater or perhaps lower if the volume of LIT is completed through two bouts of training in a day, and how this may affect the major variables which influence running performance is not clear from the literature. However, there is evidence that increasing the volume of LIT during the foundational stage of training is important to achieving peak performance because it sets the foundations upon which future performance gains can be seen (Holloszy & Coyle, 1984; Seiler, Haugen & Kuffel, 2007; Yeo Paton, Garnhamm, Burke, Carey, Hawley 2008).

Other adaptations to high volume, but low intensity endurance training include a reduction in muscle glycogen utilisation (Coggan *et al*., 1990; Karlsson *et al*., 1974), in turn leading to lower blood lactate (bLa) levels at the same absolute workload (Green *et al*., 1987; Green *et al*., 1990; Hurley *et al*., 1984). As a consequence of these adaptations, running at the same submaximal velocity appears less stressful, and the finite stores of CHO are preserved (Coggan *et al*., 1990; Karlsson *et al*., 1974). It should be noted that much of the research that has investigated this stage of training suggests these adaptations are limited to the untrained population. When runners become highly trained and LIT becomes habitual, further adaptation to central and

peripheral factors appears to plateau and increasing LIT further does not lead to greater adaptation (Daniels *et al*., 1978; Costill *et al*, 1988; Hickson *et al*., 1981; Londeree, 1997).

In comparison with the transitional or speed stages of training (below), research investigating the foundational stage of training remains limited. This could be due to the greater time course required to see performance gains, high participant dropout rates due to illness, injury or the reluctance of runners to have their valuable training prescribed for long periods of time (Hawley *et al.,* 1997). However, given the considerable length of time runners spend in this phase throughout a typical year further investigation into this stage of training, particularly the initial stages, where the volume of LIT is increased and then maintained, could prove invaluable. It is also particularly relevant to the MTR's training but coverage on LIT and the MTR is limited in the literature.

Hewson & Hopkins (1995) questioned 123 endurance running coaches, all working with highly trained athletes, and identified that the majority of coaches acknowledged the importance of LIT, however, around 9% of coaches failed to specify training intensity in terms of HR or velocity when prescribing LIT. Thus the precise parameters of LIT may be quite varied in reality. In spite of this, HIIT tends only to be incorporated after a period of LIT during the foundation stage (Galbraith, 2014). It is again noteworthy that greater scientific engagement with training has paid little attention to runners whose performance is somewhere between those in the elite category and those classified as untrained. The MTR is relatively neglected and as a consequence so are strategies to cater for runners whose access to time for training may be limited by lifestyle. Twice daily training is rarely mentioned.

Following the foundational stage (Fig.2.1), the runner then begins the transitional stage of training where a small portion of HIIT is combined with the large base of LIT. During the transitional stage the majority of training remains at low intensity. The goal of these HIIT sessions is to expose the body to sustained exercise at an intensity (or effort) which corresponds to the athlete's highest current steady-state pace (Lydiard and Gilmore, 1983; Hopkins, 1993;

Hawley, 1995b; Hawley and Hopkins, 1995), defined as the highest metabolic rate where bLa concentrations are maintained (Baldari & Guidetti, 2000). During this time, improvements are seen in the lactate (Edge *et al*., 2005; Esfarjani & Laursen, 2007; Driller *et al*., 2009) and ventilatory profiles (Acevedo & Goldfarb, 1989; Hoogeveen, 2000); there is an increased ability to recruit greater volumes of muscle mass during force generation (Lucia *et al*., 2000; Creer *et al*., 2004) and, during recovery periods, an increased ability to oxidize fat relative to carbohydrate (Yeo *et al*., 2008).

Finally, during the speed phase (Fig. 2.1), a large overall reduction in training volume is seen but is compensated by increases in the amount of HIIT performed. With this shift in training design further improvements in $\dot{V}O_2max$ are seen and this has been attributed to central factors, not least increased SV, which in turn leads to improved $\dot{Q}$. Other adaptations witnessed during this phase include increases in fat oxidation (Billat, 2001; Iaia *et al*., 2009) ranging from 15-38% (Burgomaster *et al.,* 2005; Burgomaster et al., 2006; Gibala *et al.,* 2006: Burgomaster *et al*., 2008). When training is completed following this approach, improved performance has been reported across a range of distances (Iaia *et al*., 2008). Once again, much of this relates to elite runners and not to MTRs

Despite gains in our understanding regarding training adaptation, there remain many unanswered questions associated with the notion of 'peak' performance. Furthermore, despite the knowledge that the ideal training plan should incorporate a mixture of both low intensity training (LIT) and high intensity training (HIIT) (Hawley, 1997; Laursen *et al.*, 2002; Seiler *et al*., 2007; Laursen, 2010), research to date has tended to focus on the comparison of LIT and HIIT rather than on their complementarity. And finally, to date, research conducted during the foundation stage of training is limited and has tended to focus on either untrained (Ingemann-Hansen & Halkjar-Kristensen, 1982) or highly trained runners (Galbraith *et al*., 2014). Far less is known about the effects that training has on MTR, or about the physiological mechanisms that might underlie any changes or indeed how these changes might then impact upon the RP of this

large – and growing - cohort. For these reasons this thesis sets out to explore the initial weeks of the foundational stage of training focusing specifically on the MTR.

2.3 Twice daily training: an alternative approach to training for the MTR

There is comparatively little literature on the subject of training programmes for MTRs - the focus of this thesis. It has been suggested that this could be due partly to researchers struggling to recruit athletes to participate in training interventions as many athletes may not wish to have their training prescribed over a lengthy period of time (Hawley, 1995; Midgley *et al*., 2007). In this research, this particular limitation has been overcome as the practical experience of the researcher as a competitive athlete, coach and exercise physiologist working with many of the local running groups has allowed the researcher to gain the confidence of potential participants in programme design and as such, achieve a greater sample size (see Chapter 3). From personal experience reluctance of the MTR to commit to lengthy prescribed training programs is because most have to fit training around lives which include work and family life. With a shortage of time to train being a major constraint for the MTR, and with the need for a high volume of LIT in the foundational stage of training, this thesis explores whether utilizing a twice-daily strategy might allow the MTR to achieve a higher daily training volume.

Sjodin & Svedenhag (1985) suggested that LIT might have a saturation point of ~120km running distance per week, beyond which no further improvements are seen. However, the distance achieved by MTRs is unlikely to exceed this amount and is likely to be within a range of 45-80 km per week (Walter *et al*., 1988; Hewson & Hopkins 1995; Singletrack, 2011). Therefore, the ultimate goal of the MTR during this phase is to increase the volume of LIT and the adoption of a twice-daily training strategy could be one way of achieving this.

Within the current research into twice daily training clear differences exist in methodologies. These differences include, but are not limited to, differences in intervention lengths, the training background of participants, the use of either one or two HIIT training sessions during twice daily training throughout the intervention, and in some cases, a training plan that bears little

resemblance to real world application. This has resulted in little consensus within the scientific community over whether twice daily training results in improved performance. It has also meant that much of the literature is simply not relevant to this thesis. Added to this, research has frequently been driven by a reductionist approach, for example, the effects of either HIIT *or* LIT on performance, and in spite of evidence that the ideal training plan should incorporate a mixture of both LIT and HIIT (Hawley, 1997; Laursen *et al.*, 2002; Laursen, 2010), there has been relatively little research that considers the training plan in a more holistic manner. Furthermore, given the importance of LIT for training adaptation it is surprising that research has been limited on interventions that have investigated the combination of two LIT sessions within twice daily training programs.

To date, the majority of studies that have investigated twice-daily training have focused on the manipulation of substrate availability (Croft *et al.,* 2009; Hansen *et al.,* 2005; Hulston *et al.,* 2010; Yeo *et al.,* 2008), where the first training session is used to reduce the muscle glycogen stores. The second session is then performed with reduced muscle glycogen. More detail on this is provided in section 2.5 (below) in Substrate Utilization. Research suggests that twice daily training prompted increased signalling responses in cytoplasmic and nuclear proteins: CS, AMPK, CaMPK, as well as the genes encoding mitochondrial proteins, including PGC-1α, PGC-1α mRNA (Croft *et al.,* 2009; Hansen *et al.,* 2005; Hulston *et al.,* 2010; Yeo *et al.,* 2008). This is in comparison with once daily training and may point towards the possible benefits of twice daily training. However, it is unknown whether these greater signalling responses during twice daily training are due to low muscle glycogen or to performing two exercise sessions on the same day. Whether the effects of twice daily training would deliver similar benefits without the manipulation of glycogen stores remains a fundamental question.

Of the research that has been conducted on twice daily training, it seems that relatively few studies to date (Hansen *et al*., 2005; Cochran *et al*., 2015) have reported improved performance with this training method when compared with once daily training. The evidence, however, is easily contested: of these studies, one was conducted on untrained participants (Hansen *et al.,*

2005) and therefore improvements could have been attributed simply to initiating a structured exercise plan and not necessarily to twice daily training. In the majority of research findings, despite improvements in metabolic markers, there were no performance improvements (Croft *et al*., 2009; Morton *et al.*, 2009; Ijichi *et al*., 2015), with some actually reporting reductions in exercise intensity and total work completed (Yeo *et al*., 2008; Hulston *et al*., 2010).

With the literature being far from clear on the effects of twice daily training, and with there being good reason for assuming that it could result in higher performance for MTRs when it is included in the foundational stage of their training, this piece of research investigates whether twice daily training by MTRs can result in improved running performance over 5km in comparison with once daily training over the same distance.

2.4 Scientific assessment of physiological factors influencing endurance performance

Key physiological parameters, RP, $\dot{V}O_2max$, Lactate Threshold (LT)/ Ventilatory Threshold (VT) and Running Economy (RE), which have been widely identified as influencing successful endurance performance are now discussed and the research is reviewed on how training affects these parameters. What is clearly evident from the literature is the paucity of research on endurance training in MTRs, nor is there much work on the effects of once vs twice daily training on these key parameters in elite, moderately trained or untrained runners. Nevertheless, the literature is explored to reveal how training can affect these parameters.

2.4.1 Maximal O_2 Uptake ($\dot{V}O_2max$)

Maximal oxygen uptake is typically defined as the maximal amount of oxygen (O_2) that an individual is able to extract from the atmosphere and utilize within the working muscles for cellular respiration (Midgley *et al*., 2006). This measure has a history dating back to the work of Hill and Lupton in 1923 (Hill & Lupton, 1924) who demonstrated that oxygen uptake increased linearly with running speed up to a maximal point. Once this point was reached, no further increase in oxygen intake occurred despite an increase in work rate. Since then the development

and validation of numerous protocols for assessing $\dot{V}O_2$max have been created (Yoon *et al*., 2007). Although the majority of protocols involve a graded exercise test (GXT) performed on a treadmill, they vary in their work stage durations, ranging from 30 seconds to 4 minutes, treadmill gradients, with some opting for fixed gradient of 0, 1 or 2 %, while others combine a velocity/gradient mixture where velocity is gradually increased up to a predetermined point at which the gradient is then gradually increased, as well as total test duration, with total test duration ranging from 3 min to 31 min.

It has been suggested that for untrained runners the measurement of $\dot{V}O_2$max is not affected by the exercise protocol used and that short duration protocols of less than 6 minutes are a time-efficient way to collect this measure. However, for the trained runner, protocols involving moderate velocity/gradient combinations and total test durations of 10 - 12 minute are more effective in eliciting higher $\dot{V}O_2$max scores (Kang *et al.,* 2001). While these protocols have some advantages over longer duration tests (greater than 20 minutes) such as achieving higher $\dot{V}O_2$max scores or the time-efficiency mentioned above, it is important to note that during short duration protocols (less than 12 minutes), exercise intensity must be increased at such a rate that steady state exercise cannot be achieved during each work stage. As such, the submaximal performance related variables, LT or RE, cannot be recorded. Therefore, in cases where these measures are required, the runner would need to visit the laboratory on additional occasions for appropriate tests. As the moderately trained runner is time (and often resource) constrained, this additional testing might not be feasible.

In cases where all performance ($\dot{V}O_2$max, LT/VT & RE) related variables are required, a protocol that uses longer work stages of 4 minutes is required to allow sufficient time for steady state to occur (Jones, 2006). A fixed gradient of 1% is also used throughout (Jones & Doust, 1996). During the exercise test, gas exchange is measured and $\dot{V}O_2$max is determined using the Fick principle. The Fick equation suggests that $\dot{V}O_2$max is the product of the $\dot{Q}$ and the difference between the arterial oxygen content (CaO_2) and the venous oxygen content ($CavO_2$). Therefore, gains in $\dot{V}O_2$max are attributed to enhanced $\dot{Q}$ and enhanced extraction of oxygen by

the exercising muscle (Spina *et al.*, 1996; Shephard, 1992). Adaptations in the heart (central factors), blood and skeletal muscle (peripheral factors) lead to increases in $\dot{Q}$ and the arterio-venous oxygen difference:

$\dot{V}O_2max = \dot{Q} (CaO_2 – CavO_2)$.

Maximal oxygen consumption is typically determined when a visible plateau in the participant's $\dot{V}O_2$ (< .05 $L \cdot min^{-1}$) is recorded, despite an increase in exercise intensity/velocity. However, as this plateau is not seen in up to 50% of participants (Howley *et al*, 1995), a secondary series of criteria is used to confirm that a true $\dot{V}O_2max$ has occurred. These criteria include:

- An RER of greater than 1.1
- the observation of an estimated maximum heart rate (HR)
- a bLa recording greater than $8mmol^{-1} \cdot L^{-1}$

In these cases the term $\dot{V}O_2$ peak is used to describe the data at termination.$\dot{V}O_2max$ is expressed relative to body weight ($mL \cdot kg^{-1} \cdot min^{-1}$) (Bassett & Howley, 2000). Since its introduction, $\dot{V}O_2max$ has become one of the key physiological parameters measured in the field of exercise physiology (Howley *et al.*, 1995). It is commonly used to: indicate the cardiorespiratory fitness or training status of individuals (Midgley, McNaughton & Wilkinson, 2006); to prescribe training for middle and long-distance runners (Brandon and Boileau, 1987; Pollock, 1977); to predict performance in events (Midgley *et al.*, 2006); and, in research, $\dot{V}O_2max$ is the most common method of demonstrating a training effect or performance change (Howley *et al.* 1995; Bassett *et al.* 2000). Inevitably, $\dot{V}O_2max$ will be one of the variables measured in the sample population of MTRs for this research, and comparisons will be made between the running performance of those participants conducting once or twice daily training.

Maximal oxygen consumption has been suggested by some (Helgerud *et al.*, 2007) to be the best predictor of endurance performance as it sets the upper limit for endurance performance. However, this view has been challenged as athletes with similar $\dot{V}O_2max$ do not necessarily perform equally well (Conley *et al.*, 1980; Costill *et al.*, 1970) and, in some cases, it has been

shown that a runner with a lower $\dot{V}O_2$max can out-perform an athlete with a higher $\dot{V}O_2$max by being able to sustain a higher percentage of their $\dot{V}O_2$max or being more economical with the use of O_2 (Sjodin & Svedenhag, 1985; Costill *et al.,* 1973). An example of note is that of Paula Radcliffe (reported by Jones, 2006) who reduced her $\dot{V}O_2$max but saw improvements in both her RE and LT, both of which will be discussed later in this chapter. As a result of these changes, Radcliffe's RP improved (Jones, 1998). In light of this evidence, a number of researchers are in agreement that, when compared with RE and LT, $\dot{V}O_2$max actually yields the lowest correlation with endurance performance in both trained and untrained individuals. (Conley and Krahenbuhl, 1980; Noakes *et al*., 1990; Stratton *et al*., 2009; Abad *et al.,* 2016).

It must be noted that these researchers are not attempting to suggest that $\dot{V}O_2$max is not an important variable but because theoretically $\dot{V}O_2$max sets the upper limit for an individual (Helgerud *et al., 2007*) its importance should not be over looked. However, as athletes struggle to sustain exercise above 100% of $\dot{V}O_2$max for longer than 10 minutes (Billat *et al*., 1994), and most endurance running events from 5 km upwards last longer than 20 minutes for the MTR, the ability of a runner to be able to maintain a high percentage of their $\dot{V}O_2$max (fractional capacity) for the duration of the event, coupled with their ability to resist fatigue (Hopker *et al*., 2017) in relation to the other two physiological parameters discussed later (LT/VT and RE) may be stronger predictors of RP (Saunders *et al.,* 2004).

2.4.2 Training to improve $\dot{V}O_2$max

Maximal oxygen consumption has been shown to be highly sensitive to training stimulus (Gibala, Little, MacDonald & Hawley, 2012; Laursen & Jenkins, 2002; Gibala & Jones, 2013; Gibala, Gillen & Percival, 2014). Maximal oxygen consumption tends to be higher for individuals during periods of competition when typically, a higher amount of HIIT is performed. As previously discussed, during the off-season when large volumes of LIT are performed (with little HIIT), $\dot{V}O_2$max has been shown to decrease by 4 - 5.8% (Tanaka et al., 1984; Svedenhag & Sjodin, 1985, Galbraith *et al.* 2014).

Gibala and McGee (2008) have defined HIIT as "repeated sessions of relatively brief intermittent exercise, often performed with an 'all-out' effort or at an intensity close to that which elicits VO2peak (i.e., =/>90 % of VO2peak)" (p.58). These may last from a few seconds to several minutes, with periods of rest or low-intensity exercise. The beneficial effects of HIIT on $\dot{V}O_2$max are well supported (Gibala, *et al*., 2012; Gibala *et al.,* 2012; Gibala *et al.,* 2014; Laursen & Jenkins, 2002; Costill, 1986; Acevedo *et al.,* 1989; Christensen *et al.,* 1960; Daniels *et al.,* 1984; Fox *et al.,* 1969; Miksell *et al.,* 1984; Billat *et al.,* 1999; Laffite *et al.,* 2003; Smith *et al.,* 1999; Smith *et al.,* 2003; Billat, 2001). However, how this HIIT is incorporated into a traiing plan is of critical importance as many athletes are prone to symptoms of overtraining as a result of HIIT (Billat *et al.,* 1999). Billat *et al.* (1999) reinforce this point showing that well trained runners attempting to include just three HIIT sessions per week for four weeks began to experience signs of overtraining through increased muscle soreness, reduced quality of sleep, upper respiratory infections and increased plasma norepinephrine levels. These authors went on to suggest that due to the increased stress imposed by HIIT, runners should include only one or two HIIT sessions per week with at least 48 hours' recovery separating sessions. Thus, for those runners seeking to improve their $\dot{V}O_2$max, the standard method of undertaking HIIT may be fraught with problems associated with fatigue and injury.

In comparison with HIIT, the research investigating the effects of LIT on $\dot{V}O_2$max is limited. Of the research that has been conducted there is evidence to suggest that LIT is more beneficial to $\dot{V}O_2$max in the untrained population than it is amongst trained individuals (Laursen, 2010). The improvements in $\dot{V}O_2$max seen within the untrained population conducting LIT have been attributed to an increased delivery of oxygen (central adaptation) with increased SV, $\dot{Q}$, PV and blood flow (Green *et al*., 1990; Green et al., 1987; Fritzsche & Coyle, 2000) and increased utilisation of O_2 by the working muscles (peripheral adaptations) through increased mitochondrial content and capacity (Holloszy & Coyle, 1984). Other adaptations to endurance training in this group include lower bLa levels at the same absolute workload (Green *et al*.,

1987; Green *et al*., 1990; Hurley *et al*., 1984) and a reduction in glucose and muscle glycogen utilisation, and thus an increase in estimated fat metabolised (Karlsson *et al*., 1974 Coggan *et al*., 1990; Stepto *et al*., 2002; Yeo *et al*., 2008). However, for the elite athlete it seems that LIT may not be as effective at improving $\dot{V}O_2$max: longitudinal studies of elite athletes suggest that $\dot{V}O_2$max changes very little as a consequence of LIT (Lucia 2002, Legaz-Arrese *et al*., 2005; Jones 2006). This, therefore, highlights clear differences between different levels of athlete. Although increases in $\dot{V}O_2$max in elite althletes may be limited, it is hypothesised by this researcher that increasing the volume of LIT in the foundational stage of the MTR's training plan could see a proportionately greater increase in $\dot{V}O_2$max and a subsequent improvement in running performance.

This assertion is not confirmed in the literature as there is (as yet), much less information available on MTRs than on elite athletes. However, Sjodin & Svedenhag (1985) made some interesting observations regarding the weekly kilometres run (57, 115 & 145) and $\dot{V}O_2$max levels between three groups of runners, slow runners, good and elite level, in the 10 weeks preceding a marathon. They concluded that LIT might have a saturation point of ~120km running distance per week, beyond which point no further improvements in $\dot{V}O_2$max are seen. As this statement was based upon observational research the authors were unable to offer a physiological explanation for this. Laursen & Jenkins (2002) are in agreement with Sjodin & Svedenhag (1985), however, they state that further research is needed to confirm this point. It should also be noted that $\dot{V}O_2$max was the only physiological variable used to investigate the possible effects of increased training volume undertaken through LIT on RP in the Sjodin & Svedenhag (1985) study, and it is now acknowledged that performance improvement can occur without a change in $\dot{V}O_2$max through changes in RE or LT/VT (Berg *et al*., 1995; Paavolainen *et al.,* 1999), furthermore, inverse association between $\dot{V}O_2$max and RE have been reported (Hopker *et al*., 2012; Shaw *et al*., 2015) and so it would be reasonable to hypothesize that an increase in LIT may still lead to improvements in RP and this would be particularly relevant to MTRs.

One study of note was that of Tanaka, Watanabe & Konishi (1986) who investigated the effects of a 33% increase in training volume from 90 to 120km per week in elite level runners and found an average 4.8% increase in $\dot{V}O_2$max. Although the running distance undertaken in this study did not extend beyond the 120km threshold suggested by Sjodin & Svedenhag (1985), it should be noted that the volume achieved by MTRs is unlikely to exceed this amount and likely to be within a range of 40-80 km per week (Walter *et al*., 1988; Hewson & Hopkins 1995), so it is possible that there may still be increases in $\dot{V}O_2$max if the running volume of a sample of MTR participants is increased. The aim of this thesis is not to see whether *increases* in training can improve $\dot{V}O_2$max but to see whether twice daily training can lead to improved running performance through factors such as $\dot{V}O_2$max.

While a large number of valuable studies into the effects of training on $\dot{V}O_2$max do exist, in many cases, closer examination reveals limitations in methodologies and testing protocols, which mean the results should be treated with caution. For example, many researchers who have attempted to demonstrate cause and effect have focused on HIIT or LIT in isolation, or, compared HIIT with LIT (Costill, 1986; Acevedo *et al.,* 1989; Christensen *et al.*, 1960; Daniels *et al.*, 1984; Fox *et al.*, 1969; Miksell *et al.*, 1984; Billat *et al.*, 1999; Laffite *et al.*, 2003; Smith *et al.*, 1999; Smith *et al.*, 2003; Billat, 2001). It is becoming more evident from research (Esteve-Lanao *et al*, 2005; Esteve-Lanao *et al*, 2007; Seiler *et al*, 2010) that a training plan might be more productive if it includes a mixture of intensities. Rather than comparing training intensities, it would seem that the more important question is how best to combine HIIT and LIT strategies – and one purpose of this thesis is to consider this. Tanaka *et al.* (1986) is one of the few studies that attempts to address this by including a portion of weekly HIIT, however, they failed to state pre-testing training status, therefore it is not known whether participants had participated in HIIT before the intervention and so adaptations could have been due to the HIIT rather than volume increases.

The limitations that have been highlighted in the $\dot{V}O_2$max studies reviewed in this section were considered in designing the methodology and experimental protocols followed in this thesis.

2.4.3 Lactate Threshold (LT)

Although $\dot{V}O_2$max theoretically sets the ceiling for how an athlete is able to perform, it is relatively weak in terms of differentiating the performance potential of individual runners in homogenous groups. In these cases, submaximal parameters such as the LT/VT is likely to better explain performance differences between runners, and help to predict performance more satisfactorily than $\dot{V}O_2$max scores alone (Sjodin & Svedenhag, 1985; Costill *et al*., 1973). Furthermore, when improvements to these thresholds are seen, typically, improved endurance performance is also achieved (Billat, 1996; Hawley *et al*., 1997; Jones, 2006; Tanaka, 1990).

Despite investigations into lactate dating back to 1907-1909 (Fletcher & Hopkins, 1907; Douglas & Haldane, 1909) debate continues surrounding universal terminology used, the methods that should be used to identify thresholds and the role that lactate contributes towards fatigue (Bangsbo & Juel, 2006; Lamb & Stephenson, 2006; Carins, 2006; Bourdon, 2000; Faude, Kindermann, Meyer, 2009). The two methods most commonly used to determine the lactate threshold are the fixed blood lactate (bLa) threshold, and the blood lactate curve method (Faude *et al*., 2009)

2.4.3 Fixed bLa threshold method

Obtained during a GXT, the fixed bLa threshold represents the velocity of the runner at which a predetermined fixed concentration of bLa occurs. While ranges in the fixed concentration used in the literature include 1mMol·L^{-1} (Yoshidaetal *et al*., 1987), 2.2mMol·L^{-1} (LaFontaine et al., 1981), 2.5 mMol·L^{-1} (Hurley et al., 1984) and 3 mMol·L^{-1} (Worms *et al*., 1985), the most widely used fixed concentration is 4 mMol·L^{-1} because it appears to be the highest bLa that is sustainable for a prolonged duration (~60 minutes) (Mader *et al*., 1976).

Despite its popularity (Kindermann *et al*., 1979; Sjodin and Jacobs, 1982) and high correlations to 5 km RP (r = 0.73 to -0.95 determined using the 4 $mMol{\cdot}L^{-1}$ marker) (Grant *et al*, 1997; Slattery *et al*., 2006), this method has been criticized by some to be an unreliable estimate of LT as it does not take into consideration the inter-individual differences in bLa. Furthermore, it has been shown that some athletes do not reach the point of 4 $mMol.L^{-1}$ even at the point of exhaustion in a GXT (Hagberg & Coyle, 1983), therefore, when using this method researchers are unable to determine LT.

These limitations prompted the development of more individualised methods such as the blood lactate curve method that are able to account for all individuals.

2.4.4 The blood lactate curve

As intensity of exercise is increased, a rise in bLa, VE and HR can be observed displaying a curve. When examining the bLa curve, two distinct markers can be observed. The first is the point at which there is a marked increase in bLa above resting levels and is referred to as the LT. Determined by using the bLa curve method, this has been shown to correlate to RP across a range of distances, including 3.2km (r = 0.91), 5 km (r = 0.91), 9.7km (r = 0.96), 15 km (r = 0.97), 19.3km (r = 0.97), and 42.2 km (r = 0.98) (Farrel *et al*., 1979; Forsyth *et al*., 2017). This reflects the point at which exercise intensity has increased to the degree that can no longer be fulfilled by aerobic metabolism, therefore, to compensate, anaerobic metabolism and the production of lactate begin to increase systematically from base line or resting levels (Kindermann *et al*., 1979).

The second is the point on the curve at which bLa begins to increase rapidly up to the point of $\dot{V}O_2max$ and represents a marked change in muscle metabolism. This point is referred to as the lactate turn point (LTP) or Anaerobic Threshold (AT). When using this method to assess endurance capacity, an improvement is achieved when a rightward shift of the lactate curve

(lower bLa at given workload) is reached through training (Yoshida *et al*., 1990; Bosquet *et al*., 2002).

The measurement of bLa is thus not without its limitations: first, factors known to affect readings include varying stage duration or work rate increments in the GXT. These can lead to differences in blood lactate curves and similarly, LT readings (Foxdal *et al*., 1994). Previous research (Williams, 1992) has shown that incremental protocols with stages of less than 3 minutes in duration result in non steady state conditions. It has been suggested during rapid increase protocols that lactate produced in the muscle does not have enough time to diffuse into the blood, leading to incorrect samples being recorded (Bentley *et al*., 2007).

Secondly, the sites of sampling (earlobe vs finger) may also have an impact on results. For example, samples taken from the fingertip are consistently higher in BLa than samples taken from the earlobe (Feliu, Ventura, Segura, Rodas, Riera, Estruch, Zamora, Capdevila, 1999; Moran, Prichard, Ansley, Howatson, 2012). Other factors affecting results can include the laboratory methods used to analyse bLa, muscle fibre type – fast or slow twitch, with fast twitch producing more bLa (Tanaka, 1990); and the nutritional status of an individual, with lower bLa seen in individuals at the same work rates when glycogen is depleted (through either diet or fatigue from exercise) compared with individuals in a non-depleted state (Cole, 2016; Jacobs, 1981).

Thirdly, the process of taking blood samples when running can be an invasive and challenging task (Loat & Rhodes, 2012) as the participant must stop running while the researcher takes a blood sample to record bLa, before increasing the runner's load or velocity and continuing the test programme. After this point the researcher is unable to collect any further samples at this load/velocity and can only store samples for a limited time.

As stated previously, although the extent to which lactate contributes towards fatigue remains a highly controversial issue (Carins, 2006; Bangsbo & Juel, 2006; Lamb & Stephenson, 2006), it

is widely acknowledged that the point at which lactate begins to accumulate in the blood, the LT, can be used in both the prediction of endurance performance and it can also act as a point at which to train (Tanaka & Matsuura, 1984; Tanaka, 1991; Heck, Mader, Hess, Mucke, Muller, Hollmann, 1985; Sjodin & Svedenhag, 1985; Londeree, 1997; Gaskill *et al*., 2001; Atkinson, Davison, Jeukendrup & Passfield, 2003; Jones, 2006; Faude, Kindermann, Meyer, 2009).

2.4.5 Ventilatory Threshold (VT)

In 1964, Wasserman and colleagues identified that the linear increase in bLa seen during a GXT was accompanied by a corresponding linear increase in ventilation (Wasserman *et al*., 1964). They went on to suggest that when using this less-invasive method involving the measurement of ventilatory gas exchange, a VT could be identified, and this point also represented the point of LT (Wasserman et al., 1973). As with LT, there have been multiple definitions and many variables used to identify the VT (Loat & Roads, 1993) including the ventilatory equivalent method and the v-slope method. Of these two, the more popular method is the ventilatory equivalent method, the linear increase in the ventilatory equivalent of O_2 (VE/O_2), without a concurrent rise in the ventilatory equivalent of CO_2 (VE/CO_2) (Loat & Rhodes, 1993).

Research has shown that, like LT, the velocities that can be sustained at VT are highly correlated ($r = -0.945$) with 5 km, 10 km and 10-mile race performance, compared with $r = -0.645$ for $\dot{V}O_2max$ (Kumagai, Tanaka, Matsuura, Matsuzaka, Hirakoba, Asano, 1982; Rhodes & McKenzie, 1984; Faude, Kindermann, Meyer, 2009). Furthermore, Rhodes & McKenzie, (1984) reported significantly high correlations ($r = -0.94$, $p < 0.0l$) between predicted and actual times, therefore allowing the investigators to relate laboratory performance to actual performance in the field. This method relies on the assumption that the hydrogen (H^+) ions of lactic acid are buffered by blood bicarbonate, which then leads to the production of excess CO_2 and increased expired minute ventilation (VE) (Beaver *et al*., 1986). Therefore, the point at which the initial rise in bLa occurs, the LT, coincides with the onset of hyperventilation (Caizzo *et al*, 1982; Davis *et al*, 1976; Ivy *et al*, 1980; Kumagai *et al*, 1982; Reinhard *et al*, 1979).

When using gas exchange, a second event can also be seen and is represented by a marked and sustained increase in the ventilatory equivalent of CO_2 (VE/CO_2), referred to as the second Ventilatory Threshold (VT2) (Myers & Ashley, 1997; Gaskill, Ruby, Walker, Sanchez, Serfass, & Leon, 2001).

While some suggest that as the identification of the VT1 or 2 requires visual inspection, different evaluators can choose different thresholds from the same data (Gladden *et al*., 1985; Yehet *et al*., 1983) and therefore this poses the potential for the identification of erroneous thresholds. In this research, attempts were made to reduce this type of error when identifying VT through incorporating into the protocol that three separate technicians must agree on the identification of the VT point.

2.4.6 Relationship between LT and VT

While the concept of a direct relationship between increases in ventilation and lactic acid production is strongly supported by some (Wasserman *et al*., 1973, 1981) and high correlations of 0.94 - 0.95 between LT and VT1 and 2 have been reported, giving weight to the suggestion that a direct relationship exists between LT and VT (Reinhard *et al*., 1979; Caiozzo et al., 1982; Hofmann *et al*., 1994; Lucia *et al*., 1999), there are some who suggest that LT and VT are independent variables and therefore VT should not be used to identify LT (Bosquet, Leger, Legros, 2002).

Evidence for this statement stems from patients with McArdle's disease, a glycogen storage disease where sufferers are unable to produce the muscle enzyme phosphorylase. As a consequence, they develop muscle discomfort and fatigue soon after starting to exercise. Although no lactic acid is produced in these individuals, they still experience a threshold-like ventilatory response during incremental exercise (Hagberg *et al*., 1982). However, these observations must be interpreted with caution as those with McArdle's disease are a unique group of sick people who do not represent the healthy population. Loat & Rhodes (1993)

suggested that it could be possible that individuals with McArdle's disease may exhibit a mechanism for ventilatory drive which compensates for the lack of blood acidosis.

Further evidence supporting the dissociation between LT and VT in response to different forms of training has also been reported. Hughes et al., (1982) demonstrated that the LT and VT could be manipulated independently of each other by cyclists altering their cadence between 90 rpm and 50 rpm.

Poole & Gaesser (1985) using untrained cyclists compared the response of continuous and interval training on LT and VT. Despite there being no significant difference in $\dot{V}O_2max$ they reported significantly greater increases ($p < 0.05$) in VT compared with LT when participants were interval training. They concluded that LT and VT should not be used interchangeably as indices of training adaptation. Although this provides valuable insight into the relationship between LT and VT it is important to note that Poole & Gaesser (1985) compared two types of training (continuous with interval). This researcher was unable to find any notable research that investigated the relationship between LT and VT when performing a mixture of training intensities. This seems surprising given that it is widely accepted that training plans should incorporate a mixture of training intensities. Furthermore, all participants in the research conducted by Poole & Gaesser (1985) were untrained, therefore, it would seem that further research is needed regarding this relationship in the MTR.

2.4.7 Training to improve thresholds

Like $\dot{V}O_2max$, the LT and VT, both appear to be highly sensitive to the stimulus of training, with reports of improvements to the VT of between 13-23% being achieved in just 8-10 weeks when a small portion of LIT (~20-30%) is replaced with HIIT (Yoshida *et al* ., 1981; Conley *et al*., 1984; Overend, Paterson, Cunningham, 1992; Mader, 1991; Weltman, Snead, Seip, Weltman, Rutt, & Ragol, 1990; Galbraith *et al*., 2014). The improvements seen in VT have been attributed to an increased delivery of oxygen (central adaptation), through increased stroke

volume (SV), cardiac output (Q̇), plasma volume (PV) and blood flow (Green et al., 1990; Green et al., 1987; Fritzsche & Coyle, 2000), and increased utilisation of oxygen at the working muscles (peripheral adaptations), through an increase in the number of mitochondria (mitochondrial density) and the efficiency of the mitochondria (mitochondrial capacity) (Holloszy & Coyle, 1984). It is hypothesized that this is due to the changes in training volume and intensity of the competitive athlete as they progress from the foundational to the speed stage of training (Hawley, 1995) (Fig.2.1). However, research suggests that both LT and VT might be even more sensitive to endurance training than $\dot{V}O_2max$: (Sjodin *et al.*, 1982; Yoshida, Suda, Takeuchi, 1982; Denis, Fouquet, Poty, Geyssant, Lacour, 1982). Yoshida et al, (1981) found that while participants saw a significant improvement in $\dot{V}O_2max$ of 14%, the participants saw greater gains in VT (17%) and LT (23%). Furthermore, improvements in RP of 6.8% were also reported.

Researchers investigating different training intensities have reported improvements of 10% in LT and VT emerging early on in endurance training programmes (Denis, Fouquet, Poty, Geyssant, Lacour, 1982; Smith, O'Donnell, 1984), and in some cases without a change in $\dot{V}O_2max$ (Sjodin, Jacobs, Svedenhag, 1982). This is because prolonged training at a threshold point promotes mitochondrial adaptations, which in turn shift threshold points to a higher training intensity. Furthermore, de-training studies have reported rapid declines in LT with reduced training intensity in previously endurance-trained subjects (Karvonen, Rauhala, Chwalbinska-Moneta, 1985). Thus when training is not performed at this threshold intensity, the threshold point reduces and occurs at a lower training intensity.

It appears that training at intensities close to, or slightly above, LT/VT may be effective in prompting improvements in performance in the untrained population (MacDougall & Sale, 1981; Tanaka, 1990; Carter, Jones, Doust, 1999; Henritze, Weltman, Schurrer, Barlow, 1985; Weltman, *et al.*, 1992, Sjodin *et al.*, 1982; Acavedo & Goldfarb, 1989; Tharp, Berg, Latin, Stuberg, 1997; Keith, Jacobs, McLellan, 1999). It must be acknowledged that some have reported no change (Lehmann, Dickhuth, Gendrisch, Lazar, Thum, Kaminski, Aramendi,

Peterke, Wieland, Keul, 1991) although this may have been due to inconsistent techniques or testing protocols. Amongst the research community the consensus remains that training at intensities close to, or slightly above LT/VT is effective in delivering improvements in performance.

The most recent review to date on the effects of varying training intensities on LT (Londeree, 1997) concluded that in support of previous research, training at an intensity corresponding to LT was effective in increasing LT in untrained runners, however, it was not effective for the trained runner for whom a higher training stimulus might be required. Londeree's review gives valuable insight into the differences between the untrained and the highly trained runner though further research is required to determine the effects of training at LT on the MTR for whom no noteworthy comparable research was found. Furthermore, caution should be exercised when interpreting current findings. It would seem that as with $\dot{V}O_2max$, there is little research investigating the effects of training plans incorporating a mixture of training intensities on VT and this demonstrates yet again the importance of the research on once vs twice daily training by MTRs conducted for this thesis.

The different methodologies employed in the research projects cited in the literature make valid comparisons difficult. For example, the Lehmann *et al.* (1991) study investigated the effects of overtraining on factors of endurance performance and so incorporated a 103% increase in training volume over a four-week period. Although this research is valuable in establishing limits to the amount runners should increase training, a comparison of the training intensity against normal volumes cannot be drawn. Research has shown that a 30% increase in training volume applied at a rate of 5-10% per week appears to be a manageable training increase (Tanaka *et al*., 1986). An effective volume increase to stimulate training and adaptation needs to be set. This has to be sufficient to improve performance but not be so excessive as to lead to overtraining, which could cause injury and illness.

2.4.8 Running Economy (RE)

The third of the three physiological parameters under review is RE. The importance of RE on an individual's performance has been known for over 40 years (Foster & Lucia, 2007) but in spite of this there is still a strong debate regarding the definitions of RE and also its value as a predictor of RP. The complexities surrounding the definition of RE are discussed next.

Definitions of RE are numerous and all too frequently RE is seen as a simple notion that reflects the energy demand of running at a constant submaximal velocity (Barnes & Kidling, 2015). Runners with good RE require less O_2 and require less energy to run at the same velocity than runners with poor RE at the same steady-state speed (Thomas, Fernhall & Granat, 1999). In reality, RE is far from this straightforward as it is an extremely complex multifactorial variable (Figure 2.2). There are multiple definitions of RE within the literature and as a consequence, misinterpretation and misunderstanding of its meaning. For example, it is possible to find definitions of RE that include the terms 'efficiency' (Goldspink, 1977) or 'energy cost' (Daniels, 1985). The term efficiency refers to the total ratio of work done to the energy expended, while energy cost refers to the sum of both aerobic and anaerobic metabolism. Neither of these terms should be used in connection with RE, as RE refers to the *submaximal* O_2 consumption at a given running velocity which represents *only* the aerobic proportion of the work being performed (Saunders, *et al*., 2004). In this piece of research, RE will be defined as the energy demand for a given velocity of steady state submaximal running (Saunders *et al.*, 2004). This definition of RE may be viewed as reductionist, however for purposes of clarity it is important in this case to focus on the definition of the term. In the following studies RE will be discussed in relation to other physiological variables and ultimately 5 km TT time to ensure the investigation remains relevant to the athlete and coach.

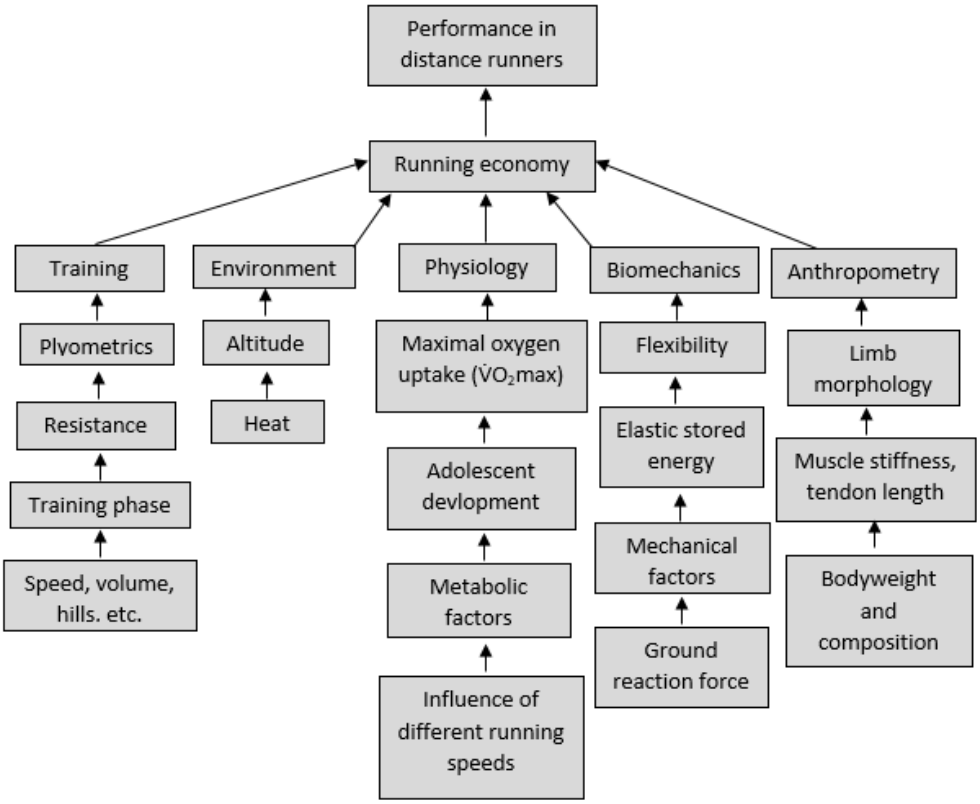


Figure 2.2. Factors affecting RE (adapted from Saunders et al., 2004)

The quantification of RE traditionally involves measuring the $\dot{V}O_2$ while running on a treadmill under standard environmental conditions, over a range of prolonged (4 – 10 minutes) steady-state submaximal velocities (Saunders et al., 2004). Four-minute stages are favoured as these allow steady state O_2 to be achieved at a number of velocities in one test with the average O_2 for the last minute of each stage being expressed relative to body mass (Morgan, Martin & Krahenbuhl, 1989; Fletcher, Esau, MacIntosh, 2009)

O_2 ($mL \cdot min^{-1}$) / Mass (kg)

And relative to velocity

O_2 (($mL \cdot kg \cdot min^{-1}$) / speed ($km \cdot h^{-1}$)/60) = $mL \cdot kg^{-1} \cdot min^{-1}$

As stated earlier, in homogenous groups of runners with similar $\dot{V}O_2max$ values, submaximal variables such as LT/VT and RE appear to be superior predictors of performance (Costill *et al*., 1973; Morgan *et al*., 1989; Saunders *et al*., 2004), although there are some who have reported that in the untrained-runner, RE may be a poor prediction of RP (Stratton *et al*., 2009; Tolfrey *et al*., 2009). This seemingly conflicting evidence for and against RE as a predictor of RP may be explained partly by the runners recruited. It is now widely accepted that clear biomechanical differences exist between trained and untrained runners with trained runners having less vertical oscillation and longer strides than untrained runners. This results in a more efficient use of oxygen and thus better RE by the trained runner (Cavanagh, Pollock, and Landa, 1971; Cavanagh & Williams, 1982).

2.4.9 Training to improve Running Economy

Unlike $\dot{V}O_2max$, LT and VT which are particularly responsive to HIIT training and can improve rapidly when including just two interval sessions per week (Billat, Flechet, Petit, 1999; Smith, McNaughton, Marshall, 1999; Smith, Coombes, Geraghty, 2003), the time course required to see improvements in RE can be far longer and require a diverse range of training methods (Berg, 2003).

While improvements of 5-8 % in RE in 8-10 weeks have been reported (Helgerud *et al*., 2007; More, Jones & Dixon, 2012), it is thought that gains in RE are due to physiological adaptions including increased SV, BV, mitochondrial enzyme activity and biomechanical variables such as improved storage and utilization of elastic energy; it seems that these early adaptations might be limited to the untrained runner (Cavagna, 1977; Sawka, Convertino, Eichner, Schnieder & Young, 2000; Tonkonogi, Walsh, Svensson, & Sahlin, 2000; More *et al*., 2012). Once runners become moderately or highly trained, further improvements in RE occur at much slower rates, generally after months to years of training with relatively high mileage performed at low intensity (Pate, Macera, Bailey, Bartou, Powell, 1995; Conley et al., 1984; Jones, 1998).

Indeed, longitudinal research supports the notion that, in general, improvements in RE are achieved in the long term (Svedenhag & Sjodin, 1985; Galbraith et al., 2014).

While improvements in RE have been achieved with HIIT training, for moderately or highly trained runners the research suggests that these gains are achieved when HIIT training is conducted either after or in combination with LIT, (Franch, Madsen, Djurhuus, & Pedersen, 1998; Billat *et al*., 1999; Denadai *et al*., 2006; Helgerud *et al*., 2007) suggesting that training at lower intensities such as velocity at VT or LT (vVT or vLT) is optimal to improve RE. When training at this lower intensity, central adaptations such as, SV, $\dot{Q}$, PV and blood flow (Green et al., 1990; Green et al., 1987; Fritzsche & Coyle, 2000), and peripheral adaptations such as an increase in the number of mitochondria (mitochondrial density), and the efficiency of the mitochondria (mitochondrial capacity) are seen (Holloszy & Coyle, 1984; Weltman, Snead, Seip, Weltman, Rutt, & Ragol, 1990; Mader, 1991; Overend, Paterson, Cunningham, 1992).

Furthermore, research has shown that exercise above the VT/LT is associated with a nonlinear increase in metabolic, respiratory and perceptual stress (Katch *et al*., 1978; Simon *et al*., 1983). Therefore, training at the VT/LT provides a high-quality aerobic training stimulus without the accumulation of lactate that could compromise training duration.

At present, research investigating the effects of LIT is limited and in many cases, small sample sizes and different methodologies adopted prevent meaningful comparisons from being drawn (Foster & Lucia, 2007; Midgley *et al*., 2007; Bishop, Granata & Eynon, 2014).

In recent years, research on RE has moved away from the more traditional approaches to training and now focuses on incorporating strength, plyometric training with run training (concurrent training) or altitude exposure to improve RE (Jung, 2003; Saunders *et al.*, 2004 Denadai, *et al*., 2016). Strength and plyometric training are effective through augmenting the stretch-shortening characteristics of the muscle or by increasing the stiffness of the muscle-tendon system reducing the amount of energy wasted in braking forces, while altitude exposure

enhances metabolic aspects of skeletal muscle, facilitating a more efficient use of oxygen (Foster & Lucia, 2007).

While these studies highlight the diverse ways in which it is possible to improve RE, the cost of equipment, the training required to perform complex movement patterns, the geographical locations and/or the facilities required might exclude many runners.

Furthermore, given the importance of acclimatising to time spent on LIT and as historically, elite athletes have devoted large percentages of their total training volume to LIT (Sellier & Kjerland 2006 Esteve-Lanao *et al*., 2005) it is surprising that the research investigating the effects of training at this intensity is so limited. This lack of research has prompted this researcher to investigate ways in which it is possible to include two different methods of increasing the volume of LIT, whilst incorporating a proportion of the runner's weekly training to HIIT, approaches which could be of benefit to the MTR.

2.5 Substrate Utilization

It has been known for many years that energy production during endurance exercise is fuelled predominantly by the oxidation of CHO and fat (Randel *et al*., 2016). The contribution that each of these substrates provides is influenced by exercise intensity, duration and substrate availability, (Spriet, 2014) and can be estimated through indirect calorimetry using the RER reflecting the $\dot{V}CO_2$ produced / $\dot{V}O_2$ consumed (see general methodology for a more detailed explanation).

In general, at low exercise intensities of between 40-65% $\dot{V}O_2$max there is a reciprocal relationship between CHO and fat oxidation (Spriet, 2014). However, as exercise intensity increases above 65% of $\dot{V}O_2$max the contribution from CHO increases while that from fat decreases (Brooks & Mercier, 2004; Coyle et al., 1997; Horowitz et al., 1997). At intensities greater than 85% $\dot{V}O_2$max, CHO becomes the main fuel source. This shift in substrate utilisation occurs because CHO oxidation is more economical in terms of ATP produced per

litre of oxygen combusted compared with fat oxidation (Cole *et al*., 2014). In the majority of endurance based running events (5 km to the marathon) exercise intensity is predominantly at near maximal pace (Tucker, 2014), therefore the ability to oxidise CHO is key to performance. Contrary to this, research has reported that, following periods of endurance training, increased rates of fat oxidation and reduced CHO oxidation can be seen by up to 41% at a range of submaximal intensities (Martin *et al*., 1993;) prompting suggestions (Holloszy, 1967; Noakes *et al*., 2014; Volek *et al*., 2015) that as fat stores are abundant in comparison with the finite CHO reserves, increasing the contribution of fat oxidation may preserve the CHO stores for periods of peak demand and should, in theory, improve performance.

Research has also shown that other methods of altering substrate oxidation, for example, the effects of adopting dietary strategies such as low CHO, high fat (LCHF) diets can increase the rates of fat oxidation and reduce CHO oxidation during exercise (Steptoe *et al*., 2002; Yeo *et al*., 2008). It seems that increased levels of fat oxidation achieved through such strategies may have beneficial effects on the runner's adaptive response through increased signalling in markers of metabolic adaptation, including increases in citrate synthase (CS), AMP-activated protein kinase (AMPK), calmodulin-dependent protein kinase (CaMPK), and peroxisome proliferator-activated receptor gamma coactivator 1-alpha (PGC-1α), all of which are known to play a role in mitochondrial biogenesis (Cox et al., 2010; Hulston *et al*., 2010). However, it also appears that an increase in fat oxidation (and thus a reduction in CHO oxidation) using nutritional methods can have detrimental effects on performance due to increased perception of effort.

Another method by which the body can become more metabolically flexible includes performing low intensity exercise. Similar to the mechanisms behind the dietary strategy discussed above, LIT has been shown to lead to increases in citrate synthase (CS), AMP-activated protein kinase (AMPK), calmodulin-dependent protein kinase (CaMPK), and peroxisome proliferator-activated receptor gamma coactivator 1-alpha (PGC-1α) (Laursen, 2010). This improves both insulin sensitivity, thus using blood glucose more effectively (Coen *et al*., 2015), and increasing the capacity for fatty acid oxidation during exercise (Jong Yeon *et*

al., 2002). This improved ability to respond or adapt to conditional changes in metabolic demand therefore results in greater metabolic flexibility.

As the ultimate goal of training is to stimulate physiological adaption then it is not the case that an athlete must rely solely on CHO *or* fat for energy production, instead the runner must be "metabolically flexible" defined as the ability to rapidly and efficiently utilize both CHO *and* fat (Burke, 2015). Therefore, a goal of the runner should be to periodise training appropriately to facilitate the adaptive response and increase levels of fat oxidation during submaximal sessions such as their weekly long run while increasing levels of CHO oxidation during HIIT sessions.

The ultimate goal of the MTR is to improve RP and coaches and researchers are constantly searching for new training techniques to maximise training adaptaton and thus performance, giving them the competitive edge. A method that has received widespread attention recently is training under conditions of low CHO availability, termed 'train low' (Jeukendrup, 2017) which involves substrate manipulation and two training sessions in a day on specified days. This is one of the few examples in the literature of the use of split training to improve endurance performance. The rationale for this training method stems from the suggestion that as both exercise and nutrition are known to enhance the transcriptional activation of some metabolic genes independently (Morton *et al.*, 2009; Hawley & Morton, 2014), exercising under conditions of low CHO might lead to greater activation of these genes compared with exercise under normal CHO conditions (Pilegaard *et al*., 2002).

Although various strategies have been used to achieve low muscle glycogen stores such as: Low-CHO high-fat or ketogenic diets (Phinney *et al*., 1983; Burke *et al*., 2000; Burke *et al.*, 2002; Burke & Hawley, 2002); reduced CHO availability during training (Morton *et al*., 2009; Hawley & Morton, 2014); training after an overnight fast (Van Proeyen *et al*., 2011; De Bock *et al*. 2005); or withholding CHO after an evening training session and then sleeping with low CHO (Lane *et al.*, 2015; Marquet *et al.*, 2015), a popular strategy has been to adopt a twice per day training protocol (Hansen *et al.*, 2005; Yeo *et al*., 2008; Croft *et al*., 2009; Hulston *et al*.,

2010; Ijichi *et al*., 2015). With this method, the first training session is used to deplete endogenous CHO. Then, after a short period (1-3 hours) a second training session is conducted under conditions of low endogenous and exogenous CHO.

The first to publish data on this method, Hansen *et al*. (2005), concluded that training twice every second day led to a greater increase in markers of metabolic adaptation compared with once daily training, and thus concluded that training twice daily was superior to once daily training. This study was conducted under the conditions of low CHO. However, the researchers were heavily criticized for their methodology which tested individuals simply kicking their legs and thus was not based on any real sporting performance, and use of untrained participants with suggestions that the research situation bore little resemblance to real world sporting application (Yeo *et al*., 2008; Hulston *et al*., 2010). More recently, interventions comparing the effects of twice daily training over once daily training have suggested that twice daily training results in a greater signalling response in markers of metabolic adaptation including increasing CS, AMPK, CaMPK and PGC-1α (Yeo et al., 2008; Cochran *et al*., 2015). Alterations in substrate use have also been seen with twice daily training, with increases in maximal rates of fat oxidation (MFO). It has been suggested that adaptations that favour fat metabolism may indirectly improve performance through the preservation of CHO stores. Twice daily training might, therefore, be a superior form of training (Yeo *et al*., 2008; Croft *et al*., 2009; Morton *et al*., 2009; Hulston *et al*., 2010; Ijichi *et al*., 2015).

Although increasing an athlete's ability to oxidise fat during exercise might seem an attractive method of enhancing RP, research has shown that the rate at which muscles are able to oxidise fat is not sufficient to support the work rates sustained by competitive athletes during running or cycling events lasting more than two hours (Williams *et al*., 1984; Jeukendrup, 2000; Spriet, 2007; Hawley & Leckey, 2015). Furthermore, research has also found that gains in fat oxidation can result in an inability to oxidise CHO (Stellingwerff *et al*., 2006), thus potentially limiting performance. Leckey *et al*. (2016) further highlighted the reliance on CHO during HIIT

demonstrating that blocking fatty acid availability artificially during exercise does not impair prolonged, continuous running to fatigue.

Until recently, a major limitation of the research into the train low approach to training was that it had been difficult to distinguish whether the training effects are due to the twice daily training or conducting the second training session under conditions of low glycogen. However, evidence is beginning to emerge that suggests that increases in PGC1-α, a known regulator of mitochondrial biogenesis, occurs irrespective of CHO availability, thus, improvements could be related to the twice daily training rather than the low CHO availability (Cochran *et al*., 2010; Bartlett *et al*., 2015; De Scouza, 2016).

2.6 The laboratory Environment

As a major motivating factor for the majority of runners is to improve their race times, interest has grown in using physiological tests conducted in the laboratory environment to help runners and coaches prescribe, monitor and evaluate the effects of training (Currell & Jeukendrup, 2008). Tests particularly popular with runners are those that closely mimic real-world race conditions such as completing a time trial (TT) on a treadmill in the shortest time possible, or tests that are used to predict how runners are likely to perform (in their current state of fitness) in a competitive environment; tests that help to guide the prescription of training programmes, and tests that track changes in training status over time (Currell & Jeukendrup, 2008).

Although the laboratory provides many methodological advantages as a testing ground such as the relative ease of repeating trials, the space required, and the ability to control for a range of environmental conditions including the speed and slope of intensities (Baur, Hirschmuller, Muller, Gollhofer, & Mayer, 2007), there are often questions over the ecological validity of laboratory based trials and their transferability into a field based competitive environment (Goulet, 2011). The term ‘ecological validity’ is increasingly encountered in the literature and in his thesis is taken to mean the extent to which the findings of a research study, conducted in a laboratory, are able to be transferred to a real-life, field based competitive environment (Goulet

2011). On this subject the literature is far from conclusive, for example, previous research has reported differences between laboratory and field cycling performances over a set distance (Jobson *et al.* 2007). These differences are attributed partially to body mass variance between participants in a non-weight bearing modality of exercise on a bike compared with an ergometer.

With regard to running, it must be acknowledged that in spite of the advantages of training in the laboratory, running on a treadmill is not the same as running outdoors: for instance, there are notably different responses by biomechanical (Anderson, 1996; Garcıa-Perez, Perez-Soriano, Llana-Belloch, Martınez-Nova, & Sanchez-Zuriaga, 2013), physiological (Pugh, 1970; Lavcanska *et al*., 2005; García-Péreza, Pérez-Sorianoa, Llana-Belloch, Lucas-Cuevasa & Sánchez-Zuriagab, 2014; Mooses *et al*., 2015) and psychological variables when athletes train indoors and outdoors (Kong, Norma, Candelaria, & Tomaka, 2008, Kong *et al*., 2012). For example, biomechanical differences include different muscle recruitment patterns on the treadmill leading to increased ventilation (physiological difference), and a higher rate of perceived exertion (RPE) at the same relative intensity (psychological difference).

The use of 5 km TT performed in the laboratory or outdoors to assess and monitor RP has become more frequent (O'Donnell & Driller, 2015) and has been used in a number of studies (Currell &Jeukendrup, 2008; Shabort *et al*., 1998; Stevens et al., 2015; Hurst & Board, 2013). While the 5 km TT has clear benefits in that it resembles the competition demands facing the runner, there appears to be a common assumption by researchers in the literature that a 5 km TT time recorded in the laboratory equates to the same time performed outdoors, though there is limited evidence to support this (Rosdahl *et al*., 2010). The assumption of equivalence ought to be closely questioned, not least because it seems that research comparing treadmill running with outdoor running has focused on sprint velocities rather than endurance running (Nummela *et al*., 2007; Morin & Seve, 2011). Sprinters and endurance runners are known to differ phenotypically, with sprinters possessing a greater proportion of fast twitch muscle fibres, whereas endurance runners have a higher proportion of slow twitch fibres (Maughan *et al*.,

1982). This piece of research therefore, questions the ecological validity of times recorded in the laboratory over 5 km and their transferability to 5km time performed outdoors.

The evidence for equivalence between performance in the laboratory and outdoors for endurance running performance is not conclusive. Therefore, it is argued that a comparison of measures in both laboratory and non-laboratory environments is warranted - and that is what this researcher has attempted in the Study 1 of this thesis.

The test most commonly used to assess the fitness of endurance runners (runners who compete over distances ranging from 5 km to the marathon) is a graded exercise test (GXT), carried out on a treadmill at a gradient of 1% (Jones & Doust, 1996) until the point of exhaustion (Jones, 2006). Although there are suggestions that a GXT does not mimic real-world race conditions and therefore may be of limited validity to the runner (Driller *et al*., 2016; Legaz-Arrese *et al*., 2011), this test does allow the assessment of many of the variables associated with performance in middle and long-distance races ($\dot{V}O_2$max, Peak Treadmill velocity (PTv,) LT/VT, and RE) under standardized conditions in a relatively short time (20-30minutes). These variables can then be used to predict RP. In addition, the GXT allows the identification of different training zones (vLT/vVT) and substrate utilization at a range of sub maximal intensities. As a consequence, the widely used GXT has been used to identify variables related to performance in this thesis.

2.7 Predicting Performance

Prediction equations are now used in many situations ranging from the early stages of talent identification and development (Reilly *et al*., 2000; Lidor *et al*., 2005; Spamer & Coetzee, 2002), to identifying which athletes are likely to develop injury or illness (Petrie & Falkstein, 1998). They are used in team based sports to predict which teams are likely to be successful based upon measures of cohesion and leadership (Bird, 2014), or to predict whether an athlete is likely to cope psychologically with the continual demands of training due to their personality, motivations and emotional state (Martin & Dubbert, 1982; Sallis *et al*., 1990).

As the numbers participating in road running races have grown significantly in recent years, interest in using variables commonly monitored in training to predict how a runner is likely to perform in a test environment or race has also grown (table 1) (Ogueta-Alday & Juan García-López, 2016). Variables in these equations include anthropometric measures, such as BMI, mass, sum of skinfolds or body fat percentage (Hagan *et al*., 1987; Hoffman, 2008; Knechtle *et al*., 2009; Zillmann *et al*., 2013; Arrese and Ostariz, 2006; Legaz and Eston, 2005; Zillmann *et al*., 2013); training characteristics, such as the number of years an individual has spent running; the training volume a runner is able to tolerate, the average velocity of training speed, (Bale *et al*., 1986; Billat *et al*., 2003; Hagan *et al*., 1981; Noakes, 1991; Houmard *et al*., 1991; Scott & Houmard, 1994; Roecker *et al*., 1998; Knechtle *et al*., 2011, 2014; Gómez-Molina *et al*., 2017), and physiological variables, such as $\dot{V}O_2$max, RE, LT/VT or the maximal velocity achieved in a GXT, also referred to as PTv (Roecker *et al*., 1998; Tolfrey *et al*., 2009).

Distance	TS	Predictors	R	Reference
2 miles	MT	vLT	.92	Tolfrey *et al*. 2009
3 km		vTS, v$\dot{V}O_2$max	.92	Bragada *et al*. 2011
5 km	NS	PTv, LT, BF, vLT	.95	Roecker *et al*. 1998
5 km	MT	vLT	.87	Haverty *et al*. 1988
5 km	UT	PTv & LT	.89, .73	Stratton *et al*. 2009
5 km	MT	VT & RE & PV	.74, .8, .92	Paavolainen *et al*. 1998
5 km	T	PTv	.9	Scott & Houmard 1994
5 km		O_2LT, Age, TV	.89	Takeshima & Tanaka, 1995
5 km		LT	.91	Forsyth *et al*., 2017
8 km		PTv	.76	Houmard *et al.* 1991
10 km		O_2LT, Age, TV	.82	Takeshima & Tanaka, 1995
10 km	MT	PTv, RE(12kph)	.83	Abad *et al.* 2016
10 km	NS	AT, PV, TV, AT, vLT	.94	Roecker *et al*. 1998
10km-marathon		PTv	.88-.94	Noakes *et al.* 1990
16 km		PTv	.89	McLaughlin *et al*. 2011
HM	NS	AT, TM, PV, HRmax, BF	.96	Roecker *et al*. 1998
HM		vTS, BF%	.89	Knechtle *et al*. 2014
HM		BMI, vTS	.66	Rust *et al*. 2011
HM	MT	PTv, vLT, YR	.94	Gómez-Molina *et al*. 2017
Marathon		O_2LT, Age, TV	.93	Takeshima & Tanaka, 1995
Marathon		VT	.94	Rhodes & McKenzie, 1984
Marathon		LT	.76	Lehmann *et al*. 1983
Marathon		MPT, vTS, TV, $\dot{V}O_2$max	.84	Hagan *et al*. 1981
Marathon	NS	AT, TM, Mass, $\dot{V}O_2$max	.95	Roecker *et al.* 1998

Table 2.3. Summary of research on existing prediction equations (Anthony 2017, unpublished)

AT = anaerobic threshold, LT= lactate threshold, vLT = velocity at lactate threshold, PTv = peak treadmill velocity, PV= plasma volume, VT = Ventilatory threshold, vTS = velocity of training speed, O_2LT = O_2 at lactate threshold, RE = running economy, RE12= running economy at 12km·h^{-1}, BF = body fat %, YR = years running, TV= training volume, HRmax= maximal heart rate, MPT= marathon performance time, TM = Training mileage, TS = Training status, NS = not stated, MT = Moderately trained, UT = Untrained, T = Trained.

The degree to which each variable contributes to performance, and the decision to include it in a prediction equation is, in theory, dictated by the length and the duration of the event (Morgan *et al*., 1989; Pate *et al*., 1992; Saunders *et al*., 2004). As differences in anthropometric and training characteristics have been reported between runners of differing competition distances (Roecker *et al*., 1998; Zillmann *et al*., 2013), so equations developed for one distance such as a half marathon are not applicable for runners competing over a 5 km event. Furthermore, while investigation into predicting performance has covered a range of events from two miles to the marathon, it seems from the literature that methodological limitations and differing methods used to collect performance variables have prevented robust equations from being developed.

Furthermore, most of the research reviewed has been conducted on male runners and thus there is a clear gender bias in the available evidence. This is deemed acceptable in this context as this study is also conducted on male runners for reasons explained in the General Methodology (Chapter 3), so the literature reviewed remains relevant.

Having said this, the literature reviewed has not always been helpful to the researcher:: methodological limitations include single tests undertaken prior to a performance test or race (Haverty *et al*., 1988; Roecker *et al*., 1998) - in some cases months after initial data collections (Roecker *et al*., 1998; Takeshima & Tanaka, 1995); the use of the same participants in a test re-test design and failure to validate the equations used on a separate sample of runners (Stratton *et al*., 2009; Paavolainen *et al*., 1998). Failure to report nutritional status prior to testing is yet another example of a methodological limitation which has prevented the creation of strong and reliable equations.

It is also of importance to note that all of the above-mentioned research has *either* used outdoor 5 km TTs (Haverty *et al*., 1988; Takeshima & Tanaka, 1995; Roecker *et al*., 1998; Paavolainen *et al*., 1999) *or* laboratory based 5 km TTs (Stratton *et al*., 2009; Scott & Houmard 1994). And of those using outdoor TTs, two used self-reported race times (Takeshima & Tanaka, 1995; Roecker *et al*., 1998), which lead one to further question the data. To date, no known research

has attempted to assess the relationship between performance variables in *both* outdoor *and* laboratory 5 km TT performance. Therefore, it is not known whether predictions developed for one environment (i.e. the laboratory) are suitable for the other (outdoors). In Study 1 of this thesis the researcher, using prediction equations, explores the relationship between indoor and outdoor performance and thus makes a contribution to a known gap in the literature.

The lack of both consistency and detail on data collection in the literature are also of key importance. In the research reviewed, rarely is sufficient detail given as to how performance data were collected. And where details were provided there were notable differences in the methods used to collect performance variables, one example being the gradient used. Traditionally, when running on a treadmill a gradient of 1% is used to account for the lack of wind resistance experienced outdoors (Jones & Doust, 1996), however, while some researchers (Stratton et al., 2009; Paavolainen *et al*., 1998) have followed the recommended 1% gradient, research conducted prior to that of Jones and Doust (1996) was often conducted with the gradient at 0% (Haverty et al., 1988; Scott & Houmard 1994) or 2% gradients (Roecker *et al*., 1998).

In some cases, work stages of less than three minutes were used during the GXT (Haverty *et al*., 1988; Scott & Houmard 1994; Stratton *et al*., 2009). Although shorter work stages can be used in testing when only a $\dot{V}O_2max$ value is required, when data on additional submaximal variables such as LT/VT and RE are needed, it is essential that three to four minute stages are used to achieve steady state exercise (Jones, 2006). Therefore, in cases where shorter work stages are used, steady state is not achieved and submaximal variables such as LT/VT or rates of substrate oxidation cannot be quantified.

Regarding the best predictors for RP (Table 1), variables expressed to velocity, such as peak PTv, velocity at lactate threshold (vLT) or velocity at ventilatory threshold (vVT) yield stronger relationships than variables expressed as O_2 ($\dot{V}O_2max$, RE or LT). This has been attributed to high inter-individual differences in running economy between participants (Cavanagh and

Kram, 1982; Havery *et al*., 1988). Although using predictive equations that favour variables expressed to velocity may seem an attractive option due to the relative ease of testing and lack of equipment required compared with O_2 related variables, they do not allow the researcher to identify the runner's limiting physiological determinants. Given that the optimal stimuli to improve each of the determinants of endurance performance ($\dot{V}O_2$max, RE and LT) may be different for each runner (Gorostiaga *et al*., 1991; Midgley *et al*., 2006; Milanović *et al*., 2015), creating a training plan based upon testing without the inclusion of physiological variables would essentially result in a trial and error approach to training.

Prediction equations which include physiological variables that allow the user firstly, to predict the athlete's current performance, and then allow them to prescribe training based upon the athlete's limiting physiological factors would be of far higher value. As this research is concerned with investigating how physiological variables of a specific group of runners (MTRs) change with two different forms of training it is vital that these measures are collected. And as they have been collected for this piece of research the author has confidence in his prediction of running performance.

2.8 Development of Research Questions

The material reviewed in the literature relating to RP brings the researcher to the overarching question of what effect splitting the weekly long training run into two equal parts will have on the running performance of MTRs. In order to investigate this the research has been broken down into three parts:

Study 1

Study 1 aims to provide context for studies 2 and 3 in terms of "real-world" improvements to running associated with improvements seen in the laboratory. In other words, study 1 examines whether improvements in running times observed in the laboratory equate to the same running times over 5km in an outdoor race environment, with the latter being what most runners are

keen to achieve. Thus before starting studies 2 and 3, which focus on differences in performance between once and twice daily training, study 1 investigates differences in indoor and outdoor running performance.

As a product of investigating whether running performance differs when running indoors and outdoors, an equation to predict 5km running performance was created.This was an additional output of study 1. As tests were performed both indoors and outdoors, the data collected was able to determine whether a single prediction equation for both environments was sufficient or whether separate prediction equations were needed. The prediction equations will provide a useful training tool for runners enabling them to identify whether they have responded to training after a period of time by performing a graded exercise test rather than a 5km time trial. The former is considered an easier form of exercise when compared with the latter and so provides an easier way for MTRs to gauge their progress.

2.8.1 Research questions for Study 1:

1.1 Are there significant differences in the running performance of a sample of moderately trained runners when they run indoors and outdoors over a distance of 5 km?

1.2 Can indoor and outdoor running performance be predicted from the same physiological variables?

Study 2

Study 2 investigates differences in running performance following a single session of training, compared with two single sessions within the same day (or twice daily training). In this study both groups are tested in an acute setting, this being a one-off test without a pre/post testing design. This is done to provide justification for Study 3 which will extend this line of enquiry to examine differences in the two groups following a six week training intervention.

2.8.2 Research question for Study 2:

2.1 Are there significant differences in selected physiological variables between the runners when a long, low intensity training session is run continuously, or is split into two sessions of equal length, and separated by 6-8 hours?

Study 3

Similar to study 2, study 3 investigates differences in running performance when performing one single session of training compared with two single sessions within the same day (or twice daily training). However, this study differs from study 2 in that runners were required to conduct this type of training for a six week period as part of a training intervention. Markers for running performance could then be compared pre and post training intervention to assess how once or twice daily training influences running performance when conducted in a chronic setting (or over a longer period of time). Study 2 examined this but in an acute or one-off setting.

2.8.3 Research Questions for Study 3:

3.1 Is there a significant difference in running performance over a distance of 5 km between two sample groups of moderately trained runners, one group having split their long weekly training run into two parts over a period of six weeks, and the other group having completed the long training run in one continuous session, also over a period of 6 weeks?

3.2 Can changes in physiological variables (defined in Study 1) be used to predict changes in running performance?

Before embarking on the analyses of the research questions above, the researcher now presents, in Chapter 3, the Methodology used in data collection.

Chapter 3 - General Methodology

This chapter provides an overview of all parts of the data collection and testing process that are common to each phase of the investigation. They range from participant recruitment and familiarisation, to test environment control, to the procedures followed in the collection of specific measurements. The methods used draw upon verified techniques indicated in the Literature Review (Chapter 2). At all times product specifications and instructions were carefully followed to ensure the accurate use of complex equipment. Before moving on to participant recruitment, a brief account is given of the research paradigm followed by the researcher:

This research is based within the scientific paradigm that is closely aligned with positivism (Cohen et al., 2007). Within positivism, the scientific paradigm which was originally used to study the natural world is applied to the social world.

The positivist ontology is one of realism, where objects have an existence that is independent of the researcher, and thus the researcher is able to discover a reality without influencing that reality. The epistemological position is one of objectivism, believing it is possible for a researcher to discover absolute, value-free, knowledge or truths. Thus positivist statements can be factual and tend to be founded on quantitative data (House, 1991).

In relation to positivist research methods, these aim to explain relationships and identify cause and effect. When data and methods fulfil specific laws, findings can be the basis for prediction and generalisation. A deductive approach is used to simplify complex phenomena to their component parts. Evidence is sought through collecting data via empirical testing, randomisation in sampling and controlling for variables. Meeting these high standards fulfil criteria for true-experiments. These true-experiments are value-free and thus the knowledge generated is value-free.

An important component in some scientific research relates to blinding experiments; ideally, double blind experiments where neither the researcher nor the participants know all details about the experiment. This is designed to separate researchers and participants from the experiment and therefore eliminate intentional or subconscious bias.

There are, however, limitations associated with positivism. These may arise when using methods that were originally developed to understand the natural world and applying them to the social world. Positivism attempts to reduce complex interactions to their constituent parts, however, this can be very difficult to achieve in reality and isolating variables can be difficult. For example, in a long term training intervention such as in this research, many contextual variables, unknown to the researcher will exist. These may include real-life events such as participants' work and family stresses, illness (such as headaches) and participants' natural levels of motivation. Although processes of randomisation argue that these unknown variables will be equally distributed between the treatment and non-treatment group, they may occur by chance at a higher frequency in one than the other.

It is also difficult to achieve standards of 'blindness' in a long term study as information about the study can 'leak' to participants. In this research, a research team of one (me) meant it was not possible to undertake a double-blind study where both researcher and participants were unaware of the experiment and possible outcomes. Therefore, in the case of this research the background of the researcher (me) may have influenced the study design. For example, having been a long distance runner for a number of years, I find weekly training plans of 15 hours a week manageable. As a result the training plans prescribed under this study appeared achievable to me; yet many of the participants found it to be a gruelling regime. It could also be argued that unintentional and subconscious researcher bias may have been present in this study. I have conducted twice daily training as part of my routine for a number of years and I feel it does improve my performance, therefore it is possible I wanted this group to perform better to prove my own hypothesis. Although this must be acknowledged as possible, I was careful to maintain rigorous standards throughout. Under the positivist approach, I followed closely pre-formulated

methods which yield commonly accepted results in order to achieve these high standards of rigour.

3.1 Participant Recruitment

All participants were recruited on a voluntary basis. Information was posted on local running club websites and forums; as a seasoned runner I both knew of most of the clubs and was well known in them. Runners who displayed an interest and fulfilled the participant criteria for the study in question were sent a participant information pack containing a copy of the participant information sheet (Appendix 1), a general health and fitness questionnaire (Appendix 2) and a consent form (Appendix 3).

Participant criteria

- Must be between the age of 18-55 years.
- Must have been running regularly for a minimum of one year.
- Must have completed a 5 km race in under 18 minutes (for Study 1).
- Must have completed at least 5 hours' running per week in the three months prior to the study (for Study 2).
- Have no medical condition that will impair their ability to perform all tests.
- Have no known heart conditions or diabetes.
- Must not have been diagnosed with metabolic syndrome.
- Must be a non-smoker.
- Must not be using any performance enhancing substances for the duration of testing.

All those who volunteered were interviewed by the researcher to confirm whether or not they were appropriate participants for the research.

3.2 Informed Consent & Ethical Approval

Each participant was provided with a full, written explanation of testing procedures (see participant information pack in Appendix 1) stating the full inclusion and exclusion criteria for the study in question as well as screening for any potential health issues that might exclude them from the study in question. Further to this, all procedures were clearly demonstrated to each participant (individually) on the day of their first visit to the laboratory, before the first testing commenced, so that they were familiar with protocols. Participants were required to complete a health and fitness questionnaire (see Appendix 2) and a health screening (see appendix 3) prior to all testing and gave their written informed consent to participate in the study. In addition, all participants were informed that they were free to withdraw from the study in question at any time, should they wish to do so. Finally, all studies and procedures were formally approved by the Faculty Research Ethics Committee at Canterbury Christ Church University.

3.3 Pre-testing Controls

Prior to each visit, participants were asked to refrain from strenuous exercise for 48 hours, caffeine for 24 hours and to arrive in a fully rested and hydrated state (Fricker & Fallon, 2000). Caffeine was restricted as research has demonstrated that caffeine ingested prior to (Graham et al., 1995; Doherty & Smith, 2004; Giano et al., 2009) and during (Cox *et al.,* 2002) prolonged sub-maximal and high intensity exercise can improve performance, through its ability to act as an adenosine receptor antagonist to induce effects on both central and peripheral nervous system, improve motor recruitment (Tarnopolsky, 2008) to reduce pain and perception of effort (Doherty & Smith, 2005), and excitation-contraction coupling (Mohr *et al.*, 2011).

3.4 Control of Laboratory Environmental Conditions

All testing undertaken in the Human Performance Laboratory at Canterbury Christ Church University was conducted under the same environmental conditions. Ambient temperature was maintained between 18-23°c via the use of an air conditioning unit and, along with relative

humidity <70% (Withers Gore, Gass, Hahn, 2000), was recorded for each testing session (RS TH07, SLS. Nottingham, UK). Additionally, barometric pressure was noted at the start of each test (F.D. & Co. Ltd. Watford, UK). In the field, environment (air) temperature, humidity and barometric pressure were recorded immediately prior to testing

3.5 Outdoor Conditions

During all outdoor experimental trials, care was taken to ensure that environmental conditions such as temperature, humidity, wind speed and direction were recorded as suggested by Sunders et al. (2004) the mean ambient temperature for all trials was 19.9 ± 1.4°c, mean relative humidity was 60.3 ± 10.2 % and mean air speed was recorded as 1.79 ± 0.2 $m.s^{-1}$

3.6 Measurement of Height and Body Mass

Prior to each testing session, the athlete's height was measured using the Frankfort plane method, to within ±0.5 cm using a Stadiometer (Seca 220, Hamburg, Germany). In addition, body mass was measured to an accuracy of ±0.1kg via balance-beam scales (Seca 761, Hamburg, Germany) whilst the participant was wearing their running vest and shorts.

3.7 Skinfold measurement

Body composition was monitored using the sum of skinfolds from the following sites: Bicep, Triceps, Subscapular, supra spinale, iliac crest, abdominal, front thigh and medial calf. Collectively these eight sites are recommended for male athletes (Norton et al., 2000). Because inter-tester variability is a major source of error in skin-fold measurements all measurements were taken on the right side of the participants by the researcher who is a trained Level 2 Anthropometrist (International Society for the Advancement of Kinanthropometry, [ISAK]). Under these conditions skinfold measurement has been shown to have high test re-test correlations (r=0.95) (Knechtle, Knechtle and Rosemann, 2011).

All sites were marked with a cross, with measurements taken by using the thumb and index finger perpendicular to the skinfold site halfway between the crest and base of the fold (Norton

et al., 2000; Knechtle *et al*, 2011). The skinfold callipers (Harpenden Skinfold Callipers, Baty International, West Sussex, UK) were applied 10 mm inferior to the centre of the cross and recorded after two seconds with dial graduation of 0.2 mm and compressibility of 10 gms/mm2. Each site was taken in rotation and then repeated. If the second measurement differed by more than ± 5 %, a third measure was taken. An average was used for the two measures and a median if three measures were recorded. The Callipers were calibrated before testing began.

3.8 Measurement of respiratory gases

The measurement of O_2 uptake ($\dot{V}O_2$, $L \cdot min^{-1}$), carbon dioxide production ($\dot{V}CO_2$, $L \cdot min^{-1}$) and respiratory exchange ratio (RER) were achieved using two breath-by-breath indirect calorimetry devices; an Oxycon Mobile, a portable device consisting of two small modules (Jäeger, Carefusion, Hoechberg, Germany) was used for study 1 as both Laboratory and field testing was conducted. As studies 2 and 3 were laboratory-based tests, an Oxycon Pro (Jäeger, Carefusion, Hoechberg, Germany) metabolic cart system was used.

The main difference between the two devices is that the Oxycon Pro uses the paramagnetic principle and infrared absorption method for $\dot{V}O_2$ and $\dot{V}CO_2$ measurements respectively, whereas the Oxycon Mobile uses an electrochemical cell for $\dot{V}O_2$ and thermal conductivity for $\dot{V}CO_2$ (Diaz et al., 2008).

Both devices were given the recommended 30-minute warm-up period with temperature, humidity and barometric pressure manually entered into the software package before being calibrated with certified calibration gas mixtures (Oxycon Pro: 5 % CO_2, 14 % O_2 and 81 % N2, Oxycon Mobile: 5 % CO2, 16 % O2 and 79 % N2). Volume calibration was achieved with a three-litre syringe (Carefusion, Hoechberg, Germany). The facemask was connected to the skin of the participant with appropriate head equipment and care was taken to ensure there was no leakage of air.

The Oxycon Mobile modules were attached to the backs of the participants with the supplied harness, with live data being transmitted telemetrically while simultaneously recording data on to a memory card. All data was recorded breath-by-breath and averaged over 10 second intervals. The Oxycon Pro had been validated previously against the gold standard Douglas bag method (Rietjens, Kuipers, Kester and Keizer, 2001; Carter and Jeukendrup, 2002). The Oxycon Mobile had also been validated against the Douglas bag method (Rosdahl, Gullstrand, Salier-Eriksson, Johansson and Schantz, 2010) as well as against the Oxycon Pro, with $\dot{V}O_2$ and $\dot{V}CO_2$ reported to be similar during steady state exercise (Perret and Mueller, 2006). Intraclass correlations of ~0.8-0.9 have been reported when comparing devices, with no significant differences reported (Akkermans, Sillen Wouters & Spruit, 2012).

3.9 Indirect calorimetry calculations

As energy expenditure is dependent on oxygen consumption, researchers must capture this in one of two ways. The first method, direct calorimetry, measures oxygen consumption directly at the muscles, through invasive methods such as a biopsy, this is known as the Respiratory Quotient (RQ) (McArdle *et.al,* 2007). The second method, indirect calorimetry is less invasive and measures O_2 consumption at the lungs and is known as the RER. Both of these methods are described below.

3.10 Respiratory Quotient (RQ)

CHO and fats and are substrates utilized for energy (ATP) production. Differences in the chemical structure of these molecules mean that they require differing amounts of oxygen for complete oxidation. As a result, the amount of CO_2 produced will vary depending on the relative contribution of each substrate (McArdle et.al, 2007).

The Respiratory Quotient (RQ) is the result of CO_2 produced within the muscle divided by O_2 consumed. Once captured, this measure enables researchers to determine which substrates (CHO or fat) are being metabolised during rest and exercise (Gropper *et.al*, 2009).

3.9.1 CHO RQ

The complete oxidation of one glucose molecule ($C_6H_{12}O_6$) requires six molecules of oxygen and produces six molecules of carbon dioxide and six molecules of water, thus the RQ equates to an RQ reading of 1.00

$C_6H_{12}O_6 + 6\ O_2 = 6\ CO_2 + 6\ H_2O$

$RQ = 6\ CO_2 / 6\ O_2 = 1.00$

Therefore, if an individual has an RQ of 1.00 the assumption is that CHO is the sole provider for energy production (McArdle *et.al,* 2007)

3.9.2 Fat RQ

The molecular structure of fat differs from CHO in that it contains more carbon and hydrogen atoms that oxygen. As a result, this fuel source requires a greater amount of Oxygen to fully oxidise.

For example, the typical fatty acid palmitic acid has a chemical structure of $C_{16}H_{32}O_2$ thus to oxidise this fuel source 23 molecules of oxygen are required. During oxidation 16 molecules of carbon dioxide are produced resulting in an RQ value of 0.696 (16/23 = 0.696)

$C_{16}H_{32}O_2 + 23\ O_2 = 16\ CO_2 + 16\ H_2O$

$RQ = 16\ CO_2 / 23\ O_2 = 0.696$

The typical RQ value for fat metabolism is generally around 0.7±03 depending on the length of the fatty acid chain being metabolised. Therefore, when values of 0.7 are observed it is assumed that the majority of the contribution of energy is from fat sources (Gropper *et.al,* 2009).

3.11 Respiratory Exchange Ratio (RER)

The RER (measured through pulmonary gas exchange) provides a less invasive method to establish the relative contribution of each macronutrient in energy production to that of RQ.

However, this method relies on one major assumption that the exchange of CO_2 and O_2 in the lungs is a representation of the exchange at the muscular level (Whipp & Wasserman, 1972). Furthermore, the RER can only assume an equivalent of RQ during steady-state exercise of 2-4 minutes to allow time for both $\dot{V}O_2$ $\dot{V}CO_2$ components to equilibrate (Whipp & Wasserman, 1972). Due to its less invasive nature RER was used over the RQ method throughout this research.

3.12 Determination of $\dot{V}$O2max/ $\dot{V}$O2 peak

Maximal oxygen consumption is typically determined when a visible plateau in the participant's $\dot{V}O_2$ (< 0.05 $L \cdot min^{-1}$) is recorded, despite an increase in exercise intensity/velocity. However, as this plateau is not seen in up to 50% of participants a secondary series of criteria were used to confirm that a true $\dot{V}O_2$max has occurred. These criteria include:

1) an RER of greater than 1.1
2) the recording of an estimated max HR
3) a blood lactate recording greater than $8mMol^{-1}$

When these criteria are met the term $\dot{V}O_2$peak can also be used (Edvardsen *et al.*, 2014).

3.13 Identification of Ventilatory thresholds

Identification of ventilatory thresholds was established using the ventilatory equivalent method. VT1 was identified by visual inspection as the point at which there was a linear increase in VE/O_2 without an increase in VE/CO_2 while VT2 was identified as the point at which there was a marked increase in the ventilatory equivalent of CO_2 (VE/CO2). When agreement on the identification of thresholds was not reached between the two independent observers a third observer was used and the average was point was used (Wasserman *et al.*, 1981).

3.14 Determination of Running Economy (RE)

Running economy was assessed over a range of prolonged steady-state submaximal velocities (4 – 10 minutes) (Saunders *et al.*, 2004) with the average $\dot{V}O_2$ for the last minute of each stage being expressed relative to body mass (Fletcher, Esau, MacIntosh, 2009).

$$\dot{V}O_2 ((mL \cdot min^{-1}) / Mass (kg) = mL \cdot kg \cdot min^{-1}$$

And relative to velocity

$$\dot{V}O_2 ((mL \cdot kg \cdot min^{-1}) / speed (km \cdot h^{-1})/60) = mL \cdot kg \cdot km^{-1}$$

Under conditions where confounding variables to RE such as the testing of environmental conditions, testing equipment, footwear, time of day of testing, running experience (Morgan *et al*., 1991; Pereira et al, 1994; Pereira *et al*., 1997; Saunders *et al*., 2004; Fuller, Bellenger, Thewlis, Tsiros & Buckley, 2015), training conducted and the nutritional status in the run up to testing are controlled, the intra-individual variation (typical error) in RE has been shown to fall within 1.3-5% at speeds between 12 – 18$km \cdot h^{-1}$ (Williams *et al.*, 1991; Brisswalter & Legros, 1994; Morgan *et al*., 1994; Saunders *et al.*, 2004).

In an attempt to control these variables, participants performed their pre and post intervention test sessions at the same time of day and in the same brand and model of running shoe. Participants were also asked to complete a food diary for the three days preceding each test and were asked to ensure that their post intervention food consumption was as similar as possible to the pre-intervention test. The volume each runner performed throughout the training intervention was also prescribed by the researcher who ensured that all participants achieved the same % volume increase in the initial three weeks of training.

3.15 Blood sampling procedure

Prior to sampling, each site was prepared to ensure reliable and valid blood collection. To achieve this the area of the participant's skin was cleaned using an alcoholic sterile wipe in order to remove any sweat or dirt that may have contaminated the sample. Once the alcohol had

evaporated (after a few seconds), the skin was pierced using a single-use disposable lancet (Accu-Check Safe T Plus). The first drop of blood was discarded (Tanner *et al.*, 2010).

3.14.1 Measurement of blood lactate

Whole blood lactate concentrations were analysed immediately after collection using a Lactate Pro LT-1710 blood lactate analyser (Arkray Inc. Kyoto, Japan). An analyser calibration strip was inserted prior to each use and a second calibration strip specific to the ones used for measurement was also inserted to ensure correct functioning of the analyser. Once prepared, a 5µl sample of blood was drawn into a measuring strip and plasma lactate concentration was recorded after 60 seconds. This method has previously been shown to be a simple, reliable and accurate method of assessing plasma lactate concentrations in field and laboratory environments (r=0.99: Pyne *et al*., 2000; Mean CV=5.7%: McNaughton *et al*., 2002; Mean r=0.93: Tanner *et al*., 2010). After collection and analysis all measuring strips and blood samples were destroyed via secure incineration.

3.14.2 Identification of blood markers

The lactate threshold was determined by visual inspection as the point preceding a 1 $mMol \cdot L^{-1}$ rise in lactate from the preceding work stage while LTP was accepted as the point at which a second distinctive rise in [bLa] occurred above baseline values (Spurway & Jones, 2007). When agreement on the identification of thresholds was not reached between the two independent observers a third observer was used and the average was point was used (Wasserman *et al*., 1981).

3.16 Measurement of heart rate

During each testing session, each participant's heart rate was recorded at five seconds intervals via close-range telemetry using a Polar S725X heart rate monitor (Polar, Kempele, Finland). Prior to testing, the heart rate strap was moistened to ensure good contact with the skin and

positioned on the participant's chest as per the manufacturer's guidelines (Polar, Kempele, Finland).

3.17 Graded Exercise Test (GXT) procedure

Before completing the graded exercise test all participants completed a ten minute warm-up on the same motorised treadmill (Woodway, ELG 70/250 sport), calibrated to the manufacturer's instructions and adjusted to a 1% gradient (Jones & Doust, 1996).

The purpose of this test was to determine the participant's maximal aerobic capacity. The test began at a low intensity calculated from the participant's 5 km race time (Jones, 2006). Each stage was four minutes in duration to allow steady state exercise to occur before increasing by 1 $km \cdot h^{-1}$ at the end of each stage until volitional exhaustion was achieved (Jones, 2006).

While GXT protocols vary in their work stage durations, ranging from 30 seconds to 4 minutes, in cases where all performance ($\dot{V}O_2max$, LT/VT & RE) related variables were required, a protocol that used longer work stages of 4 minutes was required to allow sufficient time for steady state to occur (Jones, 2006). A fixed gradient of 1% was also used throughout (Jones & Doust, 1996).

Familiarisation TTs were conducted prior to the GXT test as this has been shown to reduce CV to within <3% (Driller *et al*., 2016).

Throughout the study care was taken to ensure that all test sessions were conducted at the same time of day (±2hr), to reduce any possible effect of circadian rhythms (Drust, Waterhouse, Atkinson, Edwards & Reilly, 2005). It was also ensured that the same footwear was worn as factors such as shoe mass have been shown to influence running economy, with additional shoe mass increasing metabolic cost at a given workload (Divert, Mornieux, Freychat, 2008).

3.18 Laboratory and Field time-trial testing procedure

Participants were given the opportunity to complete a ten-minute warm up at a self-selected speed. They were then fitted with a Polar heart rate monitor, the portable breath-by-breath analysis system (Oxycon, Mobile, Jaeger, Wurzburg, Germany), to measure respiratory gases (Fig 1) and a Garmin 910XT forerunner GPS system to record their velocity during outdoor assessment. There were no firmware updates during the testing period. Participants then completed a 5 km performance time trial. Time-trial (TT) testing, defined as a performance test with a known end point (Laursen, Francis, Abbiss, Newton, Nosaka. 2007) has been shown to have a high test–retest reliability in both laboratory (r = .99 & CV = 1%: Driller, Brophy-Williams, Walker, 2016) and field (r = .97 & CV = .95%: Hurst & Board, 2013) settings.

Familiarisation TTs were conducted prior to both laboratory and field tests as this has been shown to reduce CV to within <3% (Driller *et al*., 2016). Participants were made aware of the trial distance or duration to allow them to adjust their velocity in order to pace themselves towards this known endpoint (Albertus, Tucker, St Clair Gibson, Lambert, Hampson, Noakes, 2005).

3.19 Long run protocol

Prior to all long runs, participants were required to wear a Garmin 910XT forerunner GPS system. This system provided the participants with the exercise intensity (expressed to HR) they had been prescribed from the initial testing. Participants were given the opportunity to complete the first ten minutes of their long run as a warm up at a self-selected speed. Participants then completed the remainder of the run at a heart rate zone corresponding to 70-75% of $\dot{V}O_2$max.

During the laboratory-based long runs conducted pre and post training intervention, participants were required to manually adjust the velocity of the treadmill in order to maintain this HR zone. This decision to allow the participant to control the velocity was to mirror the long run

throughout the training intervention. Participants in the twice daily group were required to visit the laboratory in the morning and evening on the day of visit three but were free to leave the laboratory between sessions. During the long run, participants were free to drink water *ad libitum*. Participants were asked to conduct their training sessions at the same time of day (±2hr), to reduce any possible effect of circadian rhythms (Drust, Waterhouse, Atkinson, Edwards & Reilly, 2005)

3.20 Treadmill Mechanical Reliability Testing

Before commencing experimental trials, the mechanical reliability of the motorised treadmill (Woodway ELG 70/250 Sport, Waukesha, USA) and breath-by-breath gas analysis system (Oxycon Pro, Jaeger, Wurzburg, Germany) were evaluated. To measure the reliability of the velocity and the incline of the HP Cosmos Treadmill, the following steps were taken.

Treadmill Velocity:

1) Calibration of measuring trundle-wheel over a measured four metre distance.

2) Clamping of trundle-wheel in secure unit constructed to rest on the treadmill belt.

3) HD Camera set up focused upon the unit counter of the trundle wheel.

4) The camera started filming firstly on a tag displaying the velocity to be tested; secondly the treadmill was started at the desired velocity; thirdly a period of 30 seconds was allowed to pass after the target velocity was achieved to allow steady-state.

5) The experimenter counted down '3-2-1-Start' and then a period of 5 minutes elapsed. During the final stages of the 5 minutes the experimenter counted down '3-2-1-End' after which the filming was ended.

6) The process was repeated for the following velocities (6,8,10,12,14,16,18,20,22km·h^{-1}) on three separate occasions.

7) The predicted distance measured was calculated for each velocity over the 5 minute time period (Velocity * 1000 / 12).

8) The data was analysed for the 5 minute test phase recording the start units displayed on the trundle-wheel at the start phase and the end phase. From these two data points actual distance measured was achieved and compared with predicted distance measured (Figure 3.1).

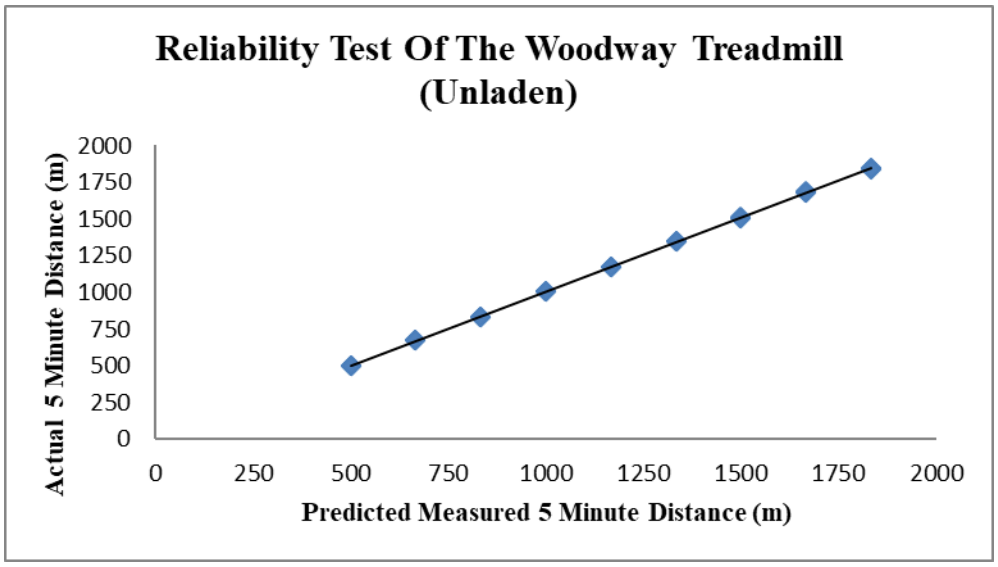


Figure 3.1: Reliability of the Velocity of the Woodway ELG 70/250 Sport Treadmill Belt (R2 = 0.9998)

Treadmill Incline:

1) The Inclinometer was calibrated at the resting level set at zero degrees on the treadmill against a fixed point that would not cause movement of the inclinometer as the incline would be adjusted.

2) The incline was raised one degree at a time from flat through to the maximum incline of 13 degrees.

3) During each degree of incline the measurement was recorded from the display.

4) This process was repeated 4 times to accrue 4 data points for each degree of incline from flat through to 13 degrees.

5) The data was analysed and an average of the data points was calculated and compared wi the predicted degree of incline (Figure 6).

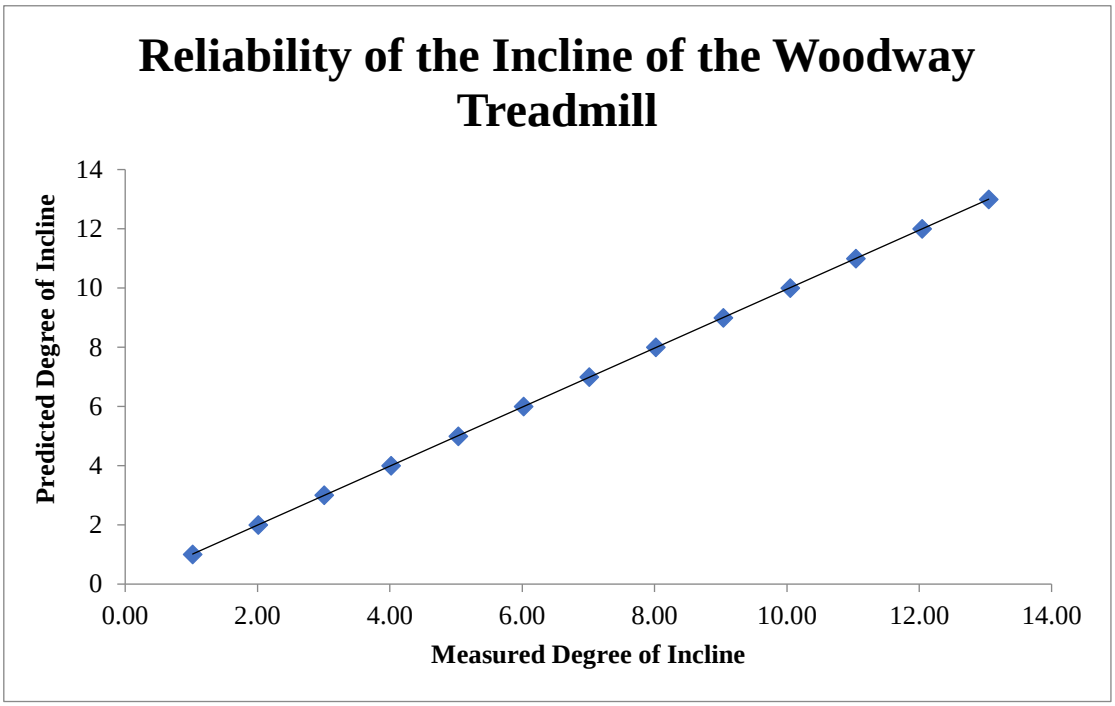


Figure 3.2: Reliability of the incline of the Woodway ELG 70/250 Sport Treadmill (R2 = 1.00)

Conclusions:

The Woodway ELG 70/250 Sport motorised treadmill demonstrates high levels of reliability and validity in terms of treadmill velocity and inclines and therefore is supported in its inclusion within the experimental studies in this thesis.

3.21 Training Log

Upon completion, training sessions were uploaded to Garmin Connect (2015) electronic software package or were recorded with a written activity diary when preferred (Appendix 7). Data was collated in individual session segments to assess differences in heart rate (bpm), time (min), speed ($km \cdot h^{-1}$) and elevation (m). This data was collected throughout the six weeks of the study.

3.22 Dietary Log

Before conducting the pre and post intervention long run in Study 3 participants completed a 72 hour food diary, either hand written (Appendix 7) or on a free electronic nutrition and activity package (MyFitnessPal, 2015). Macronutrients in grams were converted to kilocalories (kcal) using the following conversion: CHO = 3.75 kcal/g, FAT = 9 kcal/g, PRO = 4 kcal/g (Collins, Hunking and Stear, 2011).

To date MyFitnessPal has not specifically been validated against traditional dietary software (Jospe, Fairbairn, Green, and Perry, 2015). A similar online software has been compared to 24 hour dietary recall and reported only small mean differences in kcal intake (16 and 105 $kcal \cdot day^{-1}$) across two sample days with 50 participants, although some individual differences were present (Carter, Burley, Nykjaer and Cade, 2013). MyFitnessPal (2015) is the most frequently used dietary online based software, currently used by 32.4% of surveyed dieticians who monitor the dietary intake of athletes (Jospe *et al.*, 2015). MyFitnessPal (2015) was used above more traditional software as it benefits from increased accessibility via a mobile phone application, allowed for real time monitoring and has the largest food database (> 5 million foods) compared with Nutritics (2016, > 10,000 foods) and CompEat (2016, > 6000 foods), increasing the accuracy when determining calorific content between different brands. Furthermore, mobile diet applications have been demonstrated to increase engagement verses written food diaries and web based records (Turner-McGrievy *et al.*, 2013).

All participants were able to complete the food diaries and all reported that they were honest accounts of their nutritional intake. To ascertain validity of Myfitnesspal, 50 separate foods (equivalent to ~ 12000 kcals) were analysed based on 100g of each food with Myfitnesspal (2015) and Nutritics (2016) software. Limits of agreement compared the databases kcals, grams of carbohydrate, protein and fat. The error for the total kcals between online databases was 0.012 % and the limits of agreement were 0.365 % ($p > 0.05$), the carbohydrate and fat in grams were comparable ($p > 0.05$). Protein in grams was significantly lower with Myfitnesspal (2015)

($p < 0.05$) but equated to 0.75 g difference per 100 g or 3 kcals, which is considered a very small margin.

Chapter 4 - (Study 1); Laboratory predictors of performance: a comparison between indoor and outdoor time trial performance

4.1 Introduction

As discussed in chapter 2, the laboratory provides many advantages as a testing ground for researchers to investigate endurance performance, including the ability to control for a range of environmental conditions. These advantages leave many researchers opting for the laboratory over the field for the collection of performance variables. However, running on a treadmill is not identical to running outdoors and there are notable differences in the runner's biomechanical, physiological and psychological responses (Pugh, 1970; Daniels, 1985; Nummela *et al*., 2007; Morin & Seve, (2011). Rosdahl *et al*. (2010) challenge the common assumption by researchers in the literature that a 5 km TT time recorded in the laboratory equates to the same time performed outdoors stating that research comparing the two environments to date, is not conclusive.

To ensure that results from testing carried out in the laboratory for Studies 2 and 3 is transferable to an outdoor race environment, one purpose of Study 1 is to compare a 5 km TT run in the laboratory with a 5 km TT run outdoors in a homogenous group of MTRs. This will provide reassurance that any improvements seen in the laboratory in Studies 2 and 3 will also be transferred to a "real-word" outdoor 5 km race environment. A further output of Study 1, possible with the data collected when investigating differences between running indoors and outdoors, is to create an equation to predict 5km running performance.This is a useful output for coaches and athletes who may not have the time or resource to participate in more involved laboratory based testing.

- *Predicting 5 km Running Performance in the Laboratory and Outdoors*

Predicting 5 km performance through the use of equations based on performance related variables (anthropometry, training related and physiological) has been of interest for a number of years (Roecker *et al*., 1998; Haverty *et al*., 1988; Stratton *et al*., 2009; Paavolainen *et al*., 1998; Scott & Houmard 1994; Takeshima & Tanaka, 1995). As a consequence, many prediction equations have been developed (Table 2.1). However, in many cases, marked differences in GXT protocols where performance variables are collected raise questions as to the value of prediction these equations. Hence it is arguable that these equations may be of little use to runners who are unaware of their limitations.

Therefore, the two main aims of the present study were:

- to analyse the relationships between running a 5 km TT in the laboratory and outdoors, establishing the ecological validity of lab-based running.
- to establish predictive equations for 5 km performance in both laboratory and outdoor environments using anthropometry, training related, and physiological variables.

It was hypothesised that there would be a significant difference between running a 5km in the laboratory and running a 5km outdoors.

4.2 Methods

Twenty moderately trained male endurance runners were recruited (Table 4.1) for Study 1. This sample size was deemed sufficient based upon previous research investigating differences between the laboratory and the field using sample sizes of 13-18 (Mooses *et al*., 2015; Peserico & Machado 2014). An effect size of d=1.385 in RE between laboratory and field tests taken from Mooses *et al*., 2015 and an effect size of d=0.5 in mean running velocity from Peserico & Machado, 2014 were used to inform a power analysis. Taking these into consideration, a large effect size of d=0.8 was modelled in an a priori power analysis which recommended a sample size of 19 individuals for a power of 95% based on a paired t-test. The decision to recruit 20 moderately trained male endurance runners for this test was thus justified.

The participants performed three experimental trials, and three prior familiarization tests. Two tests (with an additional two familiarization tests) were conducted in the laboratory and one test (with an additional one familiarization test) was conducted outdoors on a synthetic running track. Trials performed in the laboratory were intended to, first, identify performance measures ($\dot{V}O_2$max, LT/VT and RE), and second, to complete a 5 km performance time trial in the laboratory. The same trials were then performed outdoors so all measures (physiological variables and 5 km time trial time) could be compared.

The following physiological variables; $\dot{V}O_2$max ($mL \cdot kg^{-1} \cdot min^{-1}$), RE 12 ($km \cdot h^{-1}$), RE 16 ($km.h^{-1}$), bLa 12, bLa 16, VT1 (% $\dot{V}O_2$max), vVT ($km \cdot h^{-1}$), were selected as these are variables known to affect endurance (Midgley, McNaughton & Jones, 2007). The non-physiological variable PTv ($km \cdot h^{-1}$) was selected as this variable has been reported as showing the highest relationship with running performance (Noakes *et al.*, 1990). The following anthropometric variables, height (cm), mass (kg) & $\sum$ of eight skin folds (mm) were also selected and investigated for relationships with laboratory and outdoor 5 km TTs as these variables have also been commonly used in previous investigations (Roecker *et al.*, 1998; Haverty *et al.*, 1988; Stratton *et al.*, 2009; Paavolainen *et al.*, 1998; Scott & Houmard 1994; Takeshima & Tanaka, 1995).

Table 4.1 Participant characteristics

N = 20	Mean ± SD
Age (Years)	32.2 ± 7.1
Height (cm)	177 ± 6.88
Mass (kg)	68.3 ± 7.2
Sum of eight skin fold (mm)*	50.4 ± 20.5
$\dot{V}O_2$max ($mL \cdot kg^{-1} \cdot min^{-1}$)	61.58 ± 5.5

Note: * Sum of eight skinfold sites to include: subscapular, triceps, biceps, iliac crest, supraspinale, abdominal, front thigh and medial calf.

Experimental protocol

The overview for the experimental design is shown in Table 4.2. The participants all completed six experimental trials, each separated by seven days. Four of the trials were

completed in the laboratory with the two trials completed outdoors. Visits one, two and three acted as an opportunity for the participant to become familiarised with the environments, the 5km TT and the GXT protocol (chapter 3.16), and for anthropometric measures to be collected (Chapter 3.5 & 3.6). Following familiarisation, the remaining visits were conducted in a randomised order, and included a visit to determine the participant's $\dot{V}O_2$max, LT/VT and RE (3.11, 3.12 & 3.13) and two visits to perform a 5 km performance time trial in each of the laboratory and outdoor environments.

Table 4.2: Schematic of the experimental design

Weeks 1,2,3			Weeks 4,5 & 6		
Visit 1: Familiarisation 5 km Indoors	Visit 2: Familiarisation 5 km Outdoors	Visit 3: Familiarisation $\dot{V}O_2$max test	Visit 4: $\dot{V}O_2$max test	Visit 5: 5 km Indoors	Visit 6: 5 km Outdoors

For details relating to the equipment used and the calibration process used in GXT testing the reader is referred to section 3.16 of the General Methodology.

When measuring the determinants of running performance ($\dot{V}O_2$max, LT/VT and RE), the portable breath-by-breath metabolic system Oxycon Mobile (OM) was used (Crouter *et al*., 2006; King *et al*., 1999; Lampard *et al*., 2000; McLaughlin *et al*., 1999; 2001; Parr *et al*., 2001; Hodges *et al*., 2005; Macfarlane, 2001). As variables were measured both indoors and outdoors, a portable metabolic system was used to ensure consistency.

During all outdoor experimental trials, participants ran in lane 1 of a synthetic running track. Care was taken to ensure that environmental conditions such as temperature, humidity, wind speed and direction were recorded as suggested by Sunders *et al.* (2004) (Table 4.3). Participants' running speed was measured using Garmin 910XT forerunner GPS systems. There were no firmware updates during testing. All test times remained at the same time of day and the same GPS instruments were used to ensure consistency.

4.3 Data analysis

Statistical data were analysed using Excel and SPSS. The data was assessed for normality with the Shapiro-Wilk test (1965). Where data was normally distributed, differences between the laboratory and outdoor conditions were compared with the parametric paired t-test. The Pearson Product Moment correlation coefficient (r) was performed next to examine the relationship between all variables for the parametric data, while Spearman rank-order correlation was used for the non-parametric data, to test for the extent of colinearity. Stepwise multiple-regression analyses were used to determine 5 km prediction equations from anthropometric and physiological variables. Peak treadmill velocity, (PTv) velocity at ventilator threshold (vVT) and running economy (RE) were selected following a review of the literature which revealed that these were the strongest predictors of race performance. Further stepwise multiple-regression analyses were also used to determine the physiological variables that explained variance in PTv. In the next section the best prediction equations are presented, these being the most parsimonious models.

4.4 Results

All 20 subjects completed all four trials (Table 4.2). After the first week, trials involving GXT, indoor and outdoor 5 km TT were conducted in a randomised order.

Table 4.3. Descriptive environmental conditions

Environmental parameters	Laboratory	Field
Temperature (°C)	18	19.9 ± 1.4
Relative humidity (%)	56.8	60.3 ± 10.2
Atmospheric pressure (mmHg)	1011 ± 5	1019 ± 4.4
Air speed ($m.s^{-1}$)	-	1.79 ± 0.2

Table 4.4. Mean and standard deviation (SD) of 5 km performance times, physiological and anthropometric variables.

n = 20			
Variables	Mean ± SD	r (lab)	r (track)
5 km TT (lab) (seconds)	1089 ± 92		0.9
Time Trial			
5 km TT (track - outdoors) (seconds)	1114 ± 96	0.9	
Physiological			
$\dot{V}O_2max$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	61.58 ± 5.5	-0.38	-0.4
RE 12 ($km \cdot h^{-1}$)	40.39 ± 3.76	0.68*	0.58*
RE 16 ($km.h^{-1}$)	54.97 ± 5.07	0.59*	0.49*
bLa 12	1.51 ± .6	0.22	0.11
bLa 16	5.42 ± 2.9	0.55*	0.50*
VT1 (% $\dot{V}O_2max$)	78.61 ± 3.62	-0.39	-0.2
vVT ($km \cdot h^{-1}$)	14 ± 1.09	-0.78*	-0.82*
PTv ($km \cdot h^{-1}$)	18 ± 1.25	-0.91*	-0.9*
Anthropometric			
Height (cm)	177 ± 6.88	0.02	0.00
Mass (kg)	68.3 ± 7.2	0.13	0.25
∑ of eight skin folds (mm)*	50.4 ± 20.5	0.78*	0.76*

RE12 (running economy at 12 $km \cdot h^{-1}$), RE16 (running economy at 16 $km \cdot h^{-1}$), bLa 12 (blood Lactate at 12 ($km \cdot h^{-1}$), bLa 16 (blood Lactate at 16 ($km \cdot h^{-1}$). ∑ of eight skinfolds (triceps, biceps, subscapular, iliac crest, supraspinale, abdominal, front thigh, and medial calf). * Significant correlations between performance variables and performance time ($p < 0.01$).

Table 4.4 displays the anthropometric and physiological variables of the runners and their relationship with laboratory and outdoors performance times. Analysis of the performance trials revealed that there was a significant difference between times recorded in the laboratory (1089 ± 92s) and outdoors (1114 ± 96s) (p<0.001) (table 4.4).

The relationship between performance variables and 5 km TT times in the laboratory and outdoors (table 4.4), the physiological variables RE12 (r =0.68 & 0.58) (r^2 =0.46 & 0.33), RE16 (0.59 & 0.5) ($r^2$0.18 & 0.06), bLa16 (0.68 & 0.5) ($r^2$0.46 & 0.25), vVT (-0.79 & -0.84) (r^2-0.64 &-0.72), and PTv (-0.94 & -0.9) (r^2 0.88 & -0.85) were significantly related to laboratory TT times, and outdoor times, but $\dot{V}O_2max$ (-0.22 & -0.11) (r^2 0.04 & 0.01), bLa12 (0.23 & 0.2) (r^2 0.05 & 0.04) and VT1% (0.38 & 0.4) (r^2 0.14 & 0.16) showed no significant relationship in

either the laboratory or outdoors (table 4.4). Furthermore, variables expressed to PTv (-0.94 & -0.9) (r^2 0.88 & -0.85) and vVT (-0.79 &-0.84) (r^2 0.64 &-0.72) were the most strongly related with performance for both laboratory and outdoors.

For the anthropometric variables, only the ∑of 8 skin folds (SF) showed significant correlations with laboratory 5 km TT times (r^2 = 0.61) and outdoors (r^2= 0.57), while other variables including height and mass did not show significant relationship for laboratory (r^2 = 0.04, 0.01) or outdoors (r^2 = 0, 0.06).

The stepwise multiple regression analysis (table 4.5) indicated that 5 km laboratory performance times could be predicted from both physiological and anthropometric variables.

Table 4.5 Laboratory predictors

Predictors	r (laboratory)	r^2 (laboratory)	r (outdoors)	r^2 (outdoors)
PTv	-0.94	0.88	-0.92	0.85
vVT	-0.8	0.64	-0.85	0.72
RE12	0.88	0.77		
∑ of 8 SF	0.78	0.61	0.76	0.58

The stepwise multiple regression analysis also created the following equations for laboratory and outdoor 5 km TT performance predictions

Laboratory 5 km TT performance predictions

Equation 1: Predicting lab 5 km TT: (peak treadmill velocity x - 64.977) + Constant 2270.636 = predicted time (seconds)

Equation 2: Predicting lab 5 km TT: (vVT x -51.192) + (RE12 x 9.588) + constant 1417.386 = predicted time (seconds)

And outdoor 5 km TT performance predictions

Equation 3: Predicting outdoor 5 km TT: (peak treadmill velocity x - 66.710) + Constant 2327.426 = predicted time (seconds)

Equation 4: Predicting outdoor 5 km TT: (vVT x -74.292) + constant 2153.383 = predicted time (seconds)

To take the analysis further, a stepwise multiple regression analysis (table 4.6) was conducted with PTv as the dependant variable. Results indicated that PTv could be predicted from the physiological variables vVT and RE12 with r = 0.94.

Table 4.6 PTv predictors

Predictors of PTv	r	r^2
vVT	0.9	0.8
vVT, RE12	0.94	0.89

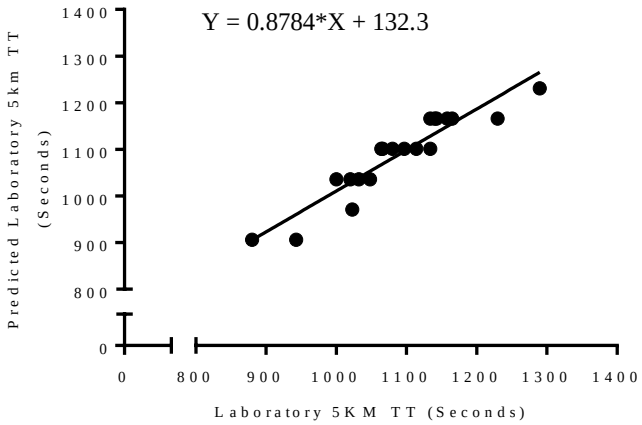


Figure 4.1. Relationship between laboratory 5 km TT and predicted laboratory 5 km TT (PTv)

($r = 0.94$, $r^2 = 0.88$) ($p<0.001$)

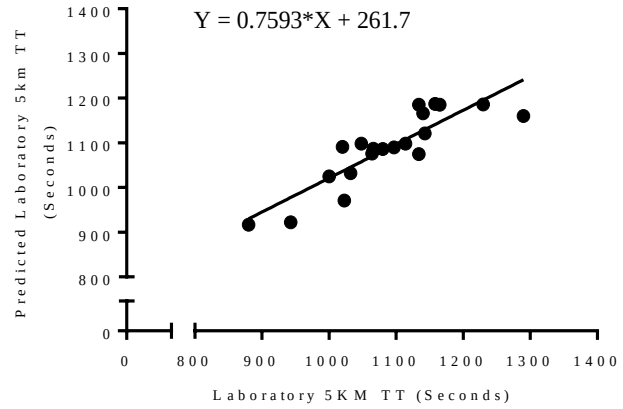


Figure 4.2. Relationship between laboratory 5 km TT and predicted laboratory 5 km TT (vVT & RE12)

($r = 0.87$, $r^2 = 0.76$) ($p<0.001$)

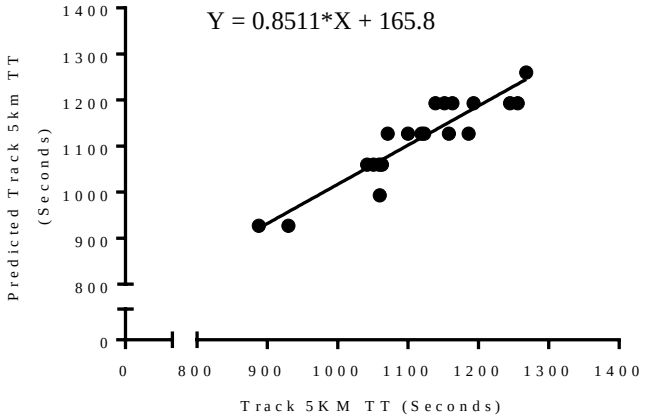


Figure 4.3. Relationship between Track 5 km TT and predicted Track 5 km TT (PTv)

($r = 0.92$, $r^2 = 0.85$) ($p<0.001$)

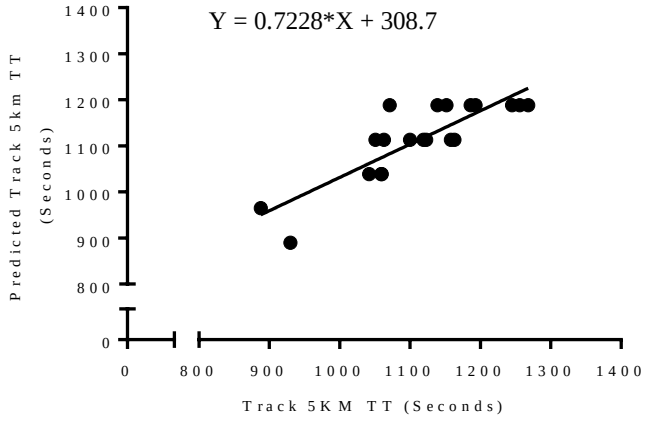


Figure 4.4. Relationship between Track 5 km TT and predicted Track 5 km TT (vVT)

($r = 0.85$, $r^2 = 0.72$) ($p<0.001$)

4.5 Discussion

This study aimed to assess the ecological validity of performing a 5 km time trial completed in the laboratory and the transferability of these times in an outdoor time trial in a group of MTRs. Secondly, this study aimed to establish predictive equations for 5 km performance in both laboratory and outdoor environments using anthropometry, training related, and physiological variables.

4.5.1 The 5 km Time Trial – a critical comparison of results in the laboratory and outdoors

In agreement with previous research (Mooses *et al*., 2015; Peserico & Machado 2014), a comparison of 5 km timed in the laboratory with 5 km timed outdoors identified that significant differences in running speed existed. The results differed from previous research comparing time trials in the laboratory with outdoors, over both short-duration, high-intensity running (sprinting) (Morin & Seve, 2011; Nummela *et al*., 2007), and longer endurance running of 60 minutes time trials (Peserico & Machado, 2014). According to these authors, times over 5 km were faster outdoors than in the laboratory. It is possible that differences in the experimental design between the current study and previous research may, in part, have influenced the findings. Evidence collected by the researcher highlighted that chapter 4 (study 1) included

runners who were all frequent treadmill users. Previous research, by contrast, has rarely provided information regarding the participants' use of treadmills (Peserico & Machado, 2014).

Furthermore, in previous research cited in the literature, information regarding test familiarisation was either not stated or only performed for laboratory tests. Although runners may have a number of years' running experience, it should not be assumed that this experience included running a time trial, alone, on an outdoor running track. Furthermore, research has shown that conducting familiarisation tests can reduce the coefficient of variation (CV) to within <3% for subsequent trials (Hopkins, Schabort, & Hawley, 2001; Driller *et al*., 2016). Therefore, consideration should be given to familiarizing runners prior to them completing a 5 kmTT in any environment. For this reason, familiarisation trials were performed in study 1 by all participants for all tests conducted and this is perceived as a strength of this study. Although familiarization tests were conducted as a matter of course, the researcher knew from /preparatory discussions with the participants that all were familiar with the experience of running on a treadmill. All participants reported that they used a treadmill regularly, at least once every two weeks, although this was not a selection criteria for inclusion in the study.

A third difference was that all tests in the current study were conducted in a randomised order. Some researchers (Peserico & Machado, 2014) have reported that the testing sequence was not randomised and time trials on the track were performed *after* the treadmill trials. This may have led to a learning effect with the time trial test format. Research has shown the impact of a learning effect on time trial performance: Currell and Jeukendrup (2008) showed that when more than one familiarization test was conducted, error variance in running times was reduced. In other words, the more experience a runner has in performing a test, the smaller the differences observed in running times. Participants in Study 1 would not have had this learning effect with TT test format because they were familiar users of treadmills and so the testing process should not have influenced the final result.

A further potential difference concerned information made available to the runners in each environment. In previous research, when runners were on the treadmill, they were able to see both their elapsed time and velocity throughout the test. However, when running on the track, it would appear that the provision of such information may not have been available (though one cannot be sure) as this was rarely made clear in the literature. It is thus possible that these differences may have influenced the runner's motivation and / or pacing throughout the trials.

In this study, efforts were made to provide runners with both elapsed time and running velocity throughout the trial in both environments with the use of GPS systems. Keeping feedback consistent throughout testing may partially have explained the similar pacing strategy that was seen in both conditions: that was, to progressively increase the pace over the first two kilometers and then maintain this pace throughout the trial. This pacing strategy differed from previous studies which saw recreational runners adopt a pacing strategy that was progressive throughout the trial on the treadmill, while their outdoor strategies were markedly different: they began at high velocity, this was followed by a progressive decrease over the duration of the time trial, and velocity was increased towards the end (Peserico & Machado, 2014). As 5 km road race pacing strategies for elite runners were different still, with runners showing significant decreases in speed towards the end of the run (Hanley *et al*., 2011). Having considered information cited in the literature, this researcher believes that providing runners with both elapsed time and running velocity throughout the trial in both environments was a major strength of Study 1 and contributed to the consistency and comparablilty of the results.

Finally, a difference is wind speed: this has been shown to affect runners biomechanically and physiologically by altering their posture. When running into a head wind, the runner leans into the wind and possibly alters their energy expenditure (Davies, 1980). In past research comparing treadmill and track running, wind speed has not been reported (Mooses *et al*., 2014; Peserico & Machado, 2014), thus it is not known to what extent the wind might have affected the runners' performance. In this study, outdoor trials were limited to days when the average wind speed was 1.79 ±0.2 $m.s^{-1}$ and below the threshold of 2.0 $m\ s^{-1}$ for outdoor performance

testing recommended by Jones & Doust (1996). This too was believed to contribute to the consistency and comparability of results.

4.5.2 The influence of runners' physiological and anthropometric characteristics on 5 km performance

This study demonstrated that PTv, vVT, RE at 12 $km \cdot h^{-1}$ (RE12) and ∑ of 8SF are all strongly related to performance over a distance of 5 km.

4.5.3 PTv and performance

The strongest relationship was found between PTv and 5 km performance in both laboratory (r^2 = 0.88) and outdoor conditions (r^2 =0.84) (table 4.5). This result is consistent with previous research that found PTv correlated with performance across a range of distances including 3 km (r^2 = 0.4), 5 km (r^2 = 0.83 to r^2 = 0.89), 10km (r^2 = -0.94), half marathon (r^2 = -0.94) and the marathon (r^2 = -0.95) (Noakes et al., 1990; Scott & Houmard, 1994; Paavolainen *et al*., 1999; Lacour *et al*., 1990; Stratton *et al*., 2009). This supports the view that the measure of treadmill-based performance can be a good predictor of endurance performance (Houmard *et al*., 1991; Noakes *et al*., 1990; Scott & Houmard, 1994).

As the literature confirms that there is a strong correlation between PTv and 5km performance, understanding how the major physiological determinants, $\dot{V}O_2max$, RE and LT/VT affect RP is also extensively debated in the literature. Some researchers (McLaughlin *et al.,* 2010) have suggested that when using a fixed horizontal gradient running protocol, PTv is usually the same measured velocity at which $\dot{V}O_2max$ occurs, therefore, one would expect these two variables (PTv and $\dot{V}O_2max$) to be highly correlated with each other. McLaughlin *et al*. (2010) supported this statement, reporting a high negative correlation (r = -0.902) between $\dot{V}O_2max$ and RP. Conversely, Noakes *et al*. (1990, p42) have suggested that $\dot{V}O_2max$ is not a good predictor of PTv, stating that "The physiological determinants of peak treadmill running velocity are not known. If the absolute rate of oxygen consumption was the most important determinant of peak treadmill running velocity, then $\dot{V}O_2max$ would be an equivalent predictor of running

performance. That it is not indicates that the absolute rate of oxygen consumption cannot be the principal determinant of the peak treadmill running velocity".

The findings presented here support the statement of Noakes *et al*., (1990). A regression analysis demonstrated that the performance variables vVT and RE12 were able to predict PTv with a correlation coefficient of r = 0.94 (Table 4.6), explaining 88% of the variance. The addition of $\dot{V}O_2$max did not improve the predictive power. Therefore, for the MTR, achieving a higher PTv (and most probably a faster 5 km time) is likely to be accomplished by improvements in vVT or RE in training rather than $\dot{V}O_2$max. In the view of this researcher, this is because the performance in the GXT (which is where PTv is established), and 5 km performance are both linked to the same physiological variables (RE12, vVT) (Table 4.4).

Peak treadmill velocity has many advantages for the runner in that it is easily assessed on the treadmill by the runner, or coach, through increasing the velocity of the treadmill until the point of fatigue is reached. It does not require invasive techniques needed to assess physiological predictors of endurance performance such as $\dot{V}O_2$max, LT/VT or RE, and it provides runners with a practical method of monitoring how their 5 km performance in a real-world situation may have altered as a result of training. Furthermore, due to the high correlations (r = 0.94 & 0.92) between PTv and 5 km RP found in this study, and in previous research (Noakes *et al*., 1990; Scott & Houmard, 1994; Paavolainen *et al*., 1999; Lacour *et al*., 1990; Stratton *et al*., 2009) further assessment is required to ascertain if improvements in PTv would be accompanied by improvements in RP.

It is important to remember that despite the above-mentioned advantages of PTv, this measure is not without limitations. One drawback is that as PTv is essentially a running test used to predict running performance it is not a physiological model predicting performance. Therefore, in cases where this test is conducted by the runner or coach, physiological measures are not usually recorded. As a consequence, it is not possible to make comparisons with normative data and thus potentially ascertain if there are weaknesses to be targeted through training (e.g. very

high VT1 and very poor RE could result in an identical PTv with an athlete with a low VT1 and exceptionally high RE). This makes it difficult for the runner to target 'weaker' factors. Nor will it indicate how the determinants of endurance performance ($\dot{V}O_2$max, RE and LT/VT) may have changed over time. Although a visit to a laboratory may require more time, and in some cases expense for the runner, the information made available to the runner on which determinants are limiting PTv allows the runner or coach to adjust training accordingly. Given that the training required to improve each factor differs, this method avoids the trial and error approach to training.

4.5.4 $\dot{V}O_2$max and performance

A second important finding of Study 1 is the low correlations between $\dot{V}O_2$max and 5 km RP (r = 0.38 & 0.4) for both the laboratory and outdoor running performances. As shown in Table 4.5, $\dot{V}O_2$max was not included in either the indoor or outdoor prediction equations following the results of the stepwise regression. These showed that $\dot{V}O_2$max did not contribute any further explanation to the result. This finding is in marked contrast to many previous studies where moderate to high correlations have been found between $\dot{V}O_2$max and a range of distances including 3km (r = 0.8 and 0.7) (Slattery *et al*., 2006; Grant *et al*., 1997); 5 km (r = 0.51 to r = 0.56) (Stratton *et al*., 2009; Paavolainen *et al*., 1999); 9 km (r = 0.88 to 0.91) (Farrell *et al*., 1979; Evans *et al*., 1995; Sleivert & Wenger) and 10 miles (r = -0.91) (Costill *et al*., 1973). However, in many cases where positive correlations between $\dot{V}O_2$max and RP have been reported, researchers have included in their studies participants with a wide range of $\dot{V}O_2$max values (54.8 to 81.6 $mL \cdot kg \cdot min^{-1}$) with large standard deviation values. In this research, there was not such a wide variation in the VO_2max values of the participants of MTRs, with all values within the range 57.8 to 68.6 $mL \cdot kg \cdot min^{-1}$, with a standard devisation of 5.5. This is likely to be due to the more homogenous population of MTRs who had similar running experience and training routines than participants in the studies referenced above. A correlation coefficient measures the amount of spread about the linear least-squares eqution. Therefore a larger (positive or negative) correlation coefficient may be more likely to emerge from data with a

wide range of values, as within these data points a linear relationship has more chance of being found. This would be represented on a scatterplot as a weakly linear relationship. In contrast, data points that are clustered more closely, as they would be in an homogenous population, may be less liikely to reveal a linear relationship, as there is less opportunity (due to a narrower spread of data) to find an increase of one unit on the X axis with an increase of one unit on the Y axis. However, even a low correlation coefficient does not mean there is no relationship whatsoever, but there is no straight line which fit the data. Thus comparison of these results with those of other studies performed on a more diverse population may be misleading.

In cases where relationships have been investigated in more homogenous groups, such as the untrained or elite, correlation coefficients between $\dot{V}O_2$max and RP are greatly reduced with reports of moderate correlations (r = -0.51) (Stratton *et al*., 2009). The correlation in Study 1 (r = -0.38 & -0.4) was lower than that found by Stratton *et al*. (2009) who used a more untrained population to explore correlations between peak treadmill velocity and velocity at lactate threshold and 5km running times. There are strong similarilites between this research and that of Stratton *et al*. (2009), with both investigating relationships between physiological variables and 5 km performance. However, the running experience of the participants differed with Stratton *et al.,* (2009) testing untrained runners and this research focusing on MTRs. A possible explanation for the lower correlation between $\dot{V}O_2$max and RP seen in this study could be related to the participants recruited being classified as MTRs with $\dot{V}O_2$max values of 61.58 ± 5.5, therefore, more trained than the recreational runners used in previous research.

Although the importance of $\dot{V}O_2$max in performance is not in question as it essentially sets the ceiling for an athlete's ability (Bassett & Howley, 2000), it may be that as runners become faster (more trained) the predictive power of $\dot{V}O_2$max weakens relative to other variables that are better able to predict performance. Previous research (Conley & Krahenbuhl, 1980) using a group of homogenous highly trained runners (67 – 77 $mL \cdot kg^{-1} \cdot min^{-1}$) gives further support to this argument, where a weak correlation (r = -0.12) between $\dot{V}O_2$max and 5 km running performance was found. Consequently, we are in agreement with Bassett and Howley's

statement (1997, p.598) that "$\dot{V}O_2$max is not a good predictor of performance in runners with similar $\dot{V}O_2$max values". This once again highlights the importance of this research because there is so little published work on the relationship between physiological variables and performance within the MTR group.

4.5.5 Velocity at Ventilatory Threshold and performance

The second highest relationship in this study was found between velocity at vVT and 5 km performance with correlation coefficients of (r^2 = 0.627) for the laboratory and (r^2 = 0.706) for outdoors. This finding is consistent with previous research which reported moderate correlations of r^2 = 0.55 between vVT and outdoor performance (Paavolainen *et al*., 1999), but higher than others such as Dellagrana *et al*. (2015) who reported slightly lower correlations between vVT and outdoor performance of r^2= 0.41. The final r^2 values used in both predicition equations, indoors and outdoors, were 0.77 and 0.72 respectively. Both being considered strong values, these explain 77% and 72% of the variablility in 5km performance. This gives strength to the equations as predictors of 5km performance.

Research conducted by Farrel *et al*. (1979) has shown a strong correlation between velocity corresponding to onset of bLa and performance at a range of distances including 3.2 km (r = 0.91), 9.7km (r = 0.96), 15 km (r = 0.97), 19.3 km (r = 0.97), and 42.2 km (r = 0.98). Surprisingly, data was not collected over a distance of 5 km. Although the measurement of blood lactate is different from the ventilatory method used in this study, the two methods are closely related (Havery *et al*., 1988) and are often used interchangeably, as discussed in chapter 2).

While other researchers have also reported high correlations between vLT and running performance ranging from r = 0.73 to -0.95 (Grant *et al*, 1997; Slattery *et al*., 2006), these researchers used a fixed protocol of 4 $mMol{\cdot}L^{-1}$ to define LT. This method has been criticized by Hagberg & Coyle (1983) as being an unreliable estimate of LT as some athletes do not reach 4 $mMol{\cdot}L^{-1}$, even at the point of exhaustion in a GXT. The identification of ventilatory

threshold used in Study 1 differs from the researchers cited above who used a fixed lactate marker which was arbitrary, rather than a marked physiological event or a definitive change in oxygen use. Study 1 is therefore a valuable piece of research as it adds to the growing evidence base regarding which variables may be used to predict running performance in MTRs.

In contrast with the results above, when the VT was expressed as a percentage of $\dot{V}O_2$max, a low correlation was found with RP in both the laboratory and outdoors (r = 0.39, 0.2) (r^2 = 0.152, 0.04). This finding supports previous research (Kumagai *et al*., 1982; Mc Laughlin *et al*., 2010) but is in contrast with Roecker *et al*. (1998). Differences between this study and the Roecker *et al*. (1998) study could again be partly explained by the large heterogeneous performance group that they tested in comparison with the smaller, more homogenous group used in Study 1, made up entirely of MTRs. As discussed above, inclusion of a homogenous group of participants can lead to smaller correlations when compared with trials which incluse a diverse population. This is because when data for a physiological variable, in this case vVT, are clustered more tightly, a linear relationship may be less likely to emerge than within data that is more dispersed. In other words, correlation lines may be more easily found within dispersed data. If data are homogenous it doesn't necessarily mean there is a positive correlation, if the angle of spread results in a regression line with an angle of 45 degrees, this will give you r=1. If data are scattered in a horizontal plane then the r will be closer to zero, in other words, for every increase on the x axis there won't be an equivalent increase on the y axis.

4.5.6 Running Economy and performance

The moderate to strong correlation coefficient between running economy (RE12) and 5 km performance of r = 0.68 for the laboratory and r = 0.58 for outdoors gives support to previous suggestions that in comparison with $\dot{V}O_2$max, RE emerges as a better predictor of RP (Farrell *et al*., 1979; Tanaka *et al*., 1983; Tanaka *et al*., 1984; Takeshima & Tanaka, 1995; Morgan *et al*., 1989; Saunders *et al*., 2004) and is similar to previous findings (r = 0.69) (Paavolainen *et al*.,

1999) and (r = 0.53) (Farrel *et al*., 1979). The relationship between RE16 and 5 km performance was weaker for both laboratory (r = 0.55) and outdoors (r = 0.5).

It has been suggested that runners are typically more economical at speeds at which they habitually train (Saunders *et al*., 2004), and this could partially explain the stronger correlation between RE at 12 $km \cdot h^{-1}$ and 5 km performance, compared with 16 $km \cdot h^{-1}$ in Study 1. For the MTRs, the exercise intensity at 16 $km \cdot h^{-1}$ equated to ~90% of $\dot{V}O_2max$. It is unlikely that the runners would be able to maintain this velocity for a length of time in training. Conversely, when running at 12$km \cdot h^{-1}$ exercise intensity equated to ~66% $\dot{V}O_2max$, so they were more likely to accrue a greater length of time training at 12 $km.h^{-1}$ rather than at 16 $km \cdot h^{-1}$.

Furthermore, the higher correlation between RE12 and 5 km than between RE16 and 5 km questions the validity of 16 $km \cdot h^{-1}$ (268$m.min^{-1}$ or 4.41$m \cdot s^{-1}$) or 3:44 per km being cited as the most common velocity for training. The widespread use of 16 $km \cdot h^{-1}$ may well be due to early investigations into RE, which used highly trained or elite individuals who were able to maintain this velocity and remain below the ventilatory threshold point (Saunders *et al*, 2004). This method has, however, gained criticism (Saunders *et al.*, 2004) as attempting to run at 16 $km \cdot h^{-1}$ would force the majority of non-elite runners well beyond the ventilatory threshold and thus increase the anaerobic contribution. In the group of MTRs used in the present study, this was indeed the case. Furthermore, it could be argued that using a RE measure recorded at 16 $km \cdot h^{-1}$ for MTRs is of limited value as this does not represent a speed at which they are likely to spend a length of time, with typical running speeds for the MTR participants derived from vVT between 12 and 14 $km \cdot h^{-1}$. Therefore, in cases where a single velocity is used to report RE measures (as is often the case) RE12 would be of greater value.

Study 1 also found that a stronger relationship existed between RE12 and the laboratory 5 km TT (r = 0.68), compared with the outdoor TT (r = 0.58). This finding is not a surprise given that RE measures were recorded during the GXT and the laboratory 5 km were performed on the treadmill rather than outdoors on a running track. It is therefore possible that biomechanical

differences, such as different muscle recruitment patterns when running on the treadmill (Cavanagh, Pollock, and Landa, 1971; Cavanagh & Williams, 1982) may have influenced the results.

4.5.7 Anthropometric variables and performance

Of the anthropometric variables collected, the sum of eight skin folds (∑ of 8 SFs) was significantly related to 5 km RP (Table 4.4) which is in accordance with previous studies (Knechtle *et al*., 2014; Rust *et al*., 2011), and closely mirrors the findings of Gómez-Molina *et al*. (2017) who reported correlations of r = 0.78 with the ∑ of 6 SFs and half-marathon performance. Other variables including the ∑ of 2 SFs, height or body mass did not correlate with 5 km performance. This is in agreement with Conley & Krahenbuhl (1980) and Kenney & Hodgson (1985) who both reported no significant relationship between ∑ of SFs in elite groups of runners over a distance of 10 km or 3 km, but in contrast with others who found that lower limb SF and circumference measurements to be strong predictors of RP in both elite (Arrese & Ostariz, 2006; Kong & Heer, 2008) and highly trained runners (Legaz & Eston 2005). This study thus provides additional support that the relationship between skinfolds and performance may vary according to the distance of the running event (Legaz & Easton 2005; Legaz & Serrano, 2005). Furthermore, it provides valuable information regarding anthropometric characteristics in MTRs that are specific to predicting 5 km RP, and changes that may occur to runners as they become more trained.

Although some researchers have related low height to performance (Loftin *et al*., 2007; Zillmann *et al*., 2013), others have not observed any relationship (Hoffman, 2008; Knechtle *et al*., 2009; 2010). In the current study, no significant relationship between height or mass and performance in 5 km runners was found (Table 4.4).

On the basis of these findings, it clearly highlights the importance of monitoring SFs throughout a season and asserts that attempts to reduce SF may be beneficial to the MTR. Furthermore,

during periods of illness or injury efforts should be made to ensure that the anthropometric assessment of MTRs should include all eight skinfolds.

4.5.8 Predicting Performance

As discussed earlier, Study 1 has identified the strongest single predictor of 5 km RP to be PTv. As a consequence, four prediction equations have been developed (equations 1 (laboratory) & 3 (outdoors)). Multiple stepwise regression indicated that 82.8% of the total variance in 5 km laboratory RP and 80.3% of the total variance in outdoor RP could be explained by PTv. No further variance was explained by adding other parameters to the model. This finding is similar to the 78.8% reported by Stratton *et al*. (2009) and consistent with 82.3 % found in shorter distances of 3km (Slatterly *et al*., 2006). The final r^2 values used in both predicition equations, indoors and outdoors, were 0.77 and 0.72 respectively. Both being considered strong values, these explain 77% and 72% of the variablility in 5km performance. This gives strength to the value of the equations as predictors of performance.

Equations 1 (laboratory) and 3 (outdoors) thus provide the runner with an easily accessible and practical means of predicting 5 km performance without the need for attending the laboratory. However, this method does not allow the runner to identify limiting variables to their performance, and it is limited in supporting those who prescribe training. Study 1 also aimed to investigate whether equations with similar predictive power could be created using physiological variables related to performance.

A further multiple stepwise regression analysis was completed, excluding the mechanical variable PTv, and therefore only including the physiological variables. This analysis determined that laboratory 5 km performance could be predicted using the variables vVT and RE12 (equation 2). Equation 2 was able to explain 72.4% of variance. The addition of $\dot{V}O_2max$ did not explain any further variance. It is also interesting to note that in the laboratory 5 km performance prediction equation (equation 1) independent variables (VT1, $\dot{V}O_2max$, $\sum$ of 8 SF), which correlated well with the dependent variable (5 km TT), did not necessarily provide the

best predictive combinations. When predicting outdoor 5 km performance the same variables (vVT and RE12) were able to explain 60% of the variance; however, unlike equation 2, the addition of VT% $\dot{V}O_2$max significantly increased the variance explained to 73.5% (equation 4). This addition of VT% $\dot{V}O_2$max adds weight to the realisation that differences exist between the laboratory and outdoor environments.

Therefore, the final r^2 values used in all four predicition equations explain no less than 72% of the variablility in 5km performance. This gives strength to the value of the equations in their capacity to predict running performance at a distance of 5km.

4.6 Conclusion

This study compared 5 km TT performance in both laboratory and outdoor environments and demonstrated that there are significant performance differences between these environments. This concurs with previous research (Nummela *et al*., 2007; Morin & Seve, 2011; Peserico & Machado, (2014). However, in contrast with previous research, in a homogenous group of male MTRs, 5 km performance in TTs was faster under laboratory conditions than outdoors.

Although this study supports the premise that 5 km time trials conducted within the laboratory offer low ecological validity compared to 5 km time-trials outdoors, and thus trials conducted under Studies 2 and 3 may yield data that are more relevant to "real-word" race performances if conducted outdoors. However, valuable insights also emerged when conducting Study 1 in relation to the practicalities and participant comfort of collecting data outdoors, and these factors have led to the decision to conduct all future trials in the laboratory. Many prticipants made it clear that they did not enjoy wearing the mobile oxycon machine whilst running for reasons of discomfot and embarrassment. Several runners said they found the equipment cumbersome and that they felt like they were on display at the running track when wearing it. This became an increasing concern to the researcher as it emerged how critical it was to keep participants engaged in the research in order to reduce drop out rates. It was envisaged that this

would have been a particular risk for Study 3, which demanded a lot of participants' time and focus. As a result it was felt that laboratory testing would be preferable.

This study also derived four prediction equations involving physiological variables. Equations 1 and 2 to predict laboratory 5 km TT times and 3 and 4 to predict outdoor 5 km TT times. For all prediction equations, there remains an untested hypothesis regarding how changes in predictor variables actually influence RP.

Chapter 5 - (Study 2): The acute effects of once daily and twice daily training on factors associated with running performance.

5.1 Introduction

There is increasing speculation that performing a single day of twice daily training (an acute bout) in the transition and speed phase (Fig. 2.1) might be more effective than once daily training in leading to greater physiological adaptation and improved running performance. Study 2 of this thesis which forms the focus of this chapter, investigates the immediate physiological effects of twice daily when conducted as a one off session of exercise (rather than any prolonged effects of continued training in this manner).

In Study 2 a group of MTRs are randomly allocated to either a once or twice daily training group. In the once daily training group, MTRs conduct a single, continuous run. In the twice daily training group MTRs run the same distance but split into two equal parts, one performed in the morning and the second in the evening, separated by between 6-8 hours recovery. The physiological effects of this type of running is compared between the two groups.

As has been discussed in the Literature Review, research on MTRs is limited and a further reason for investigating the effects of twice daily training is because it may be a more useful method of training for MTRs. As many have to organise their training around jobs and family commitments conducting two separate runs each day instead of one long one might be more practicable. However, whether this is the case is unknown as research of any type into MTRs is lacking.

Much of the research that has been conducted into twice daily training, discussed below, has focussed on signalling responses in cytoplasmic and nuclear proteins and suggests that twice daily training may be a superior strategy in promoting greater signalling response to induce adaptations related to mitochondrial biogenesis and fat oxidation. The physiological rationale to support the possible benefit of twice daily training can relate to the manipulation of substrate availability, and this has been the focus of much of the current research (Croft *et al.*, 2009;

Hansen *et al.,* 2005; Hulston *et al.,* 2010; Yeo *et al.,* 2008). In this context, the first training session reduces the muscle glycogen stores and the second session is performed with reduced muscle glycogen. Performing this type of split training can increase signalling responses in cytoplasmic and nuclear proteins such as CS, AMPK, CaMPK, as well as the genes encoding mitochondrial proteins, including PGC-1α, PGC-1α mRNA, when compared with once daily training (Croft *et al.,* 2009; Hansen *et al.,* 2005; Hulston *et al.,* 2010; Yeo *et al.,* 2008). This increase in signalling responses has the cumulative effect of leading to greater physiological adaptation and therefore, theoretically, to improvements in performance. Changes in signalling responses have been shown in both acute (one-off bouts of exercise) and choronic (prolonged periods of training) context. However, based on published research it is unclear whether this greater signalling response is due to performing the second session with low muscle glycogen or to performing two exercise sessions within the same day. Recent research by Andrade-Souza *et al*. (2019) investigated this by comparing signalling responses of two twice daily training groups, one with and one without reduced muscle glycogen stores. The research concluded that the elevated signalling response observed in both groups after performing the second exercise session could be attributed to the twice daily training rather than starting the second session with reduced glycogen stores.

To build on this line of enquiry, this piece of research investigates selected effects of twice daily training on measures known to effect running performance over 5km, without manipulating glycogen stores, and where both sessions are of equal length. Respiratory gases will be collected throughout the entire run using non-invasive methods which can be recorded with relative ease, in preference to invasive methods (such as the collection of tissue) that have been used in the research discussed above. From the data collected by the researcher for this study it is possible to show changes in meaures known to effect running performance during the course of the exercise session for both once and twice daily training groups within an acute setting.

Furthermore, to date, research has focused predominantly on the effects of combining different types of training (concurrent training) on performance or using twice daily training to increase

the volume of HIIT conducted each week (Granata *et al*., 2016). There is no notable research that adequately quantifies the effects of twice daily training on physiological responses where both sessions are performed at low exercise intensity.

As previously stated in Chapter 2, in comparison with the interval and speed phase of training, the foundational stage takes up the greatest proportion of the athlete's yearly training cycle and is widely acknowledged to be vital to performance (Hewson & Hopkins, 1995). While it is possible to find many published training diaries of elite level runners who claim to have completed two LIT sessions in a single day (Snell & Gilmore 1966; Wirz, 2005; Saunders, 2017), there is little notable scientific research, acute or chronic, that has investigated the effects of twice daily training where both sessions have been performed at low intensity either by elites or MTRs.

To date, when using the twice daily approach, researchers have identified that the greatest signalling responses in certain mitochondrial-related genes are seen when the two training sessions are separated by a recovery period of between one and three hours (Hansen *et al*., 2005; Yeo *et al*., 2008; Andrade-Souza *et al.,* 2019). This rest period has been shown to be sufficient to enable the runner to conduct a second training session (Galbraith *et al.,* 2014; Karsten *et al*., 2017). However, with a busy life, work and family commitments the MTR may have no option other than to separate training sessions by a six to eight hour gap. Our understanding of how this additional recovery period may affect the daily training session is far from clear and further investigation is thus warranted.

5.2 Methods

Thirty-seven moderately trained, male endurance runners were recruited (Table 5.1) and performed three experimental trials in the laboratory. Taking into consideration effect sizes from the literature (Hulston *et al*., 2010; Croft *et al*., 2009), a large effect size of d=0.5 was modelled in an a priori power analysis with a power set to 80% based on an ANCOVA. A total

sample size of 34 individuals was needed to achieve this, thus 37 were recruited to allow for drop outs.

Table 5.1 Study 2: Participant characteristics. Male, moderately trained endurance runners

	Mean ± SD All runners	Mean ± SD once daily group	Mean ± SD twice daily group
N	37	19	18
Age (Years)	34 ± 9.1	33 ± 8.7	35 ± 9.4
Height (cm)	177 ± 6.9	177 ± 6.8	177 ± 7.1
Mass (kg)	70.2 ± 6.6	70.3 ± 7.2	70.1 ± 5.8
$\dot{V}O_2$ max ($mL \cdot kg^{-1} \cdot min^{-1}$)	59.8 ± 5	60.1 ± 5	59.6 ± 5

Experimental protocol

Before the trials started the runners were randomly assigned to one of two groups: one group would conduct their training run in a single session and the second would divide their training run into two. Trial one was intended to record selected performance measures ($\dot{V}O_2$max, LT/VT and RE) whilst trial two was used to record a 5 km performance time trial. In trial three, runners performed a prolonged run indoors.

The overview for the experimental design is shown in Table 5.2. Once randomly assigned to a group, the participants in the once daily group completed three experimental trials, each separated by seven days. Participants in the twice daily group completed an additional fourth visit to the laboratory on the same day as visit three. Visit one was to determine the participant's $\dot{V}O_2$max, LT/VT and RE. Visit two was to perform the laboratory 5 km performance time trial. Visit three was to conduct a long run corresponding to the same habitual volume the runner had been completing in the three months preceding the study at a HR zone corresponding to an intensity of 70-75 % $\dot{V}O_2$max. During the long run, participants were required to manually

adjust the velocity of the treadmill in order to maintain this HR zone. Participants in the twice daily group were required to visit the laboratory in the morning and evening on the day of visit three but were free to leave the laboratory between sessions. During the long run participants were free to drink water *ad libitum*. All participants ran at a relatively low fixed intensity and all were able to maintain that intensity, thus there was no advantage of performing the run later in the day in this context as has been reported elsewhere (Thun *et al*., 2015). All runners perfomed a run in the morning and the twice daily group also performed a session if the afternoon. It was ensured that the same footwear was worn as factors such as shoe mass have been shown to influence running economy, with additional shoe mass increasing metabolic cost at a given workload (Divert, Mornieux, Freychat, 2008). For further information regarding the equipment used, the calibration procedures and the environmental conditions during testing the reader is referred to chapter 3, the General Methodology.

Table 5.2: Schematic of the experimental design for Study 2

Participants	Week 1	Week 2	Week 3
Once daily	Visit 1: $\dot{V}O_2$max test LT/VT and RE	Visit 2: 5 km TT	Visit 3: (AM) Long Run
Twice daily	Visit 1: $\dot{V}O_2$max test LT/VT and RE	Visit 2: 5 km TT	Visit 3: (AM) First half of Long Run Visit 4: (PM) Second half of Long Run

5.2.1 Pacing the run to HR

In this study all runners paced the runs to a HR zone equating to 70-75% $\dot{V}O_2$max.The use of pacing by HR is a popular method used to guide exercise intensity during training. This method has advantages over other pacing methods such as a fixed velocity as it is what runners would tend to do when training outdoors (which is where most runers train). Pacing by HR when

training outdoors is necessary due to changes in environmental conditions or topography. In cases where changes in gradient or increases in wind speed are experienced exercise intensity must be increased to maintain the predetermined pace, for some this is not possible and could result in participants being unable to maintain pace, even at maximal effort.

Despite its widespread use by runners of all abilities, many researchers have chosen to avoid using pacing to a fixed HR in experimental trials, and instead have opted for a fixed velocity pacing strategy. While a fixed velocity pacing strategy may have some advantages in that it allows individual runners to become accustomed to target race pace, and researchers to quantify how physiological variables may have changed at this target pace after a period of training, it is not without its limitations. For instance, Xu & Montgomery (1995) highlighted a high inter-individual variability in the ability of runners to maintain moderate levels of intensity for a prolonged period. Of the 14 participants whom they had recruited, only six were able to maintain a velocity associated with 80% $\dot{V}O_2$max for a 90-minute duration. For these reasons runners in this research paced their runs to HR.

5.3 Data analysis

Data were analysed using MS Excel, SPSS. The data were assessed for parametric assumptions and were checked as recommended by Field (2009). Normality was assessed using the Shapiro-Wilks (1965) test.

An independent t-test was used to establish whether there were significant differences between the two groups in terms of body mass loss and fluid intake over the course of the run (results presented in Table 5.6).

To assess the impact of training on physiological markers recorded during laboratory GXTs and long run assessments, Analysis of Covariance (ANCOVA) was used to compare groups (results presented in Table 5.7). For key physiological parameters, change scores were calculated (post

minus pre scores) and change scores in each group were compared utilising the baseline scores as a covariate (Atkinson and Batterham, 2015).

The analysis of the data from the long run undertaken in the laboratory was assessed initially using an independent t-test. This analysis was conducted to assess whether differences existed in the first half of the two long run training protocols. Data from the second half of the long run was assessed using ANCOVA utilising change scores (second half values minus first half values) with the covariate of first half data included in the model (results presented in Table 5.7).

The Pearson Product Moment correlation was used to establish relationships between simulated time trial performance and data from GXT. Multiple stepwise regression analysis was also performed on raw data to establish if performance could be predicted.

Descriptive and analytical statistics used included Excel, SPSS and Graph Pad Prism. All data presented as mean+/- standard deviation, and an alpha level of 0.05 was used for these analyses.

5.4 Results

All participants completed visits one to three. Twice daily participants also completed an additional fourth visit (Table 5.2). Table 5.5 displays the laboratory performance times and their relationship with laboratory based predicted times.

Nutritional intake before the long run

All participants consumed a breakfast before conducting their long run. There was no significant difference in the mean calorific content (kcal) of the breakfast between the two groups ($p = 0.622$) or the % CHO ($p = 0.865$), % fat ($p = 0.472$) or the % protein ($p = 0.386$) (Table 5.3).

Table 5.3. Mean and Standard deviation (SD) of breakfast nutritional composition before the long run for both groups

Group	CHO %	Fat %	Protein %	Kcal
Once daily	60.2 ± 8.1	23.9 ± 8.6	15.9 ± 5.5	602 ± 119
Twice daily	59.8 ± 6.1	25.9 ± 7.7	14.3 ± 5.2	575 ± 192

There was no significant difference in lunch time meal for the mean calorific content (kcal) between the two groups ($p = 0.149$) or the % CHO ($p = 0.734$), % fat ($p = 0.091$) or % protein ($p = 0.149$) (Table 5.4). This occurred by chance as participants were not instructed as to what they should eat.

The twice daily group consumed a meal consisting of 53.1 ± 8.5 % CHO, 30.2 ± 9.6 fat & 16.7 ± 4.4 % protein, equating to 788 ± 250 Kcal before commencing the second half of the long run. Conversely, the once daily group consumed a lunch with a mean macronutrient ratio of 54.6 ± 4.9 % CHO, 24.5 ± 6.4 fat & 21.2 ± 6.5 % protein, equating to 901 ± 208 Kcal (Table 5.4). However, this was consumed upon completion of the continuous (AM) session. There were no significant differences between the two groups for macronutrient intake (%).

Table 5.4 Mean and Standard deviation (SD) of lunch time meal nutritional composition for both groups

Group	CHO %	Fat %	Protein %	Kcal
Once daily	54.6 ± 4.9	24.5 ± 6.4	21.2 ± 6.5	901 ± 208
Twice daily	53.8 ± 7.6	29.2 ± 9.4	17 ± 5	788 ± 250

Table 5.5 Mean and Standard Deviation (SD) of 5 km times and predicted 5 km times using equations 1 and 2.

Variables	Mean ± SD	r
5 km TT (lab) (seconds)	1142 ± 104	
Equation 1 (PTv)	1166 ± 85	0.93
Equation 2 (vVT, RE12)	1119 ± 93	0.89

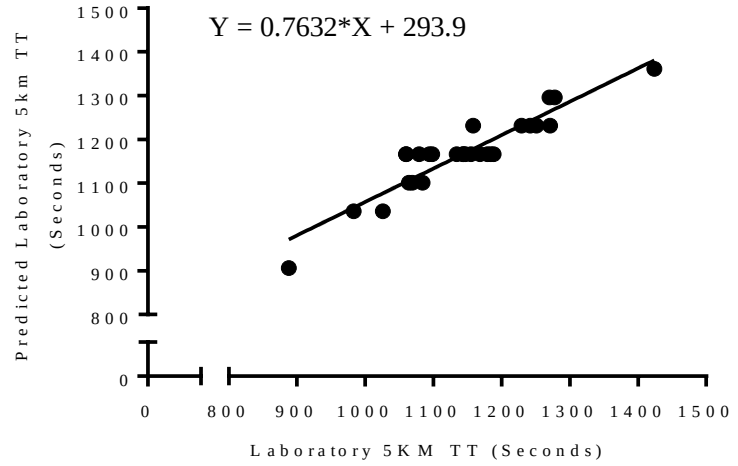


Figure 5.1. Relationship between laboratory 5 km TT and predicted laboratory 5 km TT (PTv)

(r = 0.93, r2 = 0.86)

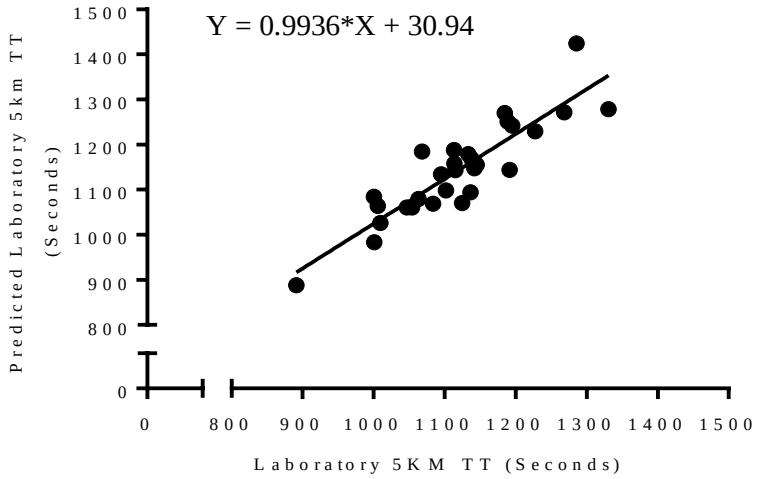


Figure 5.2. Relationship between laboratory 5 km TT and predicted laboratory 5 km TT (vVT & RE12)

(r = 0.89, r2 = 0.79)

Fluid intake & Body Mass (BM) change during the long run

During the long run, water was provided to all participants and they were free to drink *ad libitum*. Participants in the once daily group consumed 0.38 ± 0.16 (L) during the prolonged run while the twice daily group consumed 0.18 ± 0.16 (L) in the morning (AM) session and 0.14 ± 0.21 (L) in the evening (PM) session.

Table 5.6 identifies significant differences in body mass (BM) during the run for the once daily group (p = <0.001) and the twice daily group (p = <0.001). The once daily group saw a greater reduction with -1.6 ± 0.4 kg, compared with a -1.2 ± 0.3 kg reduction during the AM session and -1.3 ± 0.3 kg during the PM session for the twice daily group. This equated to a -2.4 ± 0.9 % change in BM for the once daily group, and -1.7 ± 0.4 and -1.8 ± 0.4 % change for the twice daily groups. Although perhaps this is an unfair comparison as the once daily group were running for twice as long as the twice daily group and participants of the once daily group were not stopped mid way and weighed. Furthermore, it is not known how much of the weight replacement of the PM run for the twice daily group is related to food intake and how much is hydration replacement.

Table 5.6 Mean (SD) fluid balance post long run, results of the ANCOVA. ** = significant reduction in BM during the run (p<0.001)

Group	Mass (pre-run)	Fluid intake (L)	mass loss (kg)	% body mass loss
Once Daily	69.4 ± 7.7	0.4 ± 0.16	-1.6 ± 0.4**	-2.4 ± 0.3**
Twice Daily (AM)	70.7 ± 5.8	0.18 ± 0.2	-1.2 ± 0.3**	-1.7 ± 0.4**
Twice Daily (PM)	70.5 ± 5.8	0.14 ± 0.2	-1.3 ± 0.3**	-1.8 ± 0.4**

Velocity change during the long run

As participants paced the run to a fixed HR zone, velocity was recorded during the run to assess any changes. Comparison of the velocity at the 15 minute point with the mean velocity in the final minutes of the run revealed that both groups saw a significant reduction in velocity during the run to maintain the heart rate (HR) zone corresponding to 70-75% $\dot{V}O_2$max ($p = <0.001$) (Table 5.7). Both groups were able to maintain this HR zone. Furthermore, the reduction of the once daily group was larger (-1.04 ± 0.34 $km \cdot h^{-1}$) than was seen in both the AM (-0.7 ± 0.3 $km \cdot h^{-1}$) and PM (-0.8 ± 0.3 $km \cdot h^{-1}$) sessions for the twice daily group ($p<0.001$).

Table 5.7 Mean (SD) Velocity at the 15 minute point and the final minute of each run ($^{*}p < 0.05$ $^{**}p< 0.001$)

Group	Velocity at 15 mins $km \cdot h^{-1}$	Velocity half way $km \cdot h^{-1}$	Change in Velocity $km \cdot h^{-1}$	Velocity final minute $km \cdot h^{-1}$	Change in Velocity $km \cdot h^{-1}$
Once Daily	13.1 ± 1.5	12.5 ± 1.5	-0.6 ± 0.1	12.0 ± 1.5*	-1.1 ± 0.2**
Twice Daily (AM)	13.3 ± 1.3			12.6 ± 1.3*	-0.7 ± 0.1
Twice Daily (PM)	13.3 ± 1.2			12.5 ± 1.2*	-0.8 ± 0

Volume of Oxygen ($\dot{V}O_2$) consumed during the long run

There was a significant reduction in mean $\dot{V}O_2$ consumed during the second half of the run in both groups, resulting in a mean difference of -0.095 ± 0.23 $mL \cdot min^{-1}$ ($p<0.001$) for the once daily group, and -0.047 ± 0.25 $mL \cdot min^{-1}$ ($p = 0.026$) for the twice daily group where the difference was taken between the AM and PM runs (Table 5.8). There was no statistical significant difference ($p = 0.169$) between the groups (Table 5.8).

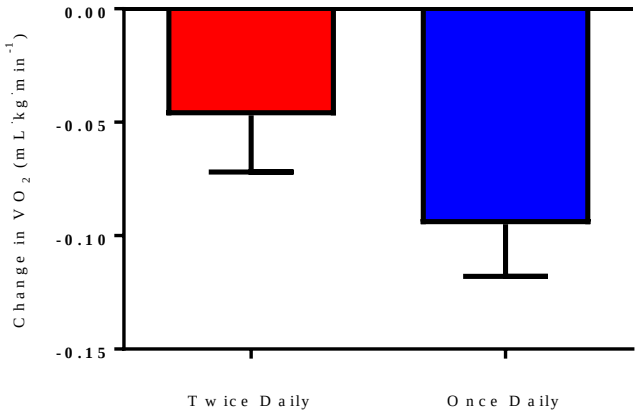


Figure 5.3. Mean change in $\dot{V}O_2$ during the long run

However, comparison of $\dot{V}O_2$ consumption at the end of the first half of the run with the end of the second half revealed a slight reduction in the (mean) difference for the once daily group to -0.073 ± 0.027 mL·min^{-1} while increasing for the twice daily group -0.052 ± 0.029 mL·min^{-1}, thus reducing the difference between the groups to -0.021 ± 0.04 mL·min^{-1}, (p= 0.608).

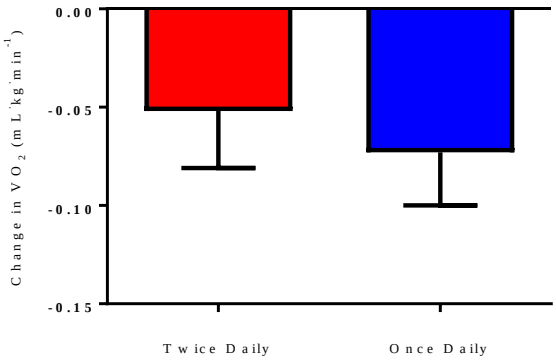


Figure 5.4. Mean change in $\dot{V}O_2$ at the end of each half of the long run

Running Economy (RE) during the long run

Running economy deteriorated during the second half of the run for the once daily group represented by an increase in the difference of 2.7 ± 1.8 mL·kg^{-1}·km^{-1}, conversely, RE improved for the twice daily group represented by a decrease in the difference of -3.7 ± 2.1 mL·kg^{-1}·km^{-1}

for the twice daily group (Table 5.8) resulting in a statistically ssignificant difference between groups of -6.4 ± 2.9 $mL \cdot kg^{-1} \cdot km^{-1}$ (p = 0.033) (Figure 5.8).

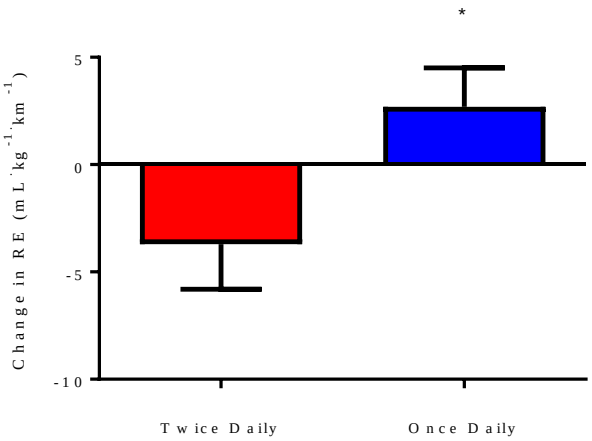


Figure 5.5 Mean change in RE during the long run

Comparison of RE at the end of the first half of the run with the end of the second half revealed that RE continued to deteriorate (represented by an increase) for the once daily group resulting in a difference of 4.4 ± 2.1 $mL \cdot kg^{-1} \cdot km^{-1}$. Conversely, the twice daily group continued to improve (represented by a decrease) resulting in a difference of -4.3 ± 2.4 $mL \cdot kg^{-1} \cdot km^{-1}$ thereby increasing the mean difference between the two groups to -8.7 ± 3.3 $mL \cdot kg^{-1} \cdot km^{-1}$ (p = 0.013).

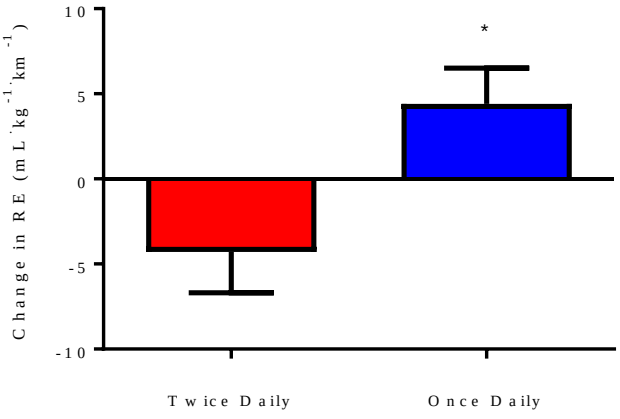


Figure 5.6 Change in RE at the end of each half of the long run *(p<0.001).

Respiratory Exchange Ratio (RER) during the long run

Mean RER decreased throughout the long run for the once daily group (Fig.5.7). For this group, comparison of the mean RER during the first half of the run with the second half revealed a difference of -0.03 ± 0. Conversely, the twice daily group displayed the opposite response with an increase in the mean RER during the second (PM) session resulting in a mean difference of 0.02 ± 0. This resulted in a statistically significant difference between the two groups of -0.05 ± 0 (p<0.001).

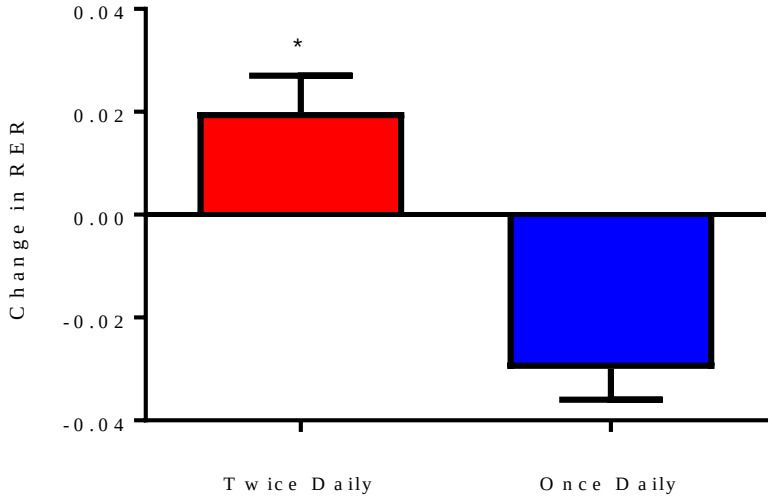


Figure 5.7 Mean change in RER during the long run

There was no further change in RER at the end of each half of the run for either group: with the once daily group maintaining a difference of -0.03 ± 0.006 and the twice daily group maintaining a difference of 0.02 ± 0.007 between the AM and PM sessions (Fig.5.8) and therefore maintaining the difference between the two groups had reduced slightly (-0.05 ± 0.009). (p<0.001).

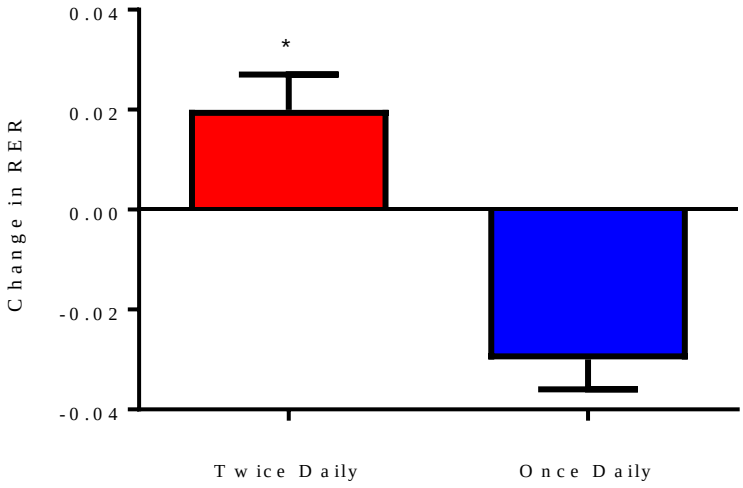


Figure 5.8 Mean change in RER at the end of each half of the long run *($p<0.001$)

Estimated fat utilisation during the long run

A comparison of the total grams of fat consumed during the first half of the run with the second half highlighted that the once daily group saw an increase during the second half resulting a difference of 5.5 ± 1.6 grams (Fig.5.9). Conversely, the twice daily group saw a decrease in the total amount of fat consumed during the second half of the run resulting in a difference of -7.4 ± 1.8 grams. This resulted in a significant difference between the two groups of 12.9 ± 2.4 grams ($p<0.001$).

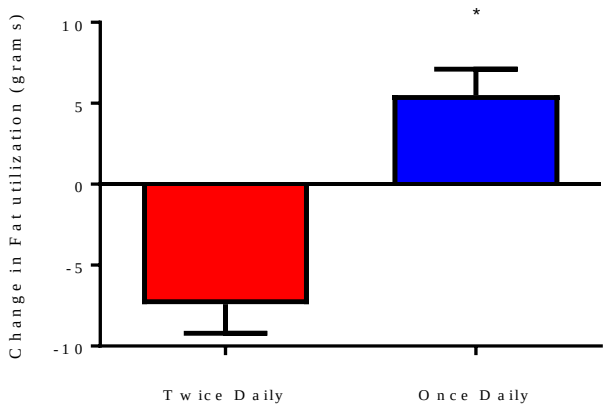


Figure 5.9. Change in Mean fat utilization during the long run (pre intervention) *($p<0.001$)

Table 5.8 Mean (SD) differences between physiological variables in once or twice daily training groups.

Variables	Mean ± SD Once daily	Mean ± SD Twice daily	End ± SD Once daily	End ± SD Twice daily
$\dot{V}O_2$ ($mL \cdot min^{-1}$)	-0.095 ± 0.023	-0.047 ± 0.025	-0.073 ± 0.027	-0.052 ± 0.029
RE ($mL \cdot kg^{-1} \cdot km^{-1}$)	2.7 ± 1.8	-3.7 ± 2.1	4.4 ± 2.1	-4.3 ± 2.4
RER	-0.03 ± 0.006	0.02 ± 0.007	-0.03 ± 0.005	0.02 ± 0.005
Fat utilisation (grams)	5.5 ± 1.6	-7.4 ± 1.8	4.3 ± 1.2	-5.2 ± 1.4

*$p < 0.001$ compared with the pre-test values

Table 5.9 Mean (SD) and End (SD) differences between once and twice daily groups. (*$p < 0.05$ **$p< 0.001$)

Mean			
Physiological Variables	Mean (Difference)	SD	P-Value
$\dot{V}O_2$ ($mL \cdot min^{-1}$)	-0.049	0.035	0.169
RE ($mL \cdot kg^{-1} \cdot km^{-1}$)	-6.4	2.9	0.033*
RER	-0.05	0.009	<0.001**
Fat Consumed (grams)	12.9	2.4	<0.001**
final minute of each run			
	Mean (Difference)	SD	P-Value
$\dot{V}O_2$ ($mL \cdot min^{-1}$)	-0.021	0.04	0.608
RE ($mL \cdot kg^{-1} \cdot min^{-1}$)	-8.7	3.3	0.013*
RER	-0.04	0.009	<0.001**

5.5 Discussion

This study aimed to assess whether significant differences emerged in selected physiological variables between two groups of runners who had undertaken either once or twice daily training. Runners were compared after completing a single day's training only, and so the study examined the immediate effects of twice daily training. This study clearly demonstrates that in a group of MTRs, there are statistically significant differences in physiological variables based on the two formats of running.

5.5.1 Differences in Velocity

A significant difference emerged between the velocities at which both groups performed their total day's run (made up of either one longer or two shorter runs). A greater reduction in speed was seen in the once daily group (-1.1 ± 0.2 $km \cdot h^{-1}$) than was seen in either the AM (-0.7 ± 0.1 $km \cdot h^{-1}$) or PM (-0.8 ± 0 $km \cdot h^{-1}$) sessions for the twice daily group (table 5.7).

It is likely that this occurred because participants paced their runs using HR. In order to maintain the heart rate in this zone both groups were required to reduce the velocity of the treadmill. During prolonged exercise, when euhydration is not maintained and dehydration increases, a gradual increase in HR is seen. This is referred to as HR drift (Hamilton et al., 1991; Montain and Coyle 1992), this results from reduced PV and in turn, a reduced SV. In order to compensate for this reduced SV, $\dot{Q}$ (and thus HR) is increased. Therefore, in cases where runners attempt to maintain a HR zone during prolonged running, as dehydration occurs and cardiac drift increases, exercise intensity (velocity) must be reduced. This was observed to a greater extent in once daily group who did not have the opportunity to stop and rehydrate fully at the mid way point like the twice daily runners.

Thus it is likely that the greater reduction in velocity seen in the once daily group (Table 5.7) occurred due to the longer run time during a single session, with the longer duration leading to greater levels of dehydration for the once daily participants. Research (Lambert *et al.,* 1998)

confirms this showing that cardiac drift increases with the duration of a training session. The additional time the once daily group spent running could therefore, have resulted in a larger drift in HR compared with the twice daily group.

It is unlikely that the greater reduction in velocity of the once daily group was due to greater levels of fatigue. This is because all runners in this study completed runs that were of a familiar duration. If this precaution had not been taken, fatigue would have become a confounding variable. Research has shown that when runners who consistently run for relatively short periods, <45 minutes, and are asked to run for far longer periods, in some cases up to four hours (Davies and Thompson, 1986), notable biomechanical alterations such as reduced stride length and reductions in muscular strength may be experienced, compared with runners who habitually run for >2 hours (Cavanagh *et al.*, 1977; Cavanagh & Williams, 1981). When these alterations are experienced, $\dot{V}O_2$ consumption is increased to a greater degree compared with those runners who regularly train for longer periods. This can lead to erroneous results.

Thus a strength of this research is that all participants conducted runs that were of the same duration as the runs they had conducted on a weekly basis for six months preceding the study and therefore represented a typical period of training. This consideration is often omitted from other published research (Xu & Montgomery, 1995, Helgerud et al., 2007) as it is assumed that a group of runners who are homogenous in terms of a physiological marker such as $\dot{V}$O2 max, or a performance marker such as a 5 km TT, would be homogenous in terms of training volume - but this is not necessarily the case. The participants recruited in Study 2 highlight this point as they were homogenous in terms of mean $\dot{V}$O2 max (60.32 ± 6.3 mL.kg-1.min-1) which placed them within the MTR category. In spite of this there was a large variation in the duration of their long run which was 95 ± 24 minutes.

5.5.2 Differences in Volume of Oxygen ($\dot{V}O_2$)

No differences in the volume of oxygen consumed ($\dot{V}O_2$) were observed between the two groups. Both groups saw reductions in the $\dot{V}O_2$ consumed throughout the day's running. At first

inspection this finding appears to conflict with other research where increases in mean $\dot{V}O_2$ consumed of up to 10 % have been reported (Saltin & Hermansen, 1966; Davies and Thompson,1986; Dressendorfer, 1991; Xu & Montgomery, 1995; Kyrolainen *et al.,* 2000). However, it is important to note that key differences exist between this study and previous research in the pacing strategy used to set and maintain exercise intensity. Much of the research referenced used pacing strategies that involve participants running at a fixed velocity associated with a predetermined percentage of $\dot{V}O_2$ max. In these cases, it is widely reported that $\dot{V}O_2$ consumed increases. The increased $\dot{V}O_2$ has been attributed to several factors, these include: increased energy expenditure associated with dissipation of the heat generated during exercise (Hagberg *et al.,* 1978); increased HR (Westerland *et al.,* 1992); increased VE (Casaburi *et al.,* 1986); increased fat metabolism (Lamb 1984); increased growth hormone and blood catecholamine concentrations (Kaciuba-Uscilko *et al.,* 1992), and increased muscle fibre recruitment due to muscle fatigue (Davies and Thompson 1986). However, as discussed in this trial participants paced their runs according to HR and so this will explain the reduction in $\dot{V}O_2$ consumed.

5.5.2.1 Differences in $\dot{V}O_2$ uptake during each half of the run

When comparing mean $\dot{V}O_2$ consumption between the two groups during each half of the run, there was a greater reduction for the once daily group compared with the twice daily group (-0.095 ± 0.23 vs -0.047 ± 0.25 $mL.min^{-1}$). As stated earlier, the once daily group reduced the velocity to a greater extent than the twice daily group (Table 5.7) to maintain the HR zone and it is likely that this was due to the longer run times leading to greater levels of dehydration and in turn a greater HR drift. A HR drift of this magnitude was also observed by Hamilton *et al*. (1991). This reduction in velocity contributed to a greater overall reduction in $\dot{V}O_2$ for the once daily group.

Interestingly, analysis of $\dot{V}O_2$ consumption at the end of each half identified that despite a continual reduction in velocity, the once daily group still experienced a slight increase in $\dot{V}O_2$

consumption in the final minutes of their single run. This increase reduced the mean difference from -0.095 ± 0.23 to a difference in the final stages of -0.073 ± 0.027 $mL \cdot min^{-1}$ (Table 5.8). Conversely, analysis of the twice daily group revealed that they did not experience the same increase, though $\dot{V}O_2$ consumption increased slightly during the final stages of the PM run resulting in a further decrease from the mean of -0.047 ± 0.25 $mL.min^{-1}$ to a final difference of -0.052 ± 0.029 $mL \cdot min^{-1}$. Therefore, the twice daily group maintained a stronger relationship between HR and $\dot{V}O_2$ than the once daily group, Increased $\dot{V}O_2$ consumption seen during the latter stages of prolonged running has also been attributed to increased energy expenditure associated with dissipation of the heat generated during exercise (Hagberg *et al*., 1978), increased growth hormone and blood catecholamine concentrations (Kaciuba-Uscilko *et al*., 1992), or a decrease in the ability of the runner to generate muscular force leading to an increase in the recruitment of smaller muscle fibers for force maintenance (Davies and Thompson 1986). Because the once daily group ran for twice the duration of the twice daily group it is quite possible that the increase in $\dot{V}O_2$ seen in the final minutes of the once daily group could be attributed to any, or a combination of, some or all of these factors.

As attempts were made to reduce the time the participants spent in the laboratory, body temperature, catecholamine concentrations or muscular strength were not measured. Therefore, at this time the researcher is unable to confirm these suggestions though it is hoped that there will be opportunity to extend this research in the future. The differences in $\dot{V}O_2$ consumption which are evident between the two groups during the second half of a prolonged run suggest that splitting a long run into two sessions exposes the runner to different physiological stresses, compared with performing the run in one continuous session.

5.5.4 Differences in Running Economy (RE)

Comparison of mean RE during the first half of the long run with the second half revealed that while RE deteriorated for the once daily group during the second half of the run, reflected by an increase of 2.7 ± 1.8 $mL \cdot kg^{-1} \cdot km^{-1}$, the opposite response was seen in the twice daily group

where an improvement in RE during the second half was seen, and reflected by a decrease of -3.7 ± 2.1 $mL \cdot kg^{-1} \cdot km^{-1}$. While the findings for the once daily group are supported by previous research where significant increases in RE were recorded during prolonged running (Saltin & Stenberg, 1964; Davies & Thompson, 1986; Xu and Montgomery, 1995, Sproule, 1998), the findings of decreased RE seen in the twice daily group appear to contradict previous findings.

However, it is important to remember that different methods employed in this study to collect physiological variables prevent direct comparisons from being made. Previous research included researchers using a fixed velocity (Saltin & Stenberg, 1964; Davies & Thompson, 1986; Dressendorfer, 1991; Xu and Montgomery, 1995; Sproule, 1998; Xu & Montgomery, 1995) to measure RE as opposed to the fixed HR zone used in this research. Although this disallows direct comparisons between this and other research, the protocol used here can be justified. It was felt that using fixed velocity, rather than fixed HR, was not an appropriate protocol choice as training to a fixed velocity is unrealistic in real-word conditions. In their weekly training schedules runners will run up and down hills, sometimes against the wind or wind assisted, making it very difficult to keep to a fixed velocity.

For these reasons, it would be unlikely that participants in the above-mentioned research, who ran at a fixed velocity, would all be running at the same intensity, as measured by a HR zone. In Study 2, a HR zone relative to 70-75% $\dot{V}O_2max$ was used. As a result, RE was not simply expressed as $\dot{V}O_2$ relative to body mass:

O_2 ($mL \cdot min^{-1}$) / Mass (kg) = $mL \cdot kg^{-1} min^{-1}$

Instead RE was expressed relative to velocity:

O_2 ($mL \cdot kg \cdot min^{-1}$) / speed ($km \cdot h^{-1}$)/60) = $mL \cdot kg^{-1} \cdot km^{-1}$

To account for differences and changes in running velocity.

As previously stated (Chapter 4.6), outdoor testing can be problematic due to adverse weather conditions. Factors such as wind speed and ambient temperature have been shown to alter RE

(Saunders *et al*., 2004). It has also been suggested that exercising in cold temperatures can lead to increased $\dot{V}O_2$ consumption due to the additional oxygen requirements of shivering (Davies *et al*., 1975; Nadel *et al*., 1974). This could partly explain the increased $\dot{V}O_2$ and thus, poorer RE seen in the study of Xu and Montgomery (1995) as they reported mean temperatures during testing of 2.6°C. Conversely, the Dressendorfer (1991) study reported mean temperatures of 25°C and interestingly, they reported that RE was unchanged after a long run.

Possible explanations as to the different responses seen between the two groups in Study 2 are likely to be due to the combination of greater levels of dehydration for the once daily participants, as evidenced by body mass loss (Table 5.6), causing a larger drift in HR for the once daily group than the twice daily group.

This study presents new insight that a twice daily training may have the potential to alter the physiological response in RE when compared with once daily training. As the researcher has been unable to find any notable published investigations into the physiological differences between using once or twice daily training at the present time further research is required.

5.5.5 Differences in Substrate utilization

During steady-state exercise, RER can be used to estimate substrate utilization. For the once daily group, comparison of mean RER (and thus substrate utilization) during the first half of the run with the second half identified a decrease in RER of -0.03 ± 0. This confirmed the findings of Costill (1970); Astrand & Rodahl (1986) and Xu & Montgomery (1995) that typically, during prolonged exercise an increase in fat oxidation is seen. Conversely, for the twice daily group, comparison of mean RER during the first (AM) session with the second (PM) session revealed an increase in RER resulting in a mean difference of 0.02 ± 0. This indicated that during the second session, the twice daily group saw an increased reliance on CHO and a decrease in fat resulting in a significant difference in RER between the two groups (-0.05 ± 0). As such, Study 2 provides further evidence that clear differences exist in key physiological variables, in this case the substrate oxidized to fuel the second half of the run. This is because during prolonged

exercise, in an attempt to preserve the body's finite glycogen stores a gradual shift towards fat oxidation is seen.

These differences in RER were also reflected in each group by the estimated fat utilization during each half of the long run. For the once daily group, this resulted in a mean increase of 5.6 ± 1.6 grams during the second half of the run while the twice daily group experienced a decrease of -7.4 ± 1.8 grams during the second half of the run.

Owing to a better economy of carbohydrate oxidation versus fat oxidation (ATP produced per L of oxygen combusted) (Zuntz & Schumburg, 1901; Krogh & Lindhard, 1920; Cole *et al.*, (2014)), in a performance setting, the ability to utilize this fuel is vital. As the group conducting twice daily training displayed an increase in CHO oxidation during the second half of the run this form of training could provide a method of regularly exposing the runner to increased periods of higher CHO oxidation. The performance benefit associated with this is that when a runner needs to use CHO in a performance setting they will be more able to do this as the CHO metabolic pathways will be more established.

Conversely, the ability to oxidize fat during prolonged periods of low intensity running also has the ability to indirectly improve performance through the preservation of CHO stores (Lambert *et al*., 1994; Yeo *et al*., 2011). While the once daily group in Study 2 displayed an increase in fat oxidation during the prolonged run, this group also saw a greater reduction in velocity (-1.1 ± 0.2 $km \cdot h^{-1}$) than the twice daily group in both the AM (-0.7 ± 0.1 $km \cdot h^{-1}$) and PM (-0.8 ± 0 $km \cdot h^{-1}$) sessions. As the motivating factor for the MTR is ultimately to improve running performance it may therefore be quite possible that the once daily training might not be as effective as the twice daily training method.

As previously mentioned, the differences in methods used to collect physiological measures in Study 2 prevent direct comparisons from being made regarding substrate use with other research. However, it is still interesting to note that there appears to be distinct lack of research investigating substrate oxidation when using different pacing strategies such as pacing to HR

rather than pacing to a fixed velocity. Hawley & Leckey (2015) also point this out by stating that direct measures of rates of fuel utilization during training or competition are scarce. As runners of all abilities frequently use HR to set and maintain pace throughout their training, Study 2 adds to our understanding by investigating how RER and estimated substrate utilisation respond under circumstances where different pacing strategies are used. Further investigation into the chronic impacts of conducting these two different forms of training on the MTR is thus warranted.

In previous cases where running velocity is fixed, a gradual decrease in RER is seen over the course of a run reflecting an increase in fat oxidation and subsequent decrease in CHO oxidation to preserve finite CHO stores (Hawley & Leckey, 2015). The findings in this second study demonstrate that when MTRs pace their long run to HR, a reduction in RER is still seen for the once daily group despite a reduction in both velocity and VO_2 during the second half. Conversely, although the twice daily group also saw a reduction in velocity and VO_2 during the second half of the run, RER increased. This finding therefore supports the previous suggestions that reductions in RER are heavily dependent on exercise duration (Bergman & Brooks, 1999) if exercise is a continuous bout.

Moreover, that the twice daily group compled the second half of the run after a relatively long period (6-8 hours) of recovery will also have inevitably influenced substrate oxidation. During this period participants would have had the opportunity to eat a carbohydrate rich meal which would then have been available as fuel for the second run of the day. Bishop (2017) suggests that when training twice daily, recovery times of less than two hours between sessions are superior in terms of the subsequent signaling responses seen compared with recovery times of greater than five hours. The researcher would argue that conducting twice daily training with recovery periods of less than two hours is likely to be problematic for the MTR due to fitting in training around work times. As such, participants in this study were given longer recovery periods of 6-8 hours in order to reflect real world conditions.

On the day of the trial both the once and twice daily groups were asked to follow their habitual dietary intake, analysis of the twice daily runner's food diaries confirmed that all runners in the twice daily group consumed a lunchtime meal with moderate levels of CHO (Table 5.4) prior to commencing the second half of the run. Research has consistently demonstrated that consuming moderate to high levels of CHO three to four hours prior to exercise increases CHO oxidation (Coyle *et al*., 1985; Wright *et al*., 1991; Coyle *et al*., 1997; Cox *et al*., 2010; Cole *et al*., 2014) and depresses fat oxidation (Costill *et al*., 1977; Coyle *et al*., 1985; Wright et al., 1991). Conversely, while the once daily group also consumed a lunch time meal with moderate levels of CHO, this was consumed after the run. They therefore completed the whole run in one session and consumed only water before the second half. As a consequence, it was highly likely that they performed the second half of the run with substantially lower stores of endogenous CHO evident from investigations by Coyle *et al*, (1986) who reported that endurance-trained cyclists comparable in training status to the runners in the current investigation utilized 30-40 % of their muscle glycogen content after 45 min of steady-state cycling at 70% of individual $\dot{V}O_2$ peak.

There is increasing evidence that performing an acute bout of training with low exogenous or endogenous CHO availability (termed 'train low') leads to greater cellular adaptations in the hours that follow (Hawley & Burke, 2010; Lane *et al*., 2015; Bartlett *et al.*, 2015). When a small portion of train low is incorporated into a periodised plan and performed over a prolonged period (6-12 weeks) specific muscle adaptation occur to a greater extent than undertaking all sessions with either high or low CHO availability. Such muscle adaptations led to improved performance in some (but not all) endurance exercise tests (Morton *et al.,* 2009).

Deliberately training with reduced CHO is a less appropriate strategy for runners competing over shorter race distances such as the 5km distance of the runners in this study as CHO is the preferred fuel source over this length of race. However, for longer distance races, this would put runners at an advantage because they will have preserved their stores of CHO for when they need them most.

In summary, RE, RER and fat consumed were significantly different between the two groups but all without a concomitant difference in VO_2 between the two groups. Further research is needed to investigate this finding.

5.6 Conclusion

Study 2 aimed to assess whether there are notable differences in selected physiological variables when performing a habitual long training run paced by HR compared with when this long run is split into two shorter runs of equal length one session performed in the morning (AM) and the second session performed in the evening (PM). Chapter 5 clearly demonstrates that in the acute setting, significant differences between once daily training and twice daily training are seen for both RE ($p<0.033$) and substrate utilization ($p<0.001$). Taking RE first, this declined for the once daily group but improved for the twice daily group and this may be linked to the substrates used. In relation to substrate utilization, the once daily group metabolised larger proportions of fat towards the end of the run whereas the twice daily metabolised larger proportions of CHO, possibly because they did not run for long enough to shift their fuel source to fat. Furthermore, a significant difference in the reduction in speed between the two groups emerged with the once daily group reducing their velocity to a greater extent than the twice daily group. This finding is in line with other research which has shown that faster running speeds, such as those needed for a 5km running race, can be maintained by utilizing CHO as a fuel source rather than fat (Brooks and Trimmer, 1996).

This study presents new insight into the acute physiological response a MTR experiences, when they split their long run, paced by HR (rather than velocity) performed at a relatively low intensity (75% $\dot{V}O_2max$) into two sessions of equal length, with one session performed in the morning (AM) and the second session in the evening (PM). It appears that splitting training into two sessions may be beneficial for runners wishing to run a fast 5km time as it encourages CHO utilization as a fuel source, rather than fat, and this has been associated with faster 5km running times. Furthermore, training velocity has been shown to predict a runner's 5km running

performance (Hagan *et al*., 1981; Knechtle *et al*., 2014) and so training faster leads to improved race times over 5km. Thus twice daily training could be of value in informing future training program design for MTRs.

Chapter 6 - (Study 3): The difference between once daily and twice daily training on factors associated with running performance in the chronic setting.

6.1 Introduction

In Study 2 (Chapter 5) the Researcher was able to confirm that in the acute setting, significant differences in physiological variables such as RE and substrate utilisation are seen during the second half of a MTR's long run when they split their normal long run (performed at low intensity) and perform the second half of this run after a period of 6-8 hours.

Study 3 therefore aims to build on the findings of chapter 5 where a comparison of once daily and twice daily training was conducted in the acute setting, by comparing the adaptions seen when MTRs perform a six-week training plan that includes five days per week of training with two days conducted as either twice daily training or once daily training.

A second aim of Study 3 is to investigate the capacity of equations (chapter 4, equations 1 – 4), developed in Study 1 (Chapter 4), to predict 5 km TT performance in a separate cohort if MTRs.

Study 3, therefore, aims to investigate if differences are seen in the variables; velocity, $\dot{V}O_2$, RE and RER, measured during the long run, between two sample groups of MTRs, one group having split their long weekly training run into two parts and the other group having completed the long training run in one continuous session over a period of 6 weeks.

To date, research design investigating twice daily training in both the acute and chronic setting has used methods that allow researchers to control for a number of environmental, physiological and nutritional variables. In some cases this can result in the training design used bearing little resemblance to real world conditions, especially for the MTR who usually performs far lower volumes of training than the elite level runner, but at the same time far higher volumes than untrained runners. Examples of such research designs which have been trialled include using uniform run distances for all runners; using exercise intensity expressed in velocity to pace the run, or using short (1-2 hour) rest periods between training sessions. However, while research suggests that these short recovery times are sufficient to conduct a second training session

(Croft *et al*., 2009; Hansen *et al*., 2005; Hulston *et al*., 2010; Yeo *et al*., 2008), conducting twice daily training with recovery periods of less than two hours is likely to be problematic for the MTR who may have to fit training around work times. In order for MTRs to use this form of training, longer recovery periods of 6-8 hours should be used in order to reflect real world conditions.

There is evidence that increasing the volume of LIT during the foundational stage of training is important to achieving peak performance because it sets the foundations upon which future performance gains can be seen (Holloszy & Coyle, 1984; Seiler, Haugen & Kuffel, 2007; Yeo Paton, Garnhamm, Burke, Carey, Hawley 2008). However, as stated in Chapter 5, the MTR may well be limited by time available to train, and therefore may not be able to commit the time for increased volumes of LIT. For these runners it may, however, be possible to perform two sessions of shorter duration, one in the morning before work and one after work in the evening (Jones, 2018). However, at present, there is little published literature to support this practice and as a result our understanding of the consequences that opting for this different approach to training may have on physiological variables, or indeed RP, is far from clear. Study 3 aims to fill this knowledge gap.

6.2 Methods

Forty-two moderately trained male endurance runners were recruited. Taking into consideration effect sizes from the literature (Hulston *et al*., 2010; Croft *et al*., 2009), a large effect size of d=0.5 was modelled in an a priori power analysis with a power set to 80% based on an ANCOVA. A total sample size of 34 individuals was needed to achieve this, thus 42 were recruited to allow for drop outs. It was felt that this extent of over-recruitment was necessary due to the length of the training programme (six weeks) a time span which might be onerous and thus increase the likelihood of participants dropping out. All participants reported they had been running for more than two years and had been running at least five hours per week in the three months leading up to the intervention. For information regarding participant consent and pre intervention procedures, the reader is referred to the General Methodology, chapter 3. The

physical characteristics of the participants can be seen in Table 6.1. Participants were randomly assigned to one of two groups, either the once daily or twice daily training group. Before testing began, all participants visited the laboratory on two occasions to complete two familiarization trials, a GXT and a 5 km time trial (TT).

Table 6.1 Participant characteristics.

	Mean ± SD All runners for	Mean ± SD once daily group	Mean ± SD twice daily group
Age (years)	30.7 ± 9.1	30.9 ± 8.7	30.5 ± 9.4
Height (cm)	177 ± 6.9	177 ± 6.8	177 ± 7.1
Mass (kg)	70.2 ± 6.6	70.3 ± 7.2	70.1 ± 5.8
∑ of eight skin fold (mm)*	57.2 ± 27.5	58.1 ± 23.9	56.3 ± 26.1
$\dot{V}O_2max$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	60 ± 5	60.1 ± 5	59.6 ± 5
Long run length (min)	89 ± 23	87 ± 21	92 ± 23

Note. *∑ of eight skinfold sites to include, subscapular, triceps, biceps, iliac crest, supraspinale, abdominal, front thigh & medial calf.

Experimental protocol

The following provides an overview for the experimental design shown in Figure 6.1. The participants were randomly divided into two groups; those who would train once daily and those who would train twice daily. Once familiarisation trials had been completed, participants in the once daily group performed three experimental laboratory visits prior to starting the intervention, while participants in the twice daily group performed four. Visit 1 was to determine the participant's $\dot{V}O_2max$, LT/VT and RE. Visit 2 was to perform a treadmill 5 km performance time trial. For details on the equipment and protocols used the reader is referred to section 3.16 and 3.17. Visits 3 and 4 were to conduct each participant's long run corresponding to the same habitual volume the runner had been completing in the three months preceding the study at a HR zone corresponding to an intensity of 70-75 % $\dot{V}O_2max$. Participants in the once

daily group were randomly assigned to either AM or PM groups and performed their long run as one continuous run. Participants in the twice daily group were required to visit the laboratory in the morning and evening, splitting their long run into two equal volume runs, performed AM and PM, with 6-8 hours of recovery between sessions. The twice daily participants were free to leave the laboratory between sessions. During the long run, participants were free to drink water *ad libitum*.

During all tests, $\dot{V}O_2$ was recorded using the breath-by-breath metabolic system Oxycon Pro (Crouter *et al*., 2006; King *et al*., 1999; Lampard *et al*., 2000; McLaughlin *et al*., 1999; 2001; Parr *et al*., 2001; Hodges *et al*., 2005; Macfarlane, 2001) to ensure consistency.

Blood lactate (bLa) was recorded during the GXT and at the end of the 5 km TT, using a Lactate Pro LT-1710 blood lactate analyser (Arkray Inc. Kyoto, Japan).

For details relating to the treadmill used, the Oxycon Pro calibration procedures and the laboratory conditions during all testing throughout chapter 6 the reader is referred to section 3.7.

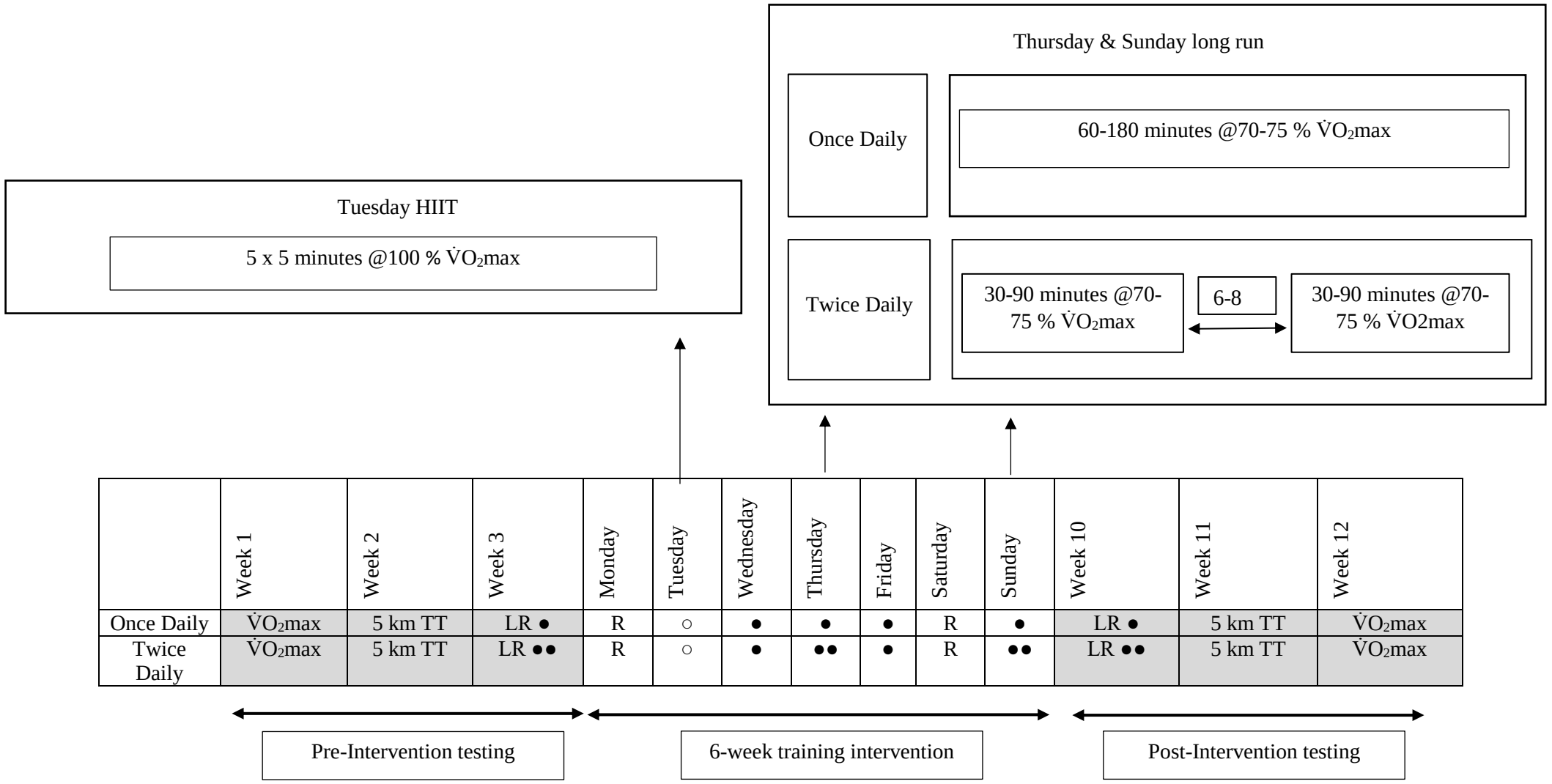
After completing the 6-week training intervention, the same pre intervention visits were completed in reverse order with the long run first (visits 3 & 4 above), followed by the 5 km treadmill TT (visit 2), and finally the GXT (visit 1) (Figure 6.1). Post intervention testing was conducted in this way to ensure that the long run data was collected as soon as possible post intervention.

Training Intervention Design

All participants were required to train five days per week with two recovery days (Monday and Saturday) (Figure 6.1). In order to reflect a training design that a MTR was likely to conduct, both groups performed one high intensity interval training session (HIIT) (5 x 5 minutes at $v\dot{V}O_2max$ with 5 minutes recovery between intervals). This decision to include HIIT was based upon knowledge that prior to commencing the study all participants recruited had habitually conducted at least one HIIT session per week. Research supports this decision suggesting that improvements in physiological variables ($\dot{V}O_2max$, RE and LT/VTs) are achieved when HIIT

training is conducted either after or in combination with LIT (Franch, Madsen, Djurhuus, & Pedersen, 1998; Billat *et al*., 1999; Denadai *et al.*, 2006; Helgerud *et al*., 2007).

Four LIT sessions were also conducted with a heart rate (HR) zone corresponding to 70-75% $\dot{V}O_2$max. Again, research supports this, suggesting that training at lower intensities such as vLT is essential for central and peripheral adaptation (Conley *et al*., 1984; Overend, Paterson, Cunningham, 1992; Mader, 1991; Weltman, Snead, Seip, Weltman, Rutt, & Ragol, 1990). Both groups performed their longest LIT runs on a Thursday and Sunday. Upon starting the intervention both the once daily and twice daily groups increased the volume of both of the Thursday and Sunday runs by 5% per week from weeks 1 to 3 (a combined increase of 30% by week 3). Both groups then maintained the increased volume for the remaining three weeks. Research has shown that a 30% increase in training volume applied at a rate of 5-10% per week appears to be a manageable training increase (Tanaka *et al*., 1986). The once daily group performed these sessions as one continual run. Conversely the twice daily group split two of these long runs into two equal volume runs performed in the morning (AM) and the evening (PM) with 6-8 hours recovery between sessions. The decision to include 2 days where the runner performed twice daily training, rather than 3 or 4 days, was based upon recommendations from Hawley (2015) and upon previous research (Yeo *et al.,* 2008) investigating twice daily training. In the Yeo *et al,* (2008) study, athletes performing twice daily training over 4 days, struggled to maintain the required training zone during the second session of the day.



	Week 1	Week 2	Week 3	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Week 10	Week 11	Week 12
Once Daily	$\dot{V}O_2$max	5 km TT	LR ●	R	○	●	●	●	R	●	LR ●	5 km TT	$\dot{V}O_2$max
Twice Daily	$\dot{V}O_2$max	5 km TT	LR ●●	R	○	●	●●	●	R	●●	LR ●●	5 km TT	$\dot{V}O_2$max

Figure. 6.1. Overview of study design and experimental trial.

● - aerobic training <75% $\dot{V}O_2$max. ○ - high-intensity interval training (HIIT). R - Rest.

LR - long run

6.3 Data analysis

Data were analysed using MS Excel, SPSS. The data were assessed for parametric assumptions, checked in line with Field (2009). Normality was assessed using the Shapiro-Wilks (1965) test.

Prior to the training intervention, an independent t-test was used to establish if there were significant differences between key parameters (body composition, velocity) that might influence changes during the training phase. An independent t-test was also used to establish if there were significant differences between the physiological variables during the first half of the run before and after training.

To assess the impact of training on physiological markers recorded during laboratory GXTs and long run assessments, Analysis of Covariance (ANCOVA) was used to compare groups. For key physiological parameters, change scores were calculated (post minus pre scores) and change scores in each group were compared utilising the baseline scores as a covariate (Atkinson and Batterham, 2015).

The data from the long run undertaken in the laboratory was assessed initially using an independent t-test. This analysis was conducted to assess if differences existed in the first half of the two long run training protocols. Data from the second half of the long run was assessed using ANCOVA utilising change scores (second half values minus first half values) with the covariate of first half data included in the model.

The Pearson Product Moment correlation was used to establish relationships between simulated time trial performance and data from GXT. Raw data was used in this analysis (for comparison to study 2), change scores (post – pre) were also correlated to assess whether changes in performance could be related to changes in the key performance predictor variables PTv, RE12 and vVT. In a similar manner to Study 2, multiple stepwise regression analysis was also performed on raw data to establish if performance could be predicted; for this study, Study 3 the change scores were also analysed in this way.

Descriptive and analytical statistics were conducted using Excel, SPSS and Graph Pad Prism. All data are presented as mean+/- standard deviation and an alpha level of 0.05 was used for these analyses.

6.4 Results

Of the 42 moderately trained male endurance runners who began Study 3, eight withdrew from the intervention, two from the once daily training group (equating to a 9.5 % drop out rate) stating injury as a reason to withdraw. Six participants withdrew from the twice daily training group (equating to a 28.57 %), and of these six runners, three were unable to conduct the training prescribed due to illness. The remaining three runners who withdrew stated low motivation as the cause and did not wish to continue with the training. The remaining 34 participants, 19 from the once daily group and 15 from the twice daily group all completed the full training intervention. Thus although higher attrition was observed in the twice daily training group, it is not possible to determine whether this was a result of the training approach due to small sample sizes. Further research is needed to investigate whether twice daily training would lead to higher attrition and therefore whether the training approach would still suit the majority of runners.

The remaining sample of 34 was sufficient to fulfil the size required after conducting the power analysis. As a result of drop outs the two groups became unequal in size but this did not negatively impact the data analysis as each group remained sufficiently large to conduct the necessary analyses.

Tables 6.2 to 6.14 compare pre and post training intervention measures *within* the two groups: once and twice-daily training. Tables 6.15 and 6.16 compare the difference in pre and post training intervention measures *between* these two groups. Asterisks indicate whether p values are statistically significant within the relevant comparison. Where asterisks are not shown in the tables the values are not statistically significant.

A comparison of the pre and post training intervention body mass (Table 6.2) revealed no significant difference in body mass for the once daily (p = 0.736) or the twice daily groups (p = 0.155).

Table 6.2. Pre and post intervention body mass and fluid intake during long run (expressed as mean ± standard deviation (SD) values). $^{**}p < 0.001$

Pre Intervention				
Group	Mass – pre-run (kg)	Fluid intake (L)	mass loss (kg)	% body mass loss
Once Daily	69.7 ± 5.9	0.3 ± 0.7	-1.8 ± 0.22**	-2.5 ± 0.6
Twice Daily (AM)	69.4 ± 8	0.2 ± 0.2	-1.2± 0.28**	-1.7 ± 0.4
Twice Daily (PM)	69.4 ± 8	0.2 ± 0.2	-1.3 ± 0.3**	-1.7 ± 0.4
Post Intervention				
Group	Mass – pre-run (kg)	Fluid intake (L)	mass loss (kg)	% body mass loss
Once Daily	69.3 ± 5.9	0.4 ± 0.44	-1.6 ± 0.4**	-2.3 ± 0.5
Twice Daily (AM)	69.5 ± 8	0.2 ± 0.6	-1.2± 0.3**	-1.7 ± 0.4
Twice Daily (PM)	69.5 ± 8	0.1 ± 0.2	-1.3 ± 0.3**	-1.8 ± 0.4

Nutritional intake before the long run (pre intervention)

All participants consumed a breakfast before conducting their long run. There was no significant difference in the mean calorific content (kcal) of the breakfast between the two groups (p = 0.917) or between the percentage of CHO (p = 0.266) fat (p = 0.833) or protein (p = 0.578) consumed (Table 6.3).

Table 6.3. Mean (±SD) of breakfast before the long run for both groups

Group	CHO %	Fat %	Protein %	Kcal

Once daily	62.8 ± 8.9	24.9 ± 8.9	14.8 ± 5	528 ± 117
Twice daily	59.9 ± 3.2	24.3 ± 4	15.8 ± 4.8	521 ± 183

There was no significant difference in the mean calorific content (kcal) for the lunch time meal between the groups (p = 0.996) or the % CHO (p = 0.454), % fat (p = 0.437) or % protein (p = 0.410). The twice daily group consumed a meal consisting of 61.3 ± 7.6 % CHO, 23.8 ± 9.6 fat & 17 ± 6.2 % protein before commencing the second half of the long run. Conversely, the once daily group consumed a lunch with a mean macronutrient ratio of 59.1 ± 8.1 % CHO, 21.8 ± 6.1 fat & 18.9 ± 6.6 % protein (Table 6.4) However, this was consumed upon completion of the continual (AM) session.

Table 6.4. Mean (±SD) of lunch time meal for both groups

Group	CHO %	Fat %	Protein %	Kcal
Once daily	59.1 ± 8.1	21.8 ± 6.1	18.9 ± 6.6	866 ± 157
Twice daily	61.3 ± 7.6	23.8 ± 8.6	17 ± 6.2	865 ± 201

Velocity change during long run

Comparison of the velocity at the 15 minute point with the final minute demonstrated that maintaining a HR zone corresponding to 70-75% $\dot{V}O_2$ max during a long run leads to a significant reduction in velocity for both the once daily (p<0.001) and twice daily groups (p<0.001) (Table 6.7). The reduction of the once daily group was greater (-1.2 ± 0.3 $km \cdot h^{-1}$) than was seen in the AM (-0.8 ± 0.1) and PM (-0.7 ± 0.1 $km \cdot h^{-1}$) sessions for the twice daily group (Table 6.5). Differences between the groups in reduction in velocity were not significant.

Pre and post-intervention analysis revealed that both groups saw a significant improvement in the post intervention velocity after 15 minutes (Table 6.5), with the once daily group increasing from 13.2 ± 1.7 to 13.5 ± 1.6 $km \cdot h^{-1}$ (p<0.001), and the twice daily group improving from 13.3 ±

1.3 to 14.1 ± 1.3 ($km \cdot h^{-1}$) ($p<0.001$) for the AM session and 13.2 ± 1.2 to 13.9 ± 1.4 ($km \cdot h^{-1}$) ($p<0.000$) for the PM session (Table 6.5). Both groups saw a reduction in velocity during the long run after the intervention with the once daily group reducing from -1.2 ± 0.3 to -1.02 ± 0.19 ($km \cdot h^{-1}$) ($p<0.000$) while the twice daily group reduced from -0.8 ± 0.1 to -0.6 ± 0.25 ($km \cdot h^{-1}$) ($p<0.001$) for the AM session and -0.7 ± 0.1 to -0.3 ± 0.2 ($km \cdot h^{-1}$) ($p<0.001$) for the PM session (Table 6.5). However, there was no statistically significant difference between the groups.

Table 6.5. Velocity at 15 minutes and at the end of the long run for both pre and post intervention Mean (±SD). ** = a significant reduction ($p < 0.001$) in the velocity within group for pre intervention and post intervention.

Pre Intervention			
Group	Velocity 15 min ($km.h^{-1}$)	Velocity End ($km \cdot h^{-1}$)	Change in Velocity ($km \cdot h^{-1}$)
Once Daily	13.2 ± 1.7	11.9 ± 1.7**	-1.2 ± 0.3**
Twice Daily (AM)	13.3 ± 1.3	12.6 ± 1.3**	-0.8 ± 0.1**
Twice Daily (PM)	13.2 ± 1.2	12.5 ± 1.2**	-0.7 ± 0.1**
Post Intervention			
Once Daily	13.5 ± 1.6**	12.4 ± 1.6	-1 ± 0.2
Twice Daily (AM)	14.1 ± 1.3**	13.5 ± 1.4	-0.6 ± 0.3
Twice Daily (PM)	13.9 ± 1.4**	13.7 ± 1.4	-0.3 ± 0.2

Oxygen consumption during split training and continuous distance running

The mean oxygen consumed ($\dot{V}O_2$) during the trials is shown in table 6.6. The training intervention did not alter the $\dot{V}O_2$ response between the groups. The mean changes were 0.1 ± 0.1 $L \cdot min^{-1}$ for the twice daily group and 0 ± 0.2 $L \cdot min^{-1}$ for the once daily group. The mean change in % $\dot{V}O_2max$ is shown in Table 6.7. The training intervention did not alter the response when data were presented as % $\dot{V}O_2max$. The mean changes were 2.2 ± 3.1 % for the twice daily group and 0.9 ± 3.9 % for the once daily group.

Direct comparison of the first and second half of each training protocol are seen in Figure 6.2.

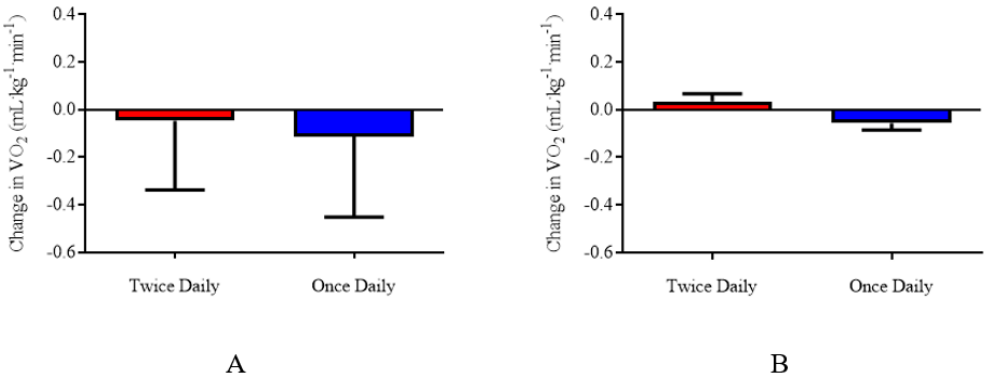


Figure 6.2 Comparison of the mean change in $\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot min^{-1}$) during the first and second half of the long run (A = Pre intervention & B = Post intervention)

The training intervention resulted in a different pattern of oxygen consumption when the first and second half of the training runs are compared. Table 6.6 indicates that the twice daily group in the pre intervention phase had a reduction in $\dot{V}O_2$ when the second half of the run was compared to the first half (-0.05 ± 0.01 $L \cdot min^{-1}$), in a similar manner to the single run group (-0.1 ± 0 $L \cdot min^{-1}$). Following training the oxygen cost of running in the second half increased in the twice daily group (-0.04 ± 0.12 $L \cdot min^{-1}$) only. These post training changes were statistically significant ($p<0.045$).

Table 6.6. Mean (±SD) Oxygen consumption during the long run pre and post intervention for the two groups

Pre Intervention $\dot{V}O_2$ ($L \cdot min^{-1}$)				Post Intervention $\dot{V}O_2$ ($L \cdot min^{-1}$)		
Group	First Half	Second Half	Change	First Half	Second Half	Change
Twice Daily	2.98 ± 0.36	2.94 ± 0.39	-0.05 ± 0.01	2.93 ± 0.37	2.97 ± 0.39	0.04 ± 0.02
Once Daily	3.17 ± 0.37	3.07 ± 0.37	-0.1 ± 0	2.99 ± 0.43	2.92 ± 0.36	-0.07 ± 0.07

Table 6.7. Mean (±SD) Oxygen consumption expressed as % $\dot{V}O_2max$ during the long run pre and post intervention for the two groups

	Pre Intervention % $\dot{V}O_2max$			Post Intervention % $\dot{V}O_2max$		
Group	First Half	Second Half	Change	First Half	Second Half	Change
Twice Daily	73.6 ± 3.9	72.5 ± 5.4	-1.1 ± 2.6	72.2 ± 4.5	73.3 ± 5.2	1.1 ± 2.1
Once Daily	74.8 ± 5.0	72.4 ± 5.2	-2.4 ± 2.6	70.6 ± 7.9	69.1 ± 7.6	-1.5 ± 4.2

Running Economy (RE) during split training and continuous distance running

The mean RE during the trials is shown in Table 6.8. The training intervention did not change the pattern of RE between the two groups when the first and second half of the training runs were recorded (p = 0.323). The mean changes were 0.3 ± 9.7 ($mL \cdot kg^{-1} \cdot km \cdot h^{-1}$) for the twice daily group and 1.6 ± 9.8 ($mL \cdot kg^{-1} \cdot km \cdot h^{-1}$) for the once daily group.

Table 6.8. Mean (±SD) RE during the long run pre and post intervention for the two groups

	Pre Intervention RE ($mL \cdot kg^{-1} \cdot km \cdot h^{-1}$)			Post Intervention RE ($mL \cdot kg^{-1} \cdot km \cdot h^{-1}$)		
Group	First Half	Second Half	Change	First Half	Second Half	Change
Twice Daily	202.8 ± 18.9	200.3 ± 5.4	-2.5 ± 7.9	189.5 ± 32.2	187.3 ± 27.9	-2.2 ± 8.2
Once Daily	216.3 ± 21.3	219.1 ± 19.5	2.8 ± 7.2	201.5 ± 23.5	205.9 ± 20.5	4.4 ± 11.5

Direct comparison of the first and second half of each training protocol are seen in figure 6.3.

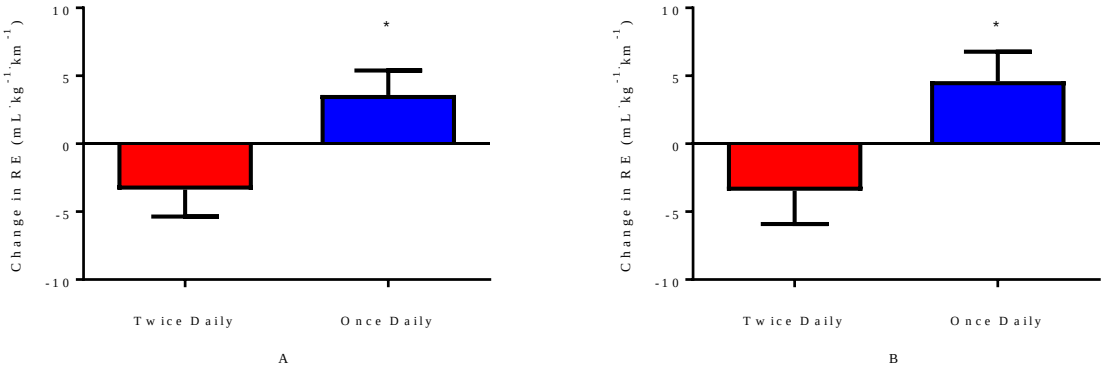


Figure 6.3. Comparison of mean RE for the first and second half of the long run for both groups (A = Pre intervention & B = Post intervention)

Comparison of mean RE during each half of the run pre and post training intervention is shown in Table 6.9. The training intervention significantly improved RE for both groups. The mean changes were -13.3 ± 23.7 $mL{\cdot}kg^{-1}{\cdot}km{\cdot}h^{-1}$ for the first half of the run and -13.3 ± 14.6 $mL{\cdot}kg^{-1}{\cdot}km{\cdot}h^{-1}$ for second half of the run for the twice daily group and -14.8 ± 16.9 $mL{\cdot}kg^{-1}{\cdot}km{\cdot}h^{-1}$ for the first half of the run and -13 ± 19.3 $mL{\cdot}kg^{-1}{\cdot}km{\cdot}h^{-1}$ for the once daily group.

Table 6.9. Comparison of the Mean (±SD) RE ($mL{\cdot}kg^{-1}{\cdot}km{\cdot}h^{-1}$) during the long run pre and post intervention for the two groups

	Pre Intervention	Post Intervention		Pre Intervention	Post Intervention	
Group	First Half	First Half	Change	Second Half	Second Half	Change
Twice Daily	202.8 ± 18.9	189.5 ± 32.2	-13.3 ± 23.7	200.3 ± 5.4	187.3 ± 27.9	-13.2 ± 14.6
Once Daily	216.3 ± 21.3	201.5 ± 23.5	-14.8 ± 16.9	219.1 ± 19.5	205.9 ± 20.5	-13 ± 19.3

Respiratory Exchange Ratio (RER) during split training and continuous distance running

The mean RER during the trials is shown in Table 6.10. Significant differences were seen between the two groups in RER after training ($p<0.001$) (Table 6.10 & Figure 6.4). This was

represented by RER values with a post intervention value reducing -0.03 ± 0.03 for the once daily group and increasing 0.04 ± 0.02 for the twice daily group (Table 6.10), resulting in an increase in the difference between the two groups of -0.06.

Table 6.10. Mean (±SD) RER during the long run pre and post intervention for the two groups ($^{*}p < 0.05$ $^{**}p < 0.001$)

	Mean RER Pre Intervention			Mean RER Post Intervention		
Group	First Half	Second Half	Change	First Half	Second Half	Change
Twice Daily	0.86 ± 0.06	0.89 ± 0.05	0.03 ± 0.04	0.86 ± 0.04	0.9 ± 0.04	0.04 ± 0.02**
Once Daily	0.89 ± 0.05	0.86 ± 0.06	-0.03 ± 0.01	0.89 ± 0.06	0.86 ± 0.06	-0.03 ± 0.03**

Direct comparison of the first and second half of each training protocol are seen in Figure 6.4. As stated above, these differences were significant ($p<0.001$).

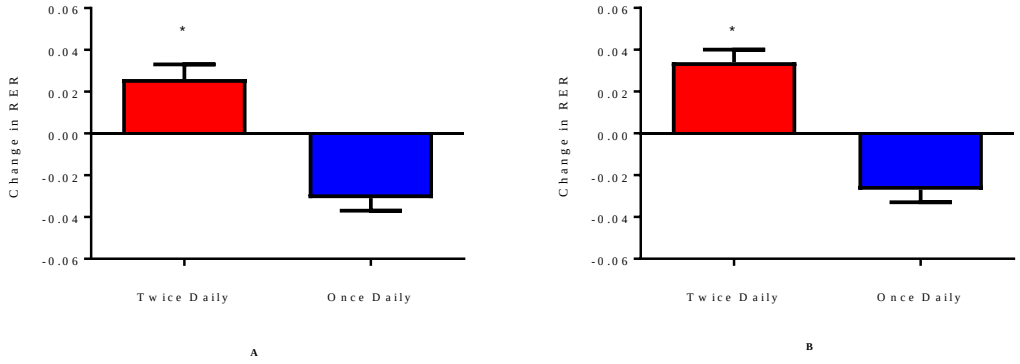


Figure 6.4. Comparison of mean RER during the first and second half of the long run for both groups (A = Pre intervention & B = Post intervention)

Estimated Fat metabolism during split training and continuous distance running

The mean estimated fat metabolised during the trials is shown in Table 6.11. The training intervention altered estimated fat metabolised between the two groups when the first and second half of the training runs were recorded. The mean changes were -1.5 ± 10.5 (grams) for the twice daily group and 0.6 ± 5.8 (grams) for the once daily group. This change between the two groups was statistically significant (p<0.001).

Table 6.11. Mean (±SD) Estimated Fat metabolised during the long run pre and post intervention for the two groups

	Fat consumed (grams) Pre Intervention			Fat consumed (grams) Post Intervention		
Group	First Half	Second Half	Change	First Half	Second Half	Change
Twice Daily	42.1 ± 24.1	32.6 ± 19.7	-9.5 ± 9.2	40.4 ± 17.7	32.3 ± 17.9	-8 ± 4.3
Once Daily	29 ± 17.6	35.3 ± 18.6	6.3 ± 3.8	29.5 ± 20.7	35.2 ± 21.3	5.7 ± 5.4

Direct comparison of the first and second half of each training protocol are seen in figure 6.5.

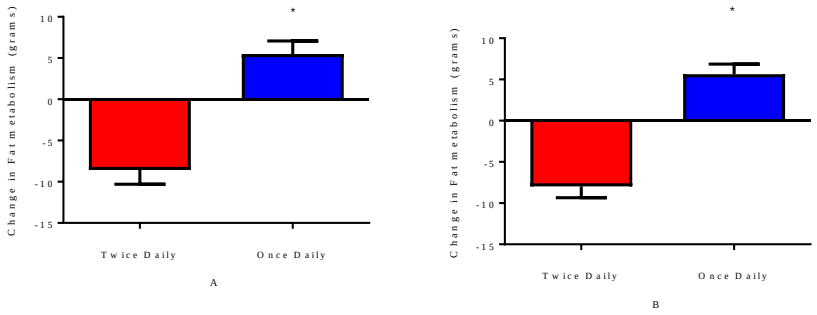


Figure 6.5 Comparison of the mean change in estimated fat metabolised during the first and second half of the long run for both groups (A = Pre intervention & B = Post intervention)

Comparison of mean estimated fat metabolised for each half of the run pre and post training intervention is shown in Table 6.12. After training, a change was seen in the pattern of estimated fat metabolised between the groups. The mean changes were -1.5 ± 10.5 (grams) for the twice daily group and 0.6 ± 5.8 (grams) for the once daily.

Table 6.12. Comparison of mean (±SD) Estimated fat metabolised during the long run pre and post intervention for the two groups

	Pre Intervention	Post Intervention		Pre Intervention	Post Intervention	
Group	First Half	First Half	Change	Second Half	Second Half	Change
Twice Daily	42.1 ± 24.1	40.4 ± 17.7	-1.7 ± 14.8	32.6 ± 19.7	32.3 ± 17.9	-0.2 ± 12.4
Once Daily	29 ± 17.6	29.5 ± 20.7	0.5 ± 14.2	35.3 ± 18.6	35.2 ± 21.3	-0.1 ± 12.4

$\dot{V}O_2$max during the GXT (before and after training)

Mean $\dot{V}O_2$max values before and after training are shown in table 6.13. There was no significant difference (p = 0.601) (table 6.15) in the change in $\dot{V}O_2$ max between the two groups after training.

The twice daily group experienced a small improvement in $\dot{V}O_2$max from the mean pre intervention value of 58.28 ± 5.84 to 58.65 ± 7.05 $mL \cdot kg^{-1} \cdot min^{-1}$ (table 6.13) after training. This equated to a mean change of 0.37 ± 4.83 ($mL \cdot kg^{-1} \cdot km \cdot h^{-1}$) (0.8 ± 8.2 % change). This change was not statistically significant (p = 0.162). Conversely, $\dot{V}O_2$max declined in the once daily group from the mean pre intervention value of 61.46 ± 5.98 to 60.19 ± 4.62 $mL \cdot kg^{-1}.min^{-1}$ after training from (Table 6.13) equating to a mean change of -1.27 ± 3.69 ($mL \cdot kg^{-1} \cdot km \cdot h^{-1}$) (-1.7 ± 6.1 % change) (Table 6.14), this change was also not statistically significant (p = 0.776).

RE at 12 $km.h^{-1}$ recorded during the GXT (before and after training)

Mean RE at 12 $km.h^{-1}$ obtained from the GXT before and after training is shown in table 6.13. There was no significant difference (p = 0.906) in the change in RE12 between the groups after training (table 6.15).

The twice daily group experienced a deterioration in RE12, this was represented by an increase from the mean pre intervention value of 198.9 ± 14.3 to 199.4 ± 14.7 $mL \cdot kg^{-1} \cdot km^{-1}$ after training (Table 6.13) equating to a mean change of 0.5 ±12.8 $mL \cdot kg^{-1} \cdot km^{-1}$ (0.4 ± 6.5 % change). Conversely, the once daily group saw an improvement in RE, represented by a reduction from the mean pre intervention value of 213.2 ± 22.1 to 209.5 ± 19.9 $mL \cdot kg^{-1} \cdot km^{-1}$ (Table 6.13) after

training, equating to a mean change of -3.7 ±11.3 $mL \cdot kg^{-1} \cdot km^{-1}$ (-1.5 ± 5.3 % change) (Table 6.14).

Ventilatory threshold (VT1) recorded during the GXT (before and after training)

Mean VT1 values before and after training are shown in Table 6.13. There was no significant change in VT1 between the groups after training when expressed as % $\dot{V}O_2max$ (p = 0.821) or expressed to velocity vVT1 (p = 0.136) (table 6.15).

Both the once and twice daily groups saw improvements in VT1 after training. For the twice daily group this was represented by a pre intervention mean value of 74 ± 1.8 (% $\dot{V}O_2max$) to 78 ± 2.7 % $\dot{V}O_2max$ after training (table 6.13). This equated to a 4.1 ± 3.3 % $\dot{V}O_2max$ (5.6 ± 4.5 % change) (p<0.001) (Table 6.14). For the once daily group this was represented by an increase from the pre intervention mean value of 74 ± 3 % $\dot{V}O_2max$ to 77.7 ± 3.5 % $\dot{V}O_2max$ (p<0.001) after training (Table 6.13). This equated to a 3.6 ± 3.2 % (5 ± 5 % change) (Table 6.14).

Ventilatory threshold (VT2) recorded during the GXT (before and after training)

Mean VT2 values before and after training are shown in Table 6.15. There was no significant difference in the change in VT2 between the groups when expressed as % $\dot{V}O_2max$ (p = 0.166) or vVT2 (p = 0.356) after training.

As with VT1, both groups saw improvements in VT2, for the twice daily group this was represented by a pre intervention mean value of 80.7 ± 1.8 to a post-intervention value of 84.4 ± 2.8 % $\dot{V}O_2max$ (p<0.001) (Table 6.13), equating to a 4.7 ± 4.2 % change (Table 6.14). For the once daily group this was represented by an increase from the pre intervention mean value of 81.2 ± 3.2 % $\dot{V}O_2max$ to 83.5 ± 2.5 % $\dot{V}O_2max$ (p<0.001) (Table 6.13) after training, equating to a 2.8 ± 2.8 % change (Table 6.14)

Table 6.13. Mean (±SD) physiological variables for both groups recorded at pre and post training intervention. $^{*}p$< 0.05, $^{**}p$ < 0.001

	Once daily	Once daily	Twice daily	Twice daily

	Pre intervention	Post intervention	Pre intervention	Post intervention
$\dot{V}O_2$max (mL·kg^{-1}·min^{-1})	61.46 ± 5.98	60.19 ± 4.62	58.28 ± 5.84	58.65 ± 7.05
RE 12 (mL·kg^{-1}·km^{-1})	213.2 ± 22.1	209.5 ± 19.9	198.9 ± 14.3	199.4 ± 14.7
VT1 (%)	74 ± 3	77.7 ± 3.5**	73.7 ± 1.8	77.7 ± 2.7**
VT1 (km·h^{-1})	13.2 ± 1.4	13.5 ± 1.2	13.1 ± 1	13.9 ± 1.4**
VT2 (%)	81.2 ± 3.2	83.5 ± 2.5**	80.7 ± 1.8	84.4 ± 2.8**
VT2 (km·h^{-1})	14.1 ± 1.1	14.3 ± 1.3	14.1 ± 1.1	14.7 ± 1.5**

Table 6.14. Percentage change in physiological variables for both groups recorded in pre and post intervention

	Once daily % change	Twice daily % change
$\dot{V}O_2$max (mL·kg^{-1}·min^{-1})	-1.7 ± 6.1	0.8 ± 8.2
RE 12 (mL·kg^{-1}·min^{-1})	-1.5 ± 5.3	0.4 ± 6.5
VT1 (%) vo2max	5 ± 4.5	5.6 ± 5
VT1 (km·h^{-1})	2.3 ± 6.6	5.6 ± 6.6
VT2 (%) $\dot{V}O_2$max	2.8 ± 2.8	4.7 ± 4.2
VT2 (km·h^{-1})	2.1 ± 6.4	3.7 ± 5.7

Table 6.15. Physiological variables between the two groups pre and post intervention

	Variables	Mean difference ± SD	*p*
5 km	$\dot{V}O_2$max (mL·kg^{-1}·min^{-1})	0.8 ± 1.5	0.601
	RE12 (mL·kg^{-1}·km^{-1})	0.5 ± 4.2	0.906
	VT1 (%) $\dot{V}O_2$max	0.3 ± 1.4	0.821
	VT1 (km·h^{-1})	0.5 ± 0.3	0.136
	VT2 (%) $\dot{V}O_2$max	1.5 ± 1.1	0.166
	VT2 (km·h^{-1})	0.3 ± 0.3	0.356

Performance times before and after training

Table 6.16 displays the results for the 5 km performance trials for before and after the 6-week training intervention. The training intervention led to significantly greater improvements in 5 km RP when expressed as seconds ($p = 0.03$) and as a percentage improvement ($p = 0.025$).

Table 6.16. Mean (±SD) 5 km performance times for both groups pre and post training intervention $^{*}p < 0.05$, $^{**}p < 0.001$

5 km TT (lab) (seconds)	Once daily	Twice daily	*Difference between groups* (*p*)
Pre intervention	1142 ± 96	1122 ± 103	
Post intervention	1128 ± 122	1092 ± 101	0.027*
Pre/Post difference (Seconds)	-13 ± 27	-30 ± 20	0.03*
Pre/Post % RP Change	-1.1 ± 2.3*	-2.7 ± 1.8**	0.025*

Predicting 5 km RP

The stepwise multiple regression analysis, including both mechanical and physiological variables, conducted before and after training (Table 6.17), indicated PTv was the strongest predictor of 5 km RP before and after training. Adding any additional variables did not improve the strength of the prediction. A comparison of r^2 before and after training revealed that r^2 increased slightly after training for the twice daily group, represented by an increase from $r^2 = 0.9$ before training to $r^2 = 0.92$. Conversely, the once daily group saw a decrease, represented by a decrease from $r^2 = 0.9$ before training to $r^2 = 0.83$ after training.

Table 6.17. The relationship between PTv and 5 km RP before and after training

PTv	r^2 Pre intervention	r^2 Post intervention
Once daily	0.90	0.83
Twice daily	0.90	0.92

The stepwise multiple regression analysis between vVT and RE12 reduced for the twice daily group, represented by a decrease from r^2 = 0.90 before training (Table 6.18) to r^2 = 0.72 after training. Conversely, the predictive power remained unchanged for the once daily group with r^2 = 0.9 before training and after training.

Table 6.18. The relationship between vVT and RE12 and 5 km RP before and after training

vVT and RE12	r^2 Pre intervention	r^2 Post intervention
Study 6 (Once daily)	0.72	0.72
Study 6 (Twice daily)	0.90	0.72

Predicting performance changes

While both groups saw improvements in performance following the training intervention (Table 6.16), analysis showed only weak correlations between the change in physiological parameters ($\dot{V}O_2$max, VT1, VT2 or RE12) and the change in 5km RP when all participants were considered as one group (Table 6.19). However, moderate correlations were seen when the groups were analysed separately.

For the twice daily group, a moderate negative correlation (r = -0.487) was found between change in $\dot{V}O_2$max and change in 5km running time. Therefore, as expected, as $\dot{V}O_2$max went up, running times decreasd for the participants of this training group. For the once daily group, no such correlation between $\dot{V}O_2$max and 5Km RP was detected. However, a moderate positive relationship was found between the change in RE12 and the change in 5 km PR for the once daily group (Table 6.19). Thus as RE12 improved, so did running time for this group. The variance explained for both groups was low with 24% for the twice daily group and 22% for the once daily group. It should be noted that although these moderate correlations where found after training, PTv, vVT & RE12 remained the strongest predictors.

Table 6.19. The relationship between the change in 5 km RP and the change in the physiological variables after training

Physiological variable	r All runners	r Twice daily	r Once daily
$\dot{V}O_2max$	-0.20	-0.487	0.084
VT1 (% $\dot{V}O_2max$)	0.065	0.031	0.121
VT2 (% $\dot{V}O_2max$)	-0.074	0.064	-0.021
RE12	0.112	-0.261	0.471

6.5 Discussion

This study, Study 3, aimed to assess the chronic impacts of both once daily and twice daily training as part of a six week periodised training plan during the foundational stage of training, and during which an increase in training volume was also achieved.

Study 3 demonstrated that significant changes (p<0.001) were seen in the pattern of RER between the once daily and twice daily groups of MTRs during the prolonged run after the six week training intervention. Secondly, Chapter 6 aimed to assess the chronic impacts of both once daily and twice daily training on 5 km running performance. Pre and post intervention testing demonstrated that there was a significant difference (p = 0.03) between the groups in the change in 5 km RP after training.

6.5.1 *The Long Run before and after the intervention*

6.5.1.1 *Volume of Oxygen ($\dot{V}O2$) consumed*

As previously discussed in chapter 5, when runners use heart rate (HR) rather than velocity to pace a prolonged run, treadmill speed is reduced and $\dot{V}O_2$ consumption is also reduced. In this study, the once daily group continued to show a decrease in $\dot{V}O_2$ consumption during the second half of the long run after training. Although the difference in $\dot{V}O_2$ consumption between the first half and the second half of the run had reduced from the pre intervention long run (Table 6.6), this reduction was not statistically significant (p = 0.448). Following the intervention both groups were able to achieve smaller reductions in velocity over the course of the run. This shows that, for both groups, velocity was better maintained after training suggesting that the

runners improved after the 6 weeks of training. However, there was no difference between the two groups.

Interestingly, after the intervention period, the once daily group no longer experienced an increase in $\dot{V}O_2$ consumed in the final minutes of the run. This change is likely to be due to the 15% increase in volume in running time achieved over the intervention period, resulting in an increased utilisation of oxygen at the working muscles (peripheral adaptations), through an increase in the number of mitochondria (mitochondrial density) and the efficiency of the mitochondria (mitochondrial capacity) (Holloszy & Coyle, 1984). Therefore, when the runners completed the same pre intervention length run they were in a less fatigued state, despite the faster velocities. The feeling of being less fatigued at the end of the run was confirmed from discussions with the runners after they had completed the training plan.

For the twice daily group, comparison of the mean $\dot{V}O_2$ consumption during the first half of the long run with the second half after the training intervention identified that this group no longer experienced a decrease (-0.047 ± 0.29 $mL \cdot min^{-1}$) in $\dot{V}O_2$ consumption during the second PM session and instead, saw an increase (0.035 ± 0.032 $mL \cdot min^{-1}$). This resulted in a significant difference between the groups after the training intervention of -0.091 ± 0.044 $mL \cdot min^{-1}$ (p = 0.045) (Table 6.5).

It could be argued that in both groups the increased starting velocity (at 15 minutes) and the finishing velocity required greater $\dot{V}O_2$ consumption. A further explanation is that smaller changes in velocity throughout the run (-0.3 ± 0.2 $km \cdot h^{-1}$) in comparison with the pre intervention change (-0.7 ± 0.1 $km \cdot h^{-1}$) could have provoked an increased demand for $\dot{V}O_2$ (table 6.3). Another possible explanation could be reduced fatigue resistance after the runners had completed the training intervention. Upon completing the first (AM) session the runners were in a state of fatigue during the PM session. Where this incurs increased muscle fibre recruitment has been reported (Davies & Thompson 1986; Morgan & Craib, 1992; Saunders *et al*., 2004) resulting in increased $\dot{V}O_2$ consumption. However, if this was the case, and the twice daily group were in a state of overreaching or overtraining, it would have been unlikely that

these participants would have improved their 5 km performance which they did in this study. As we have noted earlier the twice daily group did suffer greater attrition from illness, although further research is needed to determine whether this is a result of the training approach. It is likely that a combination of the first two factors: the increased starting velocity (at 15 minutes) and finishing velocity, together with smaller changes in velocity throughout the run, led to the increase in $\dot{V}O_2$ consumption.

6.5.1.2 *Change in Running Economy*

Both groups saw significant improvements in RE during the long run after training. The mean changes were -13.3 ± 23.7 $mL \cdot kg^{-1} \cdot km \cdot h^{-1}$ for the first half of the run and -13.3 ± 14.6 $mL \cdot kg^{-1} \cdot km \cdot h^{-1}$ for the second half of the run for the twice daily group, and -14.8 ± 16.9 $mL \cdot kg^{-1} \cdot km \cdot h^{-1}$ for the first half of the run and -13 ± 19.3 $mL \cdot kg^{-1} \cdot km \cdot h^{-1}$ for the once daily group. Improvements in RE occurred following conducting exercise over the intervention period at this intensity, leading to increased efficiency in this zone. Previous research has shown that improvements in RE are related to the intensity at which runners train (MacDougall & Sale, 1981; Tanaka, 1990; Carter, Jones, Doust, 1999; Henritze, Weltman, Schurrer, Barlow, 1985; Weltman, *et al.* 1992, Sjodin et al. 1982; Acavedo & Goldfarb, 1989; Keith, Jacobs, McLellan, 1999).

Pre and Post intervention analysis revealed the training intervention did not change the pattern of RE between the two groups when comparing RE within the first and second half of the training runs ($p = 0.323$). Further research is needed to explore why this occurred.

6.5.1.3 Substrate Utilization -Respiratory Exchange Ratio (RER) & Estimated Fat Metabolism

Next the two groups are compared with regard to the changes that occurred following the intervention. The extent of the difference between the two groups in this change is measured. Significant differences were seen between the two groups in RER ($p<0.001$) and estimated fat metabolised following the training intervention ($p<0.001$) (Table 6.10). This was represented

by increased RER values following the intervention with the once daily group recording a post intenvention value of -0.03 and the twice daily group a value of 0.03 (Table 6.4), resulting in an increase in the difference between the two groups of -0.06.

This change in substrate utilization was also demonstrated by a significant decrease ($p<0.001$) between the two groups in estimated fat metabolised. This was represented by a mean change of -1.5 ± 10.5 (grams) for the twice daily group and 0.6 ± 5.8 (grams) for the once daily group. This difference shows that the twice daily group used more CHO in the first part of the run, which is the more efficient fuel source for high intensity exercise such as a 5Km runs.

Again, as was found in chapter 5 (Study 2), and confirmed in the pre intervention testing in chapter 6 (Study 3), it is likely that differences between the two groups in substrate utilization and estimated fat metabolised is due to the participants in the twice daily group completing the second half the run after a period of six to eight hours recovery. In both pre and post intervention tests participants were asked to follow their habitual diet (chapter 6). Food diary analysis of the long run day pre and post training intervention confirmed the twice daily participants all consumed a midday meal containing moderate to high levels of CHO within three to four hours prior to commencing the second half of the run.

Research has consistently demonstrated that consuming moderate to high levels of CHO three to four hours prior to exercise increases CHO oxidation (Coyle *et al*., 1985; Wright *et al*., 1991; Coyle *et al*., 1997; Cox *et al*., 2010; Cole *et al*., 2014) and depresses fat oxidation (Costill *et al*., 1977; Coyle *et al*., 1985; Wright *et al*., 1991). This is because consuming CHO stimulates muscle glycogen synthesis (Sherman *et al*., 1991).

This study again supported the findings of chapter 5 which revealed that in the acute setting there were distinct differences in the substrate oxidized between the two groups. Regarding the once daily group, comparison of mean RER during the first half of the run with the second half identified a decrease in RER resulting in a difference of -0.03 ± 0.3. Conversely, in the twice daily group, comparison of mean RER during the first (AM) session with the second (PM)

session for the twice daily group revealed an increase in RER resulting in a mean difference of 0.04 ± 0.2 (Table 6.4). This indicated that during the second session, rather than a decrease in RER as was seen in the once daily group, the twice daily group saw an increased reliance on CHO and a decreased reliance on fat.

Comparison of estimated fat metabolised during the first half of the run with the second half of the run also revealed that the once daily group metabolised a higher amount of fat during the second half of the run resulting in a mean difference of 5.5 ± 1.6 grams. Conversely, the twice daily group metabolised a greater amount of fat during the first half of the run resulting in a difference of -8.6 ± 1.7 $g \cdot min^{-1}$. This resulted in a statistically significant difference between the two groups of -8.6 ± 1.7 $g \cdot min^{-1}$ ($p<0.001$) (Table 6.10). This finding of a significant difference in RER ($p<0.001$) and the total amount of fat metabolised ($p<0.001$) between the two groups provides evidence that clear differences exist in key physiological variables, in this case the substrate oxidized to fuel during the second half of the run.

6.5.2 *Performance variables measured during the GXT*

6.5.2.1 Change in $\dot{V}O2max$ (after training)

A comparison of the pre and post intervention GXT results highlighted that despite the twice daily group displaying a slight increase (0.37 ± 4.83 $mL \cdot kg^{-1} \cdot min^{-1}$) in $\dot{V}O_2$ max equating to a 0.8 ± 8.2 % change and the once daily group displaying a slight reduction (-1.27 ± 3.69 $mL \cdot kg^{-1} \cdot min^{-1}$) equating to -1.7 ± 6.1 % change (table 6.12) there was no significant difference (p = 0.601) in the change in $\dot{V}O_2$max between the two groups.

Research has shown that typically, during the foundational stage of training, when the greatest volume of LIT is performed, $\dot{V}O_2$max decreases (Hewson & Hopkins, 1995; Fohrenbach, Mader & Holloman, 1987; Robinson & Robinson, 1991; Galbraith *et al*. 2014), in some cases by up to 6% in as little as two to four weeks (Klausen *et al.*, 1981; Wibom *et al.*, 1992). This drop has been attributed to a lack of HIIT conducted during this time. However, as many MTRs compete in 5 km competition all year round (Parkrun, 2016) they essentially conducted a form of HIIT during this time. Thus, research design in the past does not seem to reflect how the

participants conducted their normal training. In chapter 6 the researcher attempted to control for HIIT and participants were recruited on the basis that they were accustomed to the volume and intensity of both HIIT and LIT that they would undertake in the training programme, and that they had been conducting at least one HIIT session per week in the months preceding the study. As such further changes to $\dot{V}O_2$max are likely to be a result of the once or twice daily training conducted.

Given the importance of $\dot{V}O_2$max for setting the upper limit of aerobic capacity this research presents new insight into ways in which the MTR might be able to limit any losses as $\dot{V}O_2$ max was held relatively stable for both groups over the six week training intervention.

6.5.2.2 *Change in RE12 (after training)*

Analysis of RE12 both pre and post intervention highlighted that the significant improvements seen in RE measured during the long run after training (Table 6.7) were not mirrored in RE12 measured during the GXT. Furthermore, despite training at similar speeds throughout the training intervention, the two groups had different responses in RE12 after the intervention. While RE deteriorated for the twice daily group, represented by an increase of 0.5 ±12.8 $mL \cdot kg^{-1} \cdot km^{-1}$ (0.4 ± 6.5 % change) after training, the once daily group saw an improvement in RE, represented by a reduction of -3.7 ±11.3 $mL \cdot kg^{-1} \cdot km^{-1}$ (-1.5 ± 5.3 % change) after training (Table 6.13). However, this difference between the two groups was not significant (p = 0.904).

This different response in the two measures of RE after training can be explained by previous suggestions that improvements runners experience after a period of training are generally related to the intensity, duration and the method of training (MacDougall & Sale, 1981; Tanaka, 1990; Carter, Jones, Doust, 1999; Henritze, Weltman, Schurrer, Barlow, 1985; Weltman, *et al.* 1992, Sjodin et al. 1982; Acavedo & Goldfarb, 1989; Keith, Jacobs, McLellan, 1999). In the present study RE measured during the long run testing was recorded at the same exercise intensity (70-75% $\dot{V}O_2$max) at which the runners had been conducting their long runs throughout the six week intervention. Furthermore, this was the same exercise for all runners. However, RE12

was not a prescribed training intensity during the six week intervention therefore it is unsurprising that all runners would experience improvements in RE12.

Hopkins (2000) has proposed the concept of the smallest worthwhile change (SWC) to determine the practical significance of interventions. The SWC identifies the magnitude of change required to elicit a meaningful or significant improvement in RE. The SWC, calculated as a proportion of the effect size, represents the magnitude of improvement in a variable as a function of the between-athlete standard deviation of the particular cohort. Saunders *et al*. (2004) estimated a SWC of 2.6%, 2.4%, and 2.2% for RE at 14, 16, and 18 $km \cdot h^{-1}$ in endurance runners. In the current study the once daily group improved RE12 by -1.5 % and the twice daily group deteriorated by 0.4%, therefore suggesting that there was no meaningful change. However, both groups saw improvements in RE during the long run represented by a -5.9 % change for the once daily group and a -6.6% change for the twice daily group, therefore suggesting that a meaningful change in RE had occurred.

6.5.2.3 Change in VT (after training)

Comparison of VT1 pre and post intervention highlighted that, after six weeks of training, significant increases at the point at which VT1 occurred were seen for both groups. For the twice daily group, this was represented by a mean increase of 4.1 ± 3.3 % $\dot{V}O_2max$ ($p<0.001$) after training (Table 6.13). For the once daily group this was represented by a mean increase of 3.6 ± 3.2 % ($p<0.001$) (table 6.13). However, like $\dot{V}O_2max$ and RE12, the difference between the groups for VT1 was not statistically significant ($p = 0.821$).

It has been reported that VTs have been shown to be highly responsive to training, with reports of improvements to the VT of between 13-23% being achieved in just 8-10 weeks when a small portion of LIT (~20-30%) is replaced with HIIT (Yoshida *et al* ., 1981; Conley *et al*., 1984; Overend, Paterson, Cunningham, 1992; Mader, 1991; Weltman, Snead, Seip, Weltman, Rutt, & Ragol, 1990; Galbraith *et al*., 2014). However, during the foundational stage of training, gains seen within the transition or speed phases of training are quickly lost (Coyle *et al.*, 1985

Karvonen, *et al.*, 1985), with some reporting significant losses in as little as one to two weeks (Costill *et al*., 1985).

Possible explanations as to why these MTRs saw improvements in VT1 could be related to the intensity at which they performed the long run. Research has shown that training at intensities close to LT/VT may be effective in prompting improvements in performance in the untrained population (MacDougall & Sale, 1981; Tanaka, 1990; Carter, Jones, Doust, 1999; Henritze, Weltman, Schurrer, Barlow, 1985; Weltman, et al., 1992, Sjodin et al., 1982; Acavedo & Goldfarb, 1989; Tharp, Berg, Latin, Stuberg, 1997; Keith, Jacobs, McLellan, 1999). By contrast, Londeree (1997) concluded that while training at an intensity corresponding to LT was effective in increasing LT in untrained runners, it was not effective for the trained runner for whom a higher training stimulus might be required.

In chapter 6 the MTRs performed their long run at 70-75% $\dot{V}O_2$max, therefore effectively performing these runs at VT1 (Table 6.8). The improvement in performance of the MTRs thus highlights the importance of this research as the MTRs did not show the same response as the highly trained runners.

Both the once and twice daily groups saw significant improvements in performance VT2 after the training intervention. For the twice daily group, this was represented by a mean increase of 3.8 ± 2.8 % $\dot{V}O_2$max (4.7 ± 4.2 % change) ($p<0.001$) after training (table 6.13). For the once daily group this was represented by a mean increase of 2.2 ± 2.2 % $\dot{V}O_2$max (2.8 ± 2.8 % change) ($p<0.001$) (table 6.13). Again, like the RE12 and VT1, the difference between the groups for VT2 was not significant ($p = 0.166$).

These finding demonstrated that the MTRs, upon completing the six week training intervention, appeared to have developed the ability to maintain a high percentage of their $\dot{V}O_2$max (fractional capacity).

As the participants were not prescribed any training at intensities relating to VT2, these findings are difficult to explain. As the researcher has been unable to find any notable published research

conducted to date on how MTRs respond physiologically during the initial 6 weeks of the foundational stage of training, this research highlights the need for further investigation.

6.5.2.4 Change in 5 km performance (after training)

Comparison of pre and post training intervention 5 km performance times highlighted that both groups of MTRs saw significant improvements in running performance. For the twice daily group this was represented by a mean improvement of 30 seconds after training; for the once daily group this was represented by a mean improvement of 13 seconds after training. This difference between the two groups after training was significant ($p = 0.03$).

While the once daily group did not see improvements in RP to the same level as the twice daily group, it should be noted that this group still saw a 13-second improvement – deemed by this researcher as a worthwhile change.

Analysis of the relationship between the change in 5 km TT and the change in the physiological variables ($\dot{V}O_2max$, VT1, VT2 and RE12) demonstrated that performance improvements seen in each group were possibly achieved through changes in different variables. For the twice daily group this was represented by a moderate, negative r of -0.487 between the change in 5 km TT performance and change in $\dot{V}O_2max$, while a moderate change was found in the change in 5 km TT time and RE12 in the once daily group. As the variance explained for both groups was low, with 24% for the twice daily group and 22% for the once daily group, it is possible that other variables not collected in this study (biomechanical alterations or neuromuscular adaptations) also contributed to the performance.

6.5.2.5 Predicting performance

Stepwise regression analysis revealed the relationship between 5 km TT times and PTv, RE12 and vVT was maintained after the training intervention and therefore the training did not

substantially alter predictive power (Table 6.17) of the equations (Equations 1 & 2) developed in chapter 4 for both groups.

Equation 1: Predicting lab 5 km TT: (peak treadmill velocity x - 64.977) + Constant 2270.636 = predicted time (seconds)

Equation 2: - Predicting lab 5 km TT: (vVT x -51.192) + (RE12 x 9.588) + constant 1417.386 = predicted time (seconds)

For the twice daily group this was represented by a slight increase to the correlation coefficient values from r = 0.95 to 0.96 after training. Conversely, for the once daily group there was a decrease in the correlation coefficient values from r = 0.95 to 0.85 after training.

Results of the regression analysis highlighted that PTv remained the strongest predictor before and after training. Coaches and athletes, therefore, might prefer to use this equation to predict 5 km RP during the foundational stage of training.

6.6 Conclusion

Chapter 6 has demonstrated that when MTRs split their low intensity long run (once daily) into two sessions of equal length, one performed in the morning and the second performed in the evening (twice daily), two days per week, for six weeks, appears to alter the pattern of $\dot{V}O_2$ consumption between the two groups. Significant differences are also seen in RER and the estimated fat consumed during a long run when compared to a single continuous run.

Chapter 6 has also demonstrated that conducting the twice daily method of training improved 5 km RP to a greater extent than once daily training, incorporated as part of a six week training programme during the initial six weeks of the foundational stage of training. For the twice daily group this was represented by a mean improvement of 30 seconds after training; for the once daily group this was represented by a mean improvement of 13 seconds after training. This difference between the two groups after training was significant (p = 0.03). However, it should

be noted that while the twice daily group saw greater improvements, this method of training led to far higher participant dropout rates.

In relation to these drop out rates, six participants from the twice daily training group dropped out, compared with two from the once daily training group. Of the six, three could not continue due to illness and the remaining three quoted problems with low motivation. These runners reported that they would dread the thought of doing the second run all day, and this style of training took the enjoyment factor out of their sport. Although beyond the remit of this research, it would be worthwhile conducting a psychological study to better understand whether twice daily training makes it harder for runners to stay motivated. It could be argued that this would pose even more of a problem in the winter months when the second session would most likely be conducted in the dark. This research certainly provides a rationale to justify this exploration.

Chapter 7: Discussion.

7.1 Review of thesis aims

To date research investigating the physiological adaption runners experience after a period of training has focused on either the untrained or the elite runner. Therefore, it would be reasonable to suggest that our understanding of the adaptation the MTR's experiences is limited.

Within the scientific literature, a range of variables can be found defining the classification of runners (Chapter 2, Table 2.2). However, while these variables may vary, they can still be grouped into three general groups. These include, the untrained, the moderately trained and the highly trained or elite runner. For a summary of these classifications the reader is referred to Chapter 2, Table 2.1

Throughout this thesis MTRs are defined as:

- Runners who have been running for a minimum of 1 year.
- Have a $\dot{V}O2max$ with the range of 50-70 $mL \cdot kg^{-1} \cdot min^{-1}$.
- Are able to run a 5km within the range of 22-15minutes.

This thesis therefore aimed to provide insight into our understanding of this, specifically related to the MTR.

Before addressing the primary aim of this thesis, comparisons were made between the unfamiliar laboratory environment, used throughout this research to collect physiological measures on the MTRs, and the familiar outdoor environment. Although the laboratory provides many methodological advantages as a testing ground such as the relative ease of repeating trials, the space required, and the ability to control for a range of environmental conditions including the speed and slope of intensities on the treadmill (Baur, Hirschmuller, Muller, Gollhofer, & Mayer, 2007), there are often questions over the ecological validity of laboratory based trials and their transferability into a field based competitive environment (Goulet 2011). Study 1 (Chapter 4) therefore compared the 5Km running performance of MTRs in both environments to determine whether laboratory testing or outdoor testing would be

methodologically preferable in Studies 2 and 3 (Chapters 5 and 6). It was the intention that if significant differences emerge between laboratory and outdoor testing Studies 2 and 3 would be based outdoors, to ensure the results had maxium impact in a real-word race context.

The primary aim of this thesis was to investigate selected physiological variables when MTRs split their long run, performed at low intensity, into two shorter runs of equal length; one session performed in the morning and the second session performed in the evening, after a period of 6-8 hours recovery. There is increasing speculation that twice daily training may be more effective than once daily training in promoting adaptation (Croft *et al*., 2009; Hansen *et al*., 2005; Hulston *et al*., 2010; Yeo *et al*., 2008), although these studies did not incorporate LIT into both split sessions. Drawing on the literature it would seem that the research conducted so far has not been based on training performed at low intensity (LIT), with at least one of the split sessions being at high intensity (HIT). In addition to this, LIT has received very little attention from researchers despite its frequent use by coaches and its long established place as a fundamental part of training. Therefore, it is warranted to investigate the effects of splitting training when performed at low intensity.

Study 2 (Chapter 5) examined the differences in runners' physiological variables when performing either once or twice daily training in an acute (or one-off) context. This investigation was then developed in Study 3 (Chapter 6) where a six week training intervention aimed to gain further insight into the impact of incorporating either once daily or twice daily training as part of a periodised training plan. The six week training plan was incorporated during the foundational stage of training and included two days per week where the runner performed their normal long, low intensity run as either once daily or twice daily training. Alongside the impact on physiological variables associated with running performance, Chapter 6 also examined how conducting either once or twice daily training programs affected the runners' 5 km running performance.

7.2 Field and laboratory comparison

Study 1 (Chapter 4) compared 5 km TT performance in the laboratory with the outdoor running track and demonstrated that significant differences (p<0.001) (table 4.4) were seen between 5 km TT times performed in the laboratory and 5 km TT times performed on an outdoor running track. However, unlike previous research where runners performed faster running times outdoors (Nummela *et al*., 2007; Morin & Seve, 2011; Peserico & Machado, 2014), the male MTRs participating in chapter 4 ran faster under laboratory conditions (1089 ± 92 s) compared with outdoors (1114 ± 96 s) (Table 4.4).

As stated in Chapter 4, it is possible that methodological and environmental differences between Study 1 and the literature may, in part, have influenced the findings. These differences included the recruitment of runners to this research who were frequent treadmill users. Similarly, the use of familiarisation TTs prior to both laboratory and field tests may have led to runners feeling more comfortable on the treadmill and therefore able to perform to their potential. An additional finding from this research was that participants often commented that they did not enjoy wearing the mobile oxycon machine whilst running and this may have hindered their performance in the outdoor tests.

Furthermore, in this research it was ensured that feedback given to the runners while performing their 5 km TT was consistent in both conditions, which may have influenced the result. In contrast it is not clear from the literature whether such feedback was given in the research with dissimilar findings. Finally, in this research all outdoor testing was performed under the wind speed threshold of 2.0 m s^{-1} as recommended by Jones & Doust (1996) and so runners could not benefit from a tail wind and this may have influenced the result, although it would have enhanced the similarity between the two environments and therefore the validity of the findings.

The results from Study 1 were used to inform the design of Studies 2 and 3, although not in a way that was first intended. It was the intention that if significant differences emerged between laboratory and outdoor testing (which they did) Studies 2 and 3 would be based outdoors, to

ensure the results had maxium impact in a real-word race context. However, in spite of the differences that did emerge between the two environments, it was decided that the testing for Studies 2 and 3 should be conducted in the laboratory. This was largely for practical reasons as there were a number of methodological limitations relating to testing outdoors that became apparent during Study 1. However, strong correlations (r=0.9, table 4.4) between running times across the two environments meant that, in spite of significant differences, the two environments could still be consistered comparable. In other words, any performance increases observed in the laboratory would at least 95% of the time be observed outdoors.

The primary reason for choosing not to pursue outdoor testing during Studies 2 and 3 was that, as stated above, during Study 1, participants often commented that they did not enjoy wearing the mobile oxycon machine whilst running. During this and subsequent discussions on this training programme participants reported that the equipment was uncomfortable and they felt as though they were on display at the running track. Owing to the need to keep participants engaged in the research, particularly Study 3 which demanded a great deal of participants' time and focus, it was felt that laboratory testing would be preferable. This is one example of patient and public involvement (PPI) in this research, where methods were developed collaboratively with participants to ensure they were appropriate.

There were further methodological concerns by the author, relating to the possibility of variations in outdoor environmental conditions, such as large variations in both temperature and wind speed, especially during the winter months when testing for Study 2 and Study 3 took place and this also fed into the decision to restrict all testing for subsequent studies to the laboratory.

7.2.1 Predicting performance

A secondary product of the data collected for Study 1 was that it could be used to create a prediction equation for MTRs. Predicting performance through the use of equations based on performance related variables has been a key interest for those working with runners (Roecker

et al., 1998; Haverty *et al*., 1988; Stratton *et al*., 2009; Paavolainen *et al*., 1998; Scott & Houmard 1994; Takeshima & Tanaka, 1995). As a consequence, many 5 km prediction equations have been developed (Table 2.1). However, as stated in Study 1, little attention has been given to the MTR. Given the findings that the MTRs participating in Study 1 performed differently from highly trained runners used in previous investigations when comparing 5 km running times in the laboratory with outdoors, it would be reasonable to argue that current prediction equations might not be relevant for the MTR.

Stepwise regression analysis detailed in Chapter 4 therefore provided an opportunity to create four prediction equations specifically for the MTR, and this is perceived as a strength of this research. Equations 1 and 3 were created allowing the MTR or coach to predict indoors or outdoors 5 km RP using just PTv. PTv is easily collected by the runner or coach through a GXT performed on a treadmill, meaning that a visit to the laboratory would not be required.

> Equation 1: Predicting lab 5 km TT: (peak treadmill velocity x - 64.977) + Constant 2270.636 = predicted time (seconds)
>
> Equation 3: Predicting outdoor 5 km TT: (peak treadmill velocity x - 66.710) + Constant 2327.426 = predicted time (seconds)

Although the above equations are useful in predicting the 5 km TT times a runner should be able to achieve, they do not provide information that can be used to inform a training programme. As stated in Chapter 4, information on physiological variables ($\dot{V}O_2$, RE and LT/VTs) is needed in order to determine areas of physiological weakness which need to be addressed through a prescribed training programme.

As such, Equations 2 and 4 were also created using the physiological variables ($\dot{V}O_2$max, RE and VT) determined in laboratory-based testing:

> Equation 2: Predicting lab 5 km TT: (vVT x -51.192) + (RE12 x 9.588) + constant 1417.386 = predicted time (seconds)

Equation 4: Predicting outdoor 5 km TT: (vVT x -74.292) + constant 2153.383 = predicted time (seconds)

Regression analysis conducted in Chapter 6 revealed that the relationship between 5 km TT times and PTv, RE12 and vVT was maintained after the training intervention and therefore the training did not substantially alter the prediction (Table 6.17) of the equations (Equations 1 & 2) developed in Chapter 4 for both groups. This findings upholds the validity of the prediction equations and testifies to their applicability to a wide range of MTRs at different stages in their training.

Results of the stepwise regression analysis highlighted that PTv remained the strongest predictor before and after training. As such, a coach or athlete, wishing to see how they have responded after a period of training could Equations 1 or 3 to predict how they would perform in a 5 km time trial.

7.3 The acute effects of performing once daily vs twice daily training on factors associated with running performance.

Study 2 and pre intervention results from Study 3 clearly demonstrated that in the acute setting, when MTRs split their long run paced by HR, significant differences are seen between the two groups in terms of changes in velocity throughout the run and the physiological variables (RE, RER and estimated fat metabolised) (Tables 5.7 and 6.5) during the second half of the run.

7.3.1 Changes in Velocity

Both groups started their runs (set to 70-75% of VO^2max) at similar velocities, with these being 13.1 $km{\cdot}h^{-1}$ ± 1.5 for the once daily group and 13.3 $km{\cdot}h^{-1}$ ± 1.3 for the twice daily group. The reduction in velocity at the half way point was also similar for both groups (-0.6 $km{\cdot}h^{-1}$ ± 0.1 for the once daily group and -0.7 $km{\cdot}h^{-1}$ ± 0.1 for the twice daily group). This half way point was the point at which the twice daily training group stopped their first run of the day, but the once daily group continued to run for the same length of time again.

When comparing the velocity at the start of the second half of the run, there were significant differences between the two groups. The once daily group, who were continuing their run, started (continued) at 12.5 $km \cdot h^{-1}$ ± 1.5, whereas the twice daily group, who were embarking on their second run of the day, has a starting velocity of 13.3 $km \cdot h^{-1}$ ± 1.2). Thus the twice daily group were able to start their second run at a very similar speed to their first run of the day.

The result of this was that the once daily group saw a larger total reduction in velocity over the course of the run, when compared with the total reduction in velocity for the twice daily group. For the once daily group this was a -1.1 $km \cdot h^{-1}$ ± 0.2 reduction, and the twice daily group a -0.8 $km \cdot h^{-1}$ ± 0 reduction. Therefore, the twice daily group maintained a higher average velocity throughout the entire day's running, and this was because they did not see such a large drop in velocity in the second run of the day compared with the once daily group who reduced their velocity in the latter half of their single run.

The significant differences observed in velocity between the two groups did not result in significant differences in O_2 consumption between the two groups (figure 5.3). This was an unexpected finding as the literature has shown a linear relationship between intensity and O_2 consumption (Seiler, 2010), with one variable increasing together with the other. Thus one would expect that as velocity decreased to a larger extent for the once daily group, so would O_2 consumption. Although the decrease in O_2 consumption was larger for the once daily group, the difference was not statistically significant.

The difference in velocity found in this acute setting, which was not mirrored by a difference in O_2 consumption, provides grounds for further research to explain this finding. Furthermore, it is expected that maintaining higher velocity will lead to adaptation in physiological variables such as RE, RER and substrate untilisation as research has shown that training speed predicts performance (Bragada *et al*., 2011; Hagan *et al*., 1981). Thus if the twice daily training approach was conducted as part of a long term training intervention one would expect to see improvements in the physiological variables that influence performance.

7.3.2 Changes in RE, RER and estimated fat metabolised

In Study 2 differences in RE, RER and estimated fat metabolised were observed between the two groups following a single day of running. The twice daily training group saw a reduction in the amount of estimated fat metabolised in the second run of the day when compared with the first run. The once daily training group saw an increase in the amount of estimated fat metabolised as they progressed throughout the course of the single run. This went hand in hand with the difference in RER which increased for the twice daily group and decreased for the once daily group. Thus it would appear that runners in the twice daily group were fuelling their second run with CHO to a greater extent than runners conducting single runs, with these runners metabolising larger amounts of fat during the second half of the run. This goes some way to explaining the faster velocities observed in the twice daily training group, as research shows CHO to be a more efficient fuel source for 5km distances.

In reality, conducting either once daily or twice daily training in the acute setting is unlikely to result in any noticeable physiological change to the MTR. Research has confirmed this by demonstrating that once a training stimulus has stopped, the production of signalling proteins soon returns to the body's baseline, in some cases within 24 hours (Yang *et al*., 2005). Therefore, in an acute setting when the runner splits their long run in to two shorter runs of equal length, it is possible that little adaptation will occur in the short term.

As such, while the findings of Study 2 might be of limited value to the MTR, they were valuable to this research rationale as they provided confirmation that differences were produced in physiological variables between once daily or twice daily training in the acute setting. This gave the researcher confidence that despite the known difficulties in conducting chronic (six to ten week) training interventions such as initial participant recruitment and then once recruited ensuring participant wellbeing throughout, the investigation into the effects of chronic (six weeks) exposure to either once daily or twice daily training on these variables was warranted.

7.4 The chronic effects of performing once daily vs twice daily training on factors associated with running performance.

Following on from Study 2 and the acute effects of once daily vs twice daily training on factors associated with running performance, Study 3 then focused on the chronic impacts of both once daily and twice daily training as part of a six week periodised training plan during the foundational stage of training, during which an increase in training volume was also achieved. The training invervention included two days per week where the runner performed their normal long, low intensity run as either once daily or twice daily training.

Analysis conducted in Chapter 6 found that, following the training plan there were no differences in the pattern of $\dot{V}O_2$ ($p = 0.074$) or RE ($p = 0.323$) during the long run between the two groups. However, there were differences in the pattern of RER ($p<0.001$) and estimated fat metabolised ($p<0.001$) between the two groups when the first and second half of the training runs were compared (Table 6.6).

7.4.1 Changes in RER and estimated fat metabolised

A significant difference in the substrate utilization of the two groups was detected in terms of the estimated fat metabolised by runners. The twice daily group saw a reduction in the amount of fat metabolised following the intervention (-1.5 grams ± 10.5) wheras the once daily group recorded an increase of 0.6 grams ± 5.8. Further investigation into differences in substrate untilisation during the first and second run for the twice daily training group and the first and second half of the single run for the once daily training group identified the point during the run at which differences emerge. The twice daily group used more CHO in the second run when compared with the second half of the once daily group's run. As discussed, this is because the twice daily group were able to consume CHO rich fuel during the period of recovery. Research has consistently demonstrated that consuming moderate to high levels of CHO three to four hours prior to exercise increases CHO oxidation (Coyle et al., 1985; Wright et al., 1991; Coyle et al., 1997; Cox et al., 2010; Cole et al., 2014) and depresses fat oxidation (Costill et al., 1977;

Coyle et al., 1985; Wright et al., 1991). This difference was observed in the acute setting (Study 2) as well as following the intervention (Study 3) but differences were greater following the intervention showing that the twice daily group had shifted fuel source away from fat to CHO as a result of the intervention. As CHO is the more efficient fuel source for high intensity exercise such as a 5Km runs this will have contributed to the faster speeds observed for this group.

This difference in substrate utilisation was significant and relates to 13.5 Kcal which would fuel the average male runner perofrming HIT for approximately one minute. Although this might seem minimal, a race can be won in the last minute by a matter of seconds. For example, a table presented later in this chaper (Table 7.1) shows that the men's national 5km championships in 2017 was won by nine seconds. This suggests that this amount of energy would be meaningful in a race situation.

7.4.2 Changes in RE

While the training intervention did not change the pattern of RE between the two groups when the first and second half of the training runs were recorded, it is important to note that both groups saw a significant improvement in RE during the long run after training. Improvements in RE are known to occur after individuals conduct repeated exercise (in this case over the intervention period) at a fixed intensity. In other words, improvements in RE are related to the intensity at which runners train as they become more efficient in the zone in which they train. In the case of this study, both groups of runners conducted their runs between a range of 70-75% of $\dot{V}O_2max$ which included VT1 for all runners. Research has shown that training at VT1 can be effective in improving VT1. This research suggests that training at VT1 also improves RE. However, causation cannot be claimed here due to a lack of control group.

It must be acknowledged that a limitation of Study 3 is the lack of a control group. The decision not to include a control group was primarily due to the increase in the number of participants required for additional comparisons to be conducted, and additional time required to track

multiple groups through the intervention period. The researcher simply did not have the resources. However, as such it cannot be confirmed that the changes in RE were a result of the six week training protocols without comparison to a control condition. Future research could therefore further investigate this with the additional control group.

Similar improvements (6 – 8%) in RE after 4-8 weeks of training have been reported elsewhere (Helgerud *et al*., 2007; More, Jones & Dixon, 2012), giving support to the suggestion that these improvements in RE may have occurred as a result of the intervention. However, as previously stated, none of the research mentioned above used a velocity equating to 70-75% $\dot{V}O_2max$ to measure RE. Post intervention results reported in Chapter 6 highlighted that the significant improvements seen in RE during the long run after training (table 6.7) were not mirrored in RE12 measured in the GXT after training. This finding can be linked to the previous discussion which showed how improvements in RE occur at the speed at which a runner trains, thus improvements that runners experience after a period of training are generally related to the intensity, duration and the method of training (MacDougall & Sale, 1981; Tanaka, 1990; Carter, Jones, Doust, 1999; Henritze, Weltman, Schurrer, Barlow, 1985; Weltman, et al. 1992, Sjodin et al. 1982; Acavedo & Goldfarb, 1989; Keith, Jacobs, McLellan, 1999). As runners in this study were not training at 12 $km \cdot h^{-1}$ an improvement in RE12 was not observed. This finding provides further evidence that researchers should be encouraged to collect RE measures at the intensity at to which the runners devote their training time, rather than at a fixed velocity for all runners. This reinforces the need to ensure that rather than using a fixed velocity that is the same for all runners to measure RE after a period of training, tests should be conducted at the velocity at which the runner has been training, or the velocity they wish to race at.

It should also be noted that previous research has not investigated changes during the foundational stage of training or LIT stage. Rather in the above cases the research was conducted during the speed or interval phases of training. Furthermore, the researchers used different training methods from those used in this research. This includes using high volumes of high intensity interval training (HIIT) (Billat *et al*., 1999; Helgerud *et al*., 2007; Denadai, *et*

al., 2016), strength training (Paavolainen *et al*., 1990; Spurrs *et al.*, 2003; Turner *et al.*, 2003 or altitude training (Katayama *et al*., 2004). In spite of the lack of research into the foundational stage of training, this low intensity stage is the stage at which MTRs spend the largest proportion of their annual training time (Galbraith *et al*., 2014).

To date, it appears that only one researcher (Galbraith *et al.,* 2014) has successfully tracked physiological changes seen over a typical year and thus included the foundational stage of training. The study found that participants achieved small but significant changes in $\dot{V}O^2$ max although no changes in RE were detected. Therefore, findings differed from those recorded in this research, where no significant changes in $\dot{V}O^2$ max were observed in either group following the intervention, but significant improvements in RE were recorded for both groups. However, the similarity between this study and Galbraith *et al.*'s is limited to the incorporation of low intensity training on male runners, and the differences are several. Unlike this research, the Galbraith *et al*. (2014) research did not investigate the effects of different training methods, with runners training as they normally would. Furthermore, Galbraith *et al*. observed runners over the period of a year, compared with the six week period used in this research. Thus it is not possible to draw comparisons with once and twice daily training conducted during the foundational stage. Furthermore, participants in Galbraith *et al*.'s research were classified as highly trained runners across a wide range of distances ranging from 800m to the marathon and therefore different from the MTRs recruited in this research.

7.4.3 Relationship between RE and $\dot{V}O_2$max

As discussed, no significant differences were observed in $\dot{V}O_2$max following the intervention between the two groups. In addition, neither group saw a significant change in $\dot{V}O_2$max following the intervention.

Previous research suggests that an inverse relationship exists between two key variables: $\dot{V}O_2$max and RE (Morgan & Daniels, 1994; Pate *et al.,* 1995; Moseley & Jeukendrup, 2001; Lucia *et al*., 2002, Hopker *et at*., 2012), an explanation being that as runners become more

economical with the use of O_2 the percentage of $\dot{V}O_2$max required to sustain a given velocity is also reduced. Research which has also suggested that only in very specific cases can althetes benefit from improving RE and $\dot{V}O_2$max at the same time. For this to occur training strategies must incorporate increases in volumes of both LIT (for improved RE) alongside increases in volumes of HIIT (for improved $\dot{V}O_2$max). This has been achieved in untrained runners who may have a further distance to travel in terms of the performance improvements they are able to achieve. However, in the case of this intervention, the strategies for both groups included increases in LIT (albeit conducted differently) and no changes in HIIT, with this continued as the MTRs would normally train (with one session of HIIT a week). Thus it is not surprising that overall, for both groups, improvements in RE were observed and improvements in $\dot{V}O_2$max were not.

What was not detected in the results of this research was that twice daily training leads to differences in improvements to RE when compared with once daily training when conducted at low intensity. This is in spite of significant differences in RE between the two groups observed in the acute setting (Study 2). Thus these differences did not increase following a period of training.

In relation to improving running performance over 5 km, previous research shows that in comparison with $\dot{V}O_2$max, RE emerges as a better predictor of RP (Farrell *et al*., 1979; Tanaka *et al*., 1983; Tanaka *et al*., 1984; Morgan *et al*., 1989; Takeshima & Tanaka, 1995; Paavolainen et al., 1999; Saunders *et al*., 2004). This is supported by the strong correlation coefficients to 5 km performance found in Study 1 of this research, where r = 0.68 for RE12 compared with the low correlation coefficient of r = 0.39 for $\dot{V}O_2$max. Thus even though improvements in $\dot{V}O_2$max were not observed, runners were able to improve their performance through improvements in RE.

7.5 The effects of six weeks of either once daily or twice daily training on 5 km performance.

Comparison of pre and post training intervention 5 km performance times highlighted that both groups of MTRs saw improvements in running performance. For the twice daily group this was represented by a mean improvement of 27 seconds after training, for the once daily group this was represented by a mean improvement of 13 seconds after training. This difference of 14 seconds between the two groups after training was significant ($p = 0.03$).

To provide context for the changes in running performance seen in Study 3, the top 10 placings from the 2017 National 5 km Championships all fell within 25 seconds (Table 7.1), and excluding 1st place, just 15 seconds differentiated between 2nd and 10th place. Thus an improvement of 14 seconds associated with following one training programme over another could translate into winning a race or failing to reach a podium position.

Table 7.1. The top ten placings for the 2017 national 5 km championships (RunBritainRankings, 2017)

Finish place	Time (seconds)	Difference to 1st place	Difference to 2nd place
1st place	840		
2nd place	849	9	
3rd place	853	13	4
4th place	859	19	10
5th place	859	19	10
6th place	860	20	11
7th place	861	21	12
8th place	862	22	13

9th place	863	23	14
10th place	865	25	15

7.6 Real world application of this research

By identifying the paucity of research on MTRs, this piece of research is of major importance in filling the knowledge gap for these athletes. An information bulletin communicating the essence of this research to non-experts, including coaches and athletes has been written by the researcher (Apprendix 8).

One challenge with research based on MTRs is recruiting, and retaining, a sufficiently large number of athletes to complete the necessary trials. A further challenge, important in the success of any type of research, is the extent to which researchers are asking the right questions. With these two challenges in mind, the information bulletin (Appendix 8) will be circulated to as many sports clubs as possible in the UK. It is hoped that informing athletes and coaches of the results of this piece of research would stimulate local running clubs to engage with scientific research and therefore increase the pool of potential participants.

A further method of publicising this research will be through social media and blogs. Providing space in discussion forums would engage athletes, coaches and researchers to discuss training issues pertinent to MTRs. This should highlight potential new areas of research and allow researchers the opportunity of discussing RQs with runners. It is hoped that this would generate new and relevant research directions which are not entirely defined by academics, thus incorporating the known benefits of PPI. Inevitably, the discussion would expand and this researcher hopes to set up parallel spaces in which athletes of other discplines, for example cycling where participants and coaches could be brought together with like-minded researchers.

7.7 Limitations

One possible limitation of this research is that findings are limited to a running distance of 5 km. The 5 km distance was used for the following reasons; it is a popular competition distance demonstrated by the growing participation in weekly 5 km competitions such ParkRun (ParkRun 2017), to ensure that the battery time limits for the portable mobile gas analysis equipment (used in chapter 4) were not exceeded, to ensure that the time participants would be required to spend in the laboratory was reduced where possible and bearing in mind the time participants would be required to spend in the laboratory in chapters 5 and 6 when completing their long runs, and the amount of test visits required in total throughout the testing process. However, in endurance running 5 km is a relatively short distance in comparison with events such as half or full marathon. It is quite possible that due to changes in the estimated fat metabolised during the long run, performance changes may have been different in longer duration events such as the half or full marathon where fat becomes a more efficient fuel source than CHO.

It is therefore possible that the correlations found between the changes in the physiological variables after training and the changes (improvements) in 5 km TT times might not be the same for longer distance competitions such as the marathon. Further research is therefore required to investigate the effects of once daily and twice daily on longer competition distances.

In chapter 4 a comparison was made between a 5 km run in the laboratory and a 5 km run on an outdoor running track. This study confirmed previous suggestions (Pugh ,1970; Daniels, 1985; Nummela *et al*., 2007; Morin & Seve, 2011) that running on a treadmill is not the same as running outdoors ($p<0.001$)(Table 4.4), and there are notable differences in runners' biomechanical, physiological and psychological responses. Due to the ability to control environmental conditions in an indoor running track it is likely that the indoor track would be closer in terms of comparison to outdoor running and thus would be preferable to a laboratory 5 km. The decision to use the laboratory was due to the lack of facilities in the local area and the logistical issues involved with transporting a large number of runners to an indoor track.

However, this must be noted as a limitation and if possible in future research, 5 km TT performance should be tested on an indoor running track.

A further challenge with this research was the limited published data for comparison. There is very little data on foundation training in sport and exercise sciences. Research has shown that the degree to which each physiological variable ($\dot{V}O_2$max, RE or VT/LT) contributes to performance is dictated by the length and the duration of the event (Morgan *et al*., 1989; Pate *et al*., 1992; Saunders *et al*., 2004). Longitudinal (years) observational research on elite level runners has suggested that in the years following an increase to competition distance from 5 km to the marathon, reductions in $\dot{V}O_2$max are seen, however, this reduction is accompanied by a improved RE. The researcher was unable to find any longitudinal research on MTRs which made comparisons impossible, however, it does highlight the need for this research to fill a knowledge gap.

It has been suggested that a reason longitudinal (chronic) research on how endurance athletes respond to training interventions is so limited is partly due to athletes not wishing to have their training prescribed for a prolonged period and thus initial recruitment is difficult (Hawley 1997). Once recruited the unfamiliar training methods can result in decreased levels of motivation as the intervention progresses, leading to participant dropout. Furthermore, inevitably athletes can pick up illness or injuries. This emerged as a limitation of this research where a larger number of participants from the twice daily group dropped out of the study compared with the once daily group.

When reviewing the participant dropout rates in each group, differences appear between the reasons given for withdrawal by participants in the two groups. Regarding the once daily group, the dropout rates were low with only two participants (9.5% of group) opting to withdraw, both stating muscular discomfort or injury as a cause. In the twice daily group six participants (~29 % of group) withdrew. Of these six runners, three runners were unable to conduct the training prescribed due to illness. The remaining three runners who withdrew stated low motivation as the cause and did not wish to continue with the training.

Although only three runners dropped out for reasons of low motivation, this emerged as a factor for a number of participants in the twice daily group. To limit further participants from withdrawing a great deal of communication and moral support between the researcher (myself) and participants throughout the study was required. Inevitably, some participants needed more of this type of support than others. This 'coaching' may have influenced the final results as it increases the capacity for researcher influence which in turn becomes an uncontrolled, unobserved and virtually unmeasurable variable in the experiment.

A further challenge emerged in controlling participants' food intake. Efforts were made to ensure that the participants' food intake on the day of their long runs in chapters 5 and 6 were recorded (Tables 5.8, 5.9 & 6.3, 6.4). T-test analysis conducted in chapter 5 (study two) and chapter 6 (study three) confirmed there was no difference between the two groups in the total calorific content or the macronutrient profile of the breakfast and lunchtime meals. However, it should be acknowledged that, research has shown that participant self-reporting of food intake can result in an under reporting of food intake of up to 20 % (Wrieden, Peace, Armstrong and Barton, 2003).

A final possible limitation of this research relates to the lack of investigation into how HIIT training, when incorporated as part of once or twice daily training, may influence running performance. Previous research comparing HIIT performed either once daily or twice daily training every second day has reported that twice daily training can result in a reduced capacity to perform maximally during these HIIT sessions (Achten *et al*., 2004; Yeo *et al*, 2008). In this research, both groups achieved faster 5km TT times after training, suggesting neither group experienced a reduction in their capacity to perform maximally, however, the participants' exercise capacity during a HIIT session was not assessed before or after the training. The decision not to include this analysis was primarily due to the main focus of the research being the investigation of physiological differences seen when MTRs perform once or twice daily training specifically at 70-75% $\dot{V}O_2max$. Furthermore, efforts were made by the researcher to reduce the time the participants would be required to visit the laboratory where possible.

7.8 Future Directions

The logical progression for this research is to increase the sample of runners and include a control group. Incorporating a control group into the research design in future research would allow investigation around the possible mechanisms by which RE may have been be improved. As increasing (Bailey *et al*., 1991), this research could include collection of oxidative enzyme activity and PV pre and post training intervention.

Future research could also investigate the possibility of attempting to enhance PV specifically by performing the prolonged run in hotter conditions. Throughout Study 3 the daily temperatures during the long runs ranged from 4.3 – 5.7◦c (statista.com, 2018). Research has demonstrated that performing chronic training in the heat can improve PV by as much as 12% (Saunders *et al*., 2004). Given that the runner is unable to control for environmental factors such as the outdoor temperature, a possible training method that could potentially be of benefit to the runner could be conducting their LIT either once daily or twice daily indoors on a treadmill. This allows the runner to control environmental conditions such as temperature.

Owing to the differences in the drop out rates between the two groups further research is needed to expand our understanding of why the MTRs in each group seemed to develop different signs of physical and mental stress. Although sample sizes were too small to draw conclusions, it appeared that the participants in the once daily group withdrew due to muscular discomfort or illness whereas those in the twice daily group stated low motivation to pursue the training programme. Thus future research should explore the possible differences in the immune response and motivation levels of MTRs who performed once daily or twice daily training. As none of the participants in the twice daily group reported any muscular discomfort or injuries this might suggest the mechanical stress of performing the prolonged run as a single run was greater than splitting the run into two equal runs. However, the twice daily training would need to be developed within an approach that did not lead to a disproportionate amount of mental strain for MTRs.

This research has focused on the foundational stages of a MTRs annual training programme, during which initial low intensity training is performed. This foundational stage of training covers the greatest length of time during a runner's yearly training cycle, far more than the six weeks that were included in the training intervention of Study 3. It would be possible, therefore, for runners to complete six weeks of once daily and six weeks of twice daily training within this time period. Future research could therefore investigate if any differences are seen in the running performance of MTRs after performing a 12 week block of training that begins with six weeks of once daily training and then six weeks of twice daily training or a 12 week block that begins with six weeks of twice daily training and six weeks of once daily training.

7.9 Conclusion

This research has expanded our understanding of how MTRs respond to two different training methods: once daily and twice daily training. Differences in physiological variables that are known to correlate with performance were measured in, first, the acute setting and, subsequently, following a six week training intervention conducted in foundational stage of training during which an increase in training volume was also achieved.

Findings from Study 2 demonstrated that when MTRs split their long run, performed at a relatively low intensity (75% $\dot{V}O^2max$), into two sessions of equal length, with one session performed in the morning and the second session performed in the evening, significant differences are seen in an acute setting in changes in velocity throughout the run and the RE, RER and estimated fat metabolised during the second half of the run. The twice daily group did not reduce their velocity over the course of the day to the same degree as the once daily group. Where the once daily group experienced a gradual reduction in speed throughout their long sinlge run, the once daily group were able to start their second run of the day at a very similar speed to their first run after their period of recovery. This can, to some extent, be explained by differences in the substrate utilized by runners in the two groups. Research has shown CHO to be a more efficient fuel source for 5km distances and runners in the twice daily group were fuelling their second run with CHO to a greater extent than runners conducting single runs, who

were burning larger proportions of fat. These physiological variables were then re-examined in a chronic setting to assess whether prolonged training increased differences between the two groups.

Study 3 found significant differences in RER and substrate utilization of MTRs who performed either once or twice daily training as part of a six week training plan. The twice daily group used more CHO in the second run when compared with the second half of the once daily group's run. This difference was observed in the acute setting (Study 2) but differences were greater following the intervention (Study 3) showing that the twice daily group had shifted fuel source away from fat to CHO as a result of the intervention. As CHO is the more efficient fuel source for high intensity exercise such as a 5Km runs this will have contributed to the faster speeds observed for this group.

The findings in this original research therefore demonstrate that, rather than previous suggestions that performance typically declines (Svedenhag & Sjodin, 1985) during the foundational stage of training where an increase in volume is achieved, conducting either of the once or twice daily training plans developed in Study 3 for six weeks resulted in improvements in 5 km RP.

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Appendix 1: Participant Information Sheet (Study 1)

Research Title: **A comparison between indoor and outdoor running measures**

Researcher: Phil Anthony Tel: 01227 767700 ext (3198)

e-mail: phil.anthony@canterbury.ac.uk

Superviser: Dr. Damian Coleman Tel 01227 782639

e-mail:damian.coleman@canterbury.ac.uk

Superviser: Dr. Jim Wiles Tel: 01227 767700 ext (2209)

e-mail: Jim.wiles@canterbury.ac.uk

Invitation to take part

You are invited as a volunteer to take part in a research investigation. Before you decide to take part it is important for you to understand why the research is being conducted and what will be required of you should you agree to be involved. Please take time to read the following information carefully and discuss it with the researcher. If there is anything that is not clear or if you would like more information please do not hesitate to ask.

Background

Current research has highlighted running efficiency and running economy as key factors in an individual's running performance.

These measures provide an indication of your ability to convert stored energy (e.g. fat and carbohydrate) into propulsive energy.

Typically, these measures are recorded in a laboratory; however, as very few events are performed indoors, questions remain as to the validity of measuring lab based changes in efficiency and economy. This study therefore aims to assess the reliability of running economy measures recorded in an external environment.

What will be expected of you?

If you decide to take part in this study you will be asked to attend the Sport Science Lab on three occasions (Canterbury Christ Church University, North Holmes Road, Canterbury, Kent, CT1 1QU (Sports Science Laboratory: Ag 59) with an additional visit to one of two locations: the Julie Rose Stadium (Ashford) or The Body and Mind running track (Canterbury).

Participants will be asked to refrain from any strenuous training or races in the 48 hours prior to any testing.

Study schedule

Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
Visit 1: Induction & Familiarisation Laboratory 5 km TT	Visit 2: Familiarisation Track 5 km TT	Visit 3: Familiarisation $\dot{V}O_2$max test	Visit 4: $\dot{V}O_2$max test	Visit 5: Running Economy measures and Laboratory 5 km TT	Visit 6: Running Economy measures and Track 5 km TT

Your health and wellbeing is of upmost importance, both through the study period and also on the day of each test. A brief health check will therefore be completed on the day of each visit. During the health check we will measure your resting blood pressure and heart rate and ask you to complete a health questionnaire and sign an informed consent form.

Visit 1: Induction and Familiarisation Laboratory 5 km TT

You will be given a brief tour of the laboratory, the study protocols will be discussed and there will be the opportunity to ask questions.

Some simple measurements will then be recorded:

Height and mass

Estimated body fat % using the 8-site skinfold calliper technique.

Finger prick blood sample

During all visits to the laboratory, participants will be asked to complete a 10 minute warm-up on a treadmill at a self-selected pace. Following this, participants will be fitted with a heart rate monitor and the portable breath by breath gas analysis system for the remainder of the test (Oxycon mobile) (see figure 1).

On completion of the 10 minute run, participants will complete a 5 km time trial at a self-selected pace.

Visit 2: Track 5 km Familiarisation

During outdoor testing, participants will be given a 10 minute warm up period on the running track at a pace that is comfortable to them. The participants will then be fitted with a heart rate monitor and the portable breath by breath gas analysis system for the remainder of the test (Oxycon mobile) (see figure 1). The participants will then complete a 5 km (12.5 laps) time trial on the track at a self-selected pace

Visit 3: Maximal aerobic test ($\dot{V}O_2max$) Familiarisation

Participants will complete a maximal aerobic test on treadmill. This test will involve runners reaching volitional exhaustion. The test will start at a low running speed, calculated from your current 5 km race pace, the speed will then increase by 1kph every three minutes until volitional exhaustion is reached.

Visit 4: Maximal aerobic test ($\dot{V}O_2max$)

Participants will complete the same maximal aerobic test on treadmill as completed in visit 3.

Visit 5: Lab 5 km TT

On completion of the 10 minute run, participants will complete a 5 km time trial at a self-selected pace.

Visit 6: Track 5 km TT

The participants will then complete a 5 km (12.5 laps) time trial on the track at a self-selected pace

Figure 1. An image depicting the Oxycon mobile system

To participate in this study you must:

- Be between the age of 18-55 years
- Have been running regularly for a minimum of one year
- Have completed a 5 km race in under 22 minutes
- Have no medical condition that will impair your ability to perform all tests
- Have no known heart conditions or diabetes
- Have no diagnosed with metabolic syndrome
- Be a non-smoker
- Not be using any performance enhancing substances or be willing to suspend their consumption for the duration of testing including
- Be without injury or illness
- Not be taking any performance enhancing substances (excluding caffeine)

Prior to all visits you will be expected to:

- Avoid participation in any strenuous exercise for 48 hours (above regular training intensities)
- Avoid drinking alcohol and caffeinated drinks (i.e. coffee, tea, and cola) for 24 hours
- Consume the same breakfast or lunch a minimum of 2 hours prior to testing
- In the 2 hours before the testing session consume no food or energy drinks and drink only plain water (aim to consume around 1 litre of water prior to testing)
- Bring appropriate cycling shorts, T-shirt/jersey, cycling shoes and pedals

Advantages of taking part

A benefit of taking part in this study is that you will receive feedback, with explanations, on your body composition (e.g. % body fat), cardio-respiratory fitness (e.g. maximal heart rate, maximal oxygen uptake and efficiency) and time-trial performance.

Disadvantages of taking part

For some participants, a disadvantage of taking part in this study could relate to time commitment. To complete all aspects of the study you will be required to attend the lab on three occasions and complete one outdoor time-trial. This equates to about 6 hours of your time, 1/1.5 hours per visit. Although every effort will be made to keep time spent in the lab to a minimal, in the rare occasion that an equipment malfunction occurs you may be asked to re-attend sessions. There is the possibility of muscle soreness after testing; however, this should be no different to the feeling after an intense training session.

Additional information

You may at any time withdraw from the Study. You do not have to give any reason, and no one can attempt to dissuade you. If you ever require any further explanation, please do not hesitate to ask. If you refuse to give consent to participation in this study, or withdraw from it at a later time, it will not prejudice you in any way.

In addition, the following withdrawal criteria also apply:

- If you have any known injuries
- At the request of the researcher – Mr Phil Anthony, supervisor Dr Damian Coleman or Dr Jim Wiles
- Failure of the equipment to record

Any personal information obtained during this Study will remain confidential and comply with the data protection act 1989. You have right of access to your records at any time. Data collected which cannot be identified with you, will be published or presented at meetings with the aim of benefiting others. The results of this study will be published as part fulfilment of a PhD thesis with intent to submit the research at conference and as a journal article. You have a right to obtain copies of all papers, reports, transcripts, summaries, and other material published or presented, on request to the researcher or their supervisor, if appropriate.

A full scientific protocol for this Study has been approved by Canterbury Christ Church University Research Ethics Committee. Further details of the approval will be provided to you if you wish and you have a right to have a copy of the full protocol to retain, if you so request of the researcher.

Appendix 2: Participant Information Sheet (Study 2)

Research Title: **The acute effects of once daily and twice daily training on factors associated with running performance**

Researcher: Phil Anthony Tel: 01227 767700 ext (3198)
e-mail: phil.anthony@canterbury.ac.uk

Superviser: Dr. Damian Coleman Tel 01227 782639

e-mail:damian.coleman@canterbury.ac.uk

Superviser: Dr. Jim Wiles Tel: 01227 767700 ext (2209)
e-mail: Jim.wiles@canterbury.ac.uk

Invitation to take part
You are invited as a volunteer to take part in a research investigation. Before you decide to take part it is important that you understand why the research is being conducted and what will be required of you should you agree to be involved. Please take time to read the following information carefully and discuss it with the researcher. If there is anything that is not clear, or if you would like more information, please do not hesitate to ask.

Background
Current research highlights that an elite level runner's ability to tolerate a high training volume through numerous training sessions each week, is a key factor to their capacity to convert stored energy (e.g. fat and carbohydrate) into propulsive energy, and thus, become more efficient.
.
Although many training programmes already suggest increasing training volume and frequency, questions remain over the benefits gained from this approach. This intervention intends to investigate the physiological adaptions trained runners experience with an increase of 30% total training volume.

What will be expected of you?
If you decide to take part in this study you will be allocated to one of two groups, a SINGLE or a SPLIT group.
You will be asked to attend the Sport Science Lab on a maximum of four occasions if assigned to the SPLIT group (three times if assigned to the SINGLE group) (Canterbury Christ Church University, North Holmes Road, Canterbury, Kent, CT1 1QU (Sports Science Laboratory: Ag 59). There will be an additional two visits to one of two locations: the Julie Rose Stadium (Ashford) or The Body and Mind running track (Canterbury).
Participants will be asked to refrain from any strenuous training or races in the 48 hours prior to any testing.

Study schedule for the split session group

Table 1. Schematic of the split session group

Visit 1	Visit 2	Visit 3
Visit 1: LAB $\dot{V}O_2max$ test	**Visit 2: 5 km TT**	**Visit 3:AM LAB ½ long run** **Visit 4:PM LAB ½ long run**

Your health and wellbeing are of upmost importance, both through the study period and also on the day of each test. A brief health check will therefore be completed on the day of each visit. During the health check we will measure your resting blood pressure and heart rate and ask you to complete a health questionnaire and sign an informed consent form.

Visit 1: Induction and Maximal aerobic test ($\dot{V}O_2max$)
You will be given a brief tour of the laboratory, the study protocols will be discussed and there will be the opportunity to ask questions.

Some simple measurements will then be recorded:
Height and mass
Finger prick blood sample

During all visits to the laboratory, participants will be asked to complete a 10 minute warm-up on a treadmill at a self-selected pace. Following this, participants will be fitted with a heart rate monitor and the breath by breath gas analysis system for the remainder of the test (Oxycon Pro). During visit one participants will complete a maximal aerobic test on treadmill. This test will involve runners reaching volitional exhaustion. The test will start at a low running speed, calculated from your current 5 km race pace, the speed will then increase by 1kph every three minutes until volitional exhaustion is reached.

Visit 2: 5 km TT
During outdoor testing, participants will be given a 10 minute warm up period on the treadmill at a pace that is comfortable to them. The participants will then be fitted with a heart rate monitor and the breath by breath gas analysis system for the remainder of the test (Oxycon Pro). The participants will then complete a 5 km on the treadmill at a self-selected pace.

Visit 3: AM
Participants will be given the same 10 minute warm up period as described in visits one and two before being fitted with a heart rate monitor and the portable breath by breath gas analysis system. Participants will then complete a run corresponding to half of the distance they would complete habitually on their long run at an effort of 70-75% $\dot{V}O_2max$ that was recorded on their first visit.

Visit 4: PM
Participants will be given the same 10 minute warm up period as described in visits one and two before being fitted with a heart rate monitor and the portable breath by breath gas analysis system. Participants will then complete a run corresponding to half of the distance they would

complete habitually on their long run at an effort of 70-75% $\dot{V}O_2$max that was recorded on their first visit.

To participate in this study you must:

- Be between the age of 18-55 years
- Have been running regularly for a minimum of one year
- Must have completed 5 hours per week in the three months prior to the study.
- Have no medical condition that will impair your ability to perform all tests
- Have no known heart conditions or diabetes
- Have no diagnosed with metabolic syndrome
- Be a non-smoker
- Not be using any performance enhancing substances or be willing to suspend their consumption for the duration of testing including
- Be without injury or illness
- Not be taking any performance enhancing substances (excluding caffeine)

Prior to all visits you will be expected to:

- Avoid participation in any strenuous exercise for 48 hours (above regular training intensities)
- Avoid drinking alcohol and caffeinated drinks (i.e. coffee, tea, and cola) for 24 hours
- Consume the same breakfast or lunch a minimum of 2 hours prior to testing
- In the 2 hours before the testing session consume no food or energy drinks and drink only plain water (aim to consume around 1 litre of water prior to testing)
- Bring appropriate running shorts, T-shirt and running trainers

Advantages of taking part
A benefit of taking part in this study is that you will receive feedback, with explanations, on your cardio-respiratory fitness (e.g. maximal heart rate, maximal oxygen uptake and efficiency) and time-trial performance.

Disadvantages of taking part
For some participants, a disadvantage of taking part in this study could relate to time commitment. To complete all aspects of the 12 week study you will be required to attend the lab on eight (six if you are in the single session group) occasions and complete two outdoor runs. This equates to about 15 hours of your time, 1/1.5 hours per visit. Although every effort will be made to keep time spent in the lab to a minimal, in the rare occasion that an equipment malfunction occurs you may be asked to re-attend sessions. There is the possibility of muscle soreness after testing; however, this should be no different to the feeling after an intense training session. You will also be required to complete the two prescribed training sessions per week in combination with your normal weekly training.

Additional information
You may at any time withdraw from the Study. You do not have to give any reason, and no one can attempt to dissuade you. If you ever require any further explanation, please do not hesitate to ask. If you refuse to give consent to participation in this study, or withdraw from it at a later time, it will not prejudice you in any way.

In addition, the following withdrawal criteria also apply:

- If you have any known injuries
- At the request of the researcher – Mr Phil Anthony, supervisor Dr Damian Coleman or Dr Jim Wiles
- Failure of the equipment to record

Any personal information obtained during this Study will remain confidential and comply with the data protection act 1989. You have right of access to your records at any time. Data collected which cannot be identified with you, will be published or presented at meetings with the aim of benefiting others. The results of this study will be published as part fulfilment of a PhD thesis with intent to submit the research at conference and as a journal article. You have a right to obtain copies of all papers, reports, transcripts, summaries, and other material published or presented, on request to the researcher or their supervisor, if appropriate.
A full scientific protocol for this Study has been approved by Canterbury Christ Church University Research Ethics Committee. Further details of the approval will be provided to you if you wish and you have a right to have a copy of the full protocol to retain, if you so request of the researcher.

Appendix 3: Participant Information Sheet (Study 3)

Research Title: **The difference between once daily and twice daily training on factors associated with running performance in the chronic setting.**

Researcher: Phil Anthony Tel: 01227 767700 ext (3198)
e-mail: phil.anthony@canterbury.ac.uk

Superviser: Dr. Damian Coleman Tel 01227 782639

e-mail:damian.coleman@canterbury.ac.uk

Superviser: Dr. Jim Wiles Tel: 01227 767700 ext (2209)
e-mail: Jim.wiles@canterbury.ac.uk

Invitation to take part
You are invited as a volunteer to take part in a research investigation. Before you decide to take part it is important that you understand why the research is being conducted and what will be required of you should you agree to be involved. Please take time to read the following information carefully and discuss it with the researcher. If there is anything that is not clear, or if you would like more information, please do not hesitate to ask.

Background
Current research highlights that an elite level runner's ability to tolerate a high training volume through numerous training sessions each week, is a key factor to their capacity to convert stored energy (e.g. fat and carbohydrate) into propulsive energy, and thus, become more efficient.
.
Although many training programmes already suggest increasing training volume and frequency, questions remain over the benefits gained from this approach. This intervention intends to investigate the physiological adaptions trained runners experience with an increase of 30% total training volume.

What will be expected of you?
If you decide to take part in this study you will be allocated to one of two groups, a SINGLE or a SPLIT group. Members of the SINGLE group will increase their training volume through a gradual increase in the distance of two current training sessions. Members of the SPLIT group will increase their training volume by the same amount as the SINGLE group, but will split one of their long training runs, completing a morning and then an evening session within the same day.
You will asked to attend the Sport Science Lab on a maximum of six occasions if assigned to the SPLIT group (four times if assigned to the SINGLE group), three times in weeks one to three (two if assigned to the SINGLE group) and three times (two in the SINGLE group) in weeks ten to 12 (Canterbury Christ Church University, North Holmes Road, Canterbury, Kent, CT1 1QU (Sports Science Laboratory: Ag 59). There will be an additional two visits to one of two locations: the Julie Rose Stadium (Ashford) or The Body and Mind running track (Canterbury).

Participants will be asked to refrain from any strenuous training or races in the 48 hours prior to any testing.
On the completion of visit three participants will be presented with a six week prescribed training plan that will gradually increase their training volume to 30%. This increase will be achieved over the first three weeks, through a 15% increase addition in the two longest training sessions. The volume will then remain fixed for the remaining three weeks.

Study schedule for the single session group

Table 2. Schematic of the single session group

Week 1	Week 2	Week 3
Visit 1: LAB $\dot{V}O_2max$ test	**Visit 2: 5 km TT**	**Visit 3: LAB Long run**
6 week training intervention based on 2 longer runs. Each run will be increased by 5% each week for weeks 1-3. This volume will then be maintained for weeks 4-6		
Week 10	**Week 11**	**Week 12**
Visit 4: LAB Long run +15%	**Visit 5: 5 km TT**	**Visit 6: LAB $\dot{V}O_2max$ test**

Your health and wellbeing is of upmost importance, both throughout the study period and also on the day of each test. A brief health check will therefore be completed on the day of each visit. During the health check we will measure your resting blood pressure and heart rate and ask you to complete a health questionnaire and sign an informed consent form.

Visit 1: Induction and Maximal aerobic test ($\dot{V}O_2max$)
You will be given a brief tour of the laboratory, the study protocols will be discussed and there will be the opportunity to ask questions.

Some simple measurements will then be recorded:
Height and mass
Finger prick blood sample

During all visits to the laboratory, participants will be asked to complete a ten minute warm-up on a treadmill at a self-selected pace. Following this, participants will be fitted with a heart rate monitor and the portable breath by breath gas analysis system for the remainder of the test (Oxycon mobile) (see figure 1).
During visit one, participants will complete a maximal aerobic test on treadmill. This test will involve runners reaching volitional exhaustion. The test will start at a low running speed, calculated from your current 5 km race pace, the speed will then increase by 1kph every three minutes until volitional exhaustion is reached.

Visit 2: 5 km TT
During outdoor testing, participants will be given a ten minute warm up period at a pace that is comfortable to them. The participants will then be fitted with a heart rate monitor and the portable breath by breath gas analysis system for the remainder of the test (Oxycon mobile). The participants will then complete a 5 km (12.5 laps) time trial on the track at a self-selected pace.

Visit 3:
Participants will be given the same ten minute warm up period as described in visits one and two before being fitted with a heart rate monitor and the portable breath by breath gas analysis system. Participants will then complete a run corresponding to the same distance they would complete habitually at an effort of 70-75% $\dot{V}O_2max$ that was recorded on their first visit.

Visit 4:
Participants will complete the same long run test that was completed on visit three with the additional 15% volume added.

Visit 5:
Participants will complete the same outdoor test that was completed on visit two.

Visit 6:
Participants will complete the same maximal aerobic test on treadmill that was completed on their first visit.

To participate in this study you must:

- Be between the age of 18-55 years
- Have been running regularly for a minimum of one year
- Have completed five hours per week in the three months prior to the study
- Have no medical condition that will impair your ability to perform all tests
- Have no known heart conditions or diabetes
- Have no diagnosed with metabolic syndrome
- Be a non-smoker
- Not be using any performance enhancing substances or be willing to suspend their consumption for the duration of testing including
- Be without injury or illness
- Not be taking any performance enhancing substances (excluding caffeine)

Prior to all visits you will be expected to:

- Avoid participation in any strenuous exercise for 48 hours (above regular training intensities)

- Avoid drinking alcohol and caffeinated drinks (i.e. coffee, tea, and cola) for 24 hours
- Consume the same breakfast or lunch a minimum of two hours prior to testing
- In the two hours before the testing session consume no food or energy drinks and drink only plain water (aim to consume around 1 litre of water prior to testing)
- Bring appropriate running shorts, T-shirt and running trainers

Advantages of taking part
A benefit of taking part in this study is that you will receive feedback, with explanations, on your cardio-respiratory fitness (e.g. maximal heart rate, maximal oxygen uptake and efficiency) and time-trial performance.

Disadvantages of taking part
For some participants, a disadvantage of taking part in this study could relate to time commitment. To complete all aspects of the 12 week study you will be required to attend the lab on eight (six if you are in the single session group) occasions and complete two outdoor runs. This equates to about 15 hours of your time, 1/1.5 hours per visit. Although every effort will be made to keep time spent in the lab to a minimal, in the rare occasion that an equipment malfunction occurs you may be asked to re-attend sessions. There is the possibility of muscle soreness after testing; however, this should be no different from the feeling after an intense training session. You will also be required to complete the two prescribed training sessions per week in combination with your normal weekly training.

Additional information
You may withdraw from the study at any time. You do not have to give any reason, and no one can attempt to dissuade you. If you ever require any further explanation, please do not hesitate to ask. If you refuse to give consent to participation in this study, or withdraw from it at a later time, it will not prejudice you in any way.

In addition, the following withdrawal criteria also apply:
- If you have any known injuries
- At the request of the researcher – Mr Phil Anthony, supervisor Dr Damian Coleman or Dr Jim Wiles
- Failure of the equipment to record

Any personal information obtained during this study will remain confidential and comply with the Data Protection Act 1998. You have right of access to your records at any time. Data collected that cannot be identified with you, will be published or presented at meetings with the aim of benefiting others. The results of this study will be published as part fulfilment of a PhD thesis with intent to submit the research at conference and as a journal article. You have a right to obtain copies of all papers, reports, transcripts, summaries, and other material published or presented, on request to the researcher or their supervisor, if appropriate.
A full scientific protocol for this Study has been approved by Canterbury Christ Church University Research Ethics Committee. Further details of the approval will be provided to you if you wish and you have a right to have a copy of the full protocol to retain, if you so request of the researcher.

Study schedule for the split session group

Table 3. Schematic of the split session group

Week 1	Week 2	Week 3
Visit 1: LAB $\dot{V}O_2max$ test	**Visit 2: 5 km TT**	**Visit 3:AM LAB ½ long run** **Visit 4:PM LAB ½ long run**
6 week training intervention		
Week 10	**Week 11**	**Week 12**
Visit 5:AM LAB ½ long run **Visit 6:PM LAB ½ long run + 15%**	**Visit 7: 5 km TT**	**Visit 8: LAB $\dot{V}O_2max$ test**

Your health and wellbeing is of upmost importance, both through the study period and also on the day of each test. A brief health check will therefore be completed on the day of each visit. During the health check we will measure your resting blood pressure and heart rate and ask you to complete a health questionnaire and sign an informed consent form.

Visit 1: Induction and Maximal aerobic test ($\dot{V}O_2max$)
You will be given a brief tour of the laboratory, the study protocols will be discussed and there will be the opportunity to ask questions.

Some simple measurements will then be recorded:
Height and mass
Finger prick blood sample

During all visits to the laboratory, participants will be asked to complete a 10 minute warm-up on a treadmill at a self-selected pace. Following this, participants will be fitted with a heart rate monitor and the portable breath by breath gas analysis system for the remainder of the test (Oxycon mobile) (see figure 1).
During visit one participants will complete a maximal aerobic test on treadmill. This test will involve runners reaching volitional exhaustion. The test will start at a low running speed, calculated from your current 5 km race pace, the speed will then increase by 1kph every three minutes until volitional exhaustion is reached.

Visit 2: Outdoor test
During outdoor testing, participants will be given a 10 minute warm up period on the running track at a pace that is comfortable to them. The participants will then be fitted with a heart rate monitor and the portable breath by breath gas analysis system for the remainder of the test (Oxycon mobile). The participants will then complete a 5 km (12.5 laps) time trial on the track at a self-selected pace.

Visit 3: AM
Participants will be given the same 10 minute warm up period as described in visits one and two before being fitted with a heart rate monitor and the portable breath by breath gas analysis system. Participants will then complete a run corresponding to half of the distance they would complete habitually on their long run at an effort of 70-75% $\dot{V}O_2max$ that was recorded on their first visit.

Visit 4: PM
Participants will be given the same 10 minute warm up period as described in visits one and two before being fitted with a heart rate monitor and the portable breath by breath gas analysis system. Participants will then complete a run corresponding to half of the distance they would complete habitually on their long run at an effort of 70-75% $\dot{V}O_2max$ that was recorded on their first visit.

Visit 5: AM
Participants will complete the same run test that was completed on visit three.

Visit 6: PM
Participants will complete the same run test that was completed on visit four with the additional 15% increase in volume.

Visit 7:
Participants will complete the same outdoor test that was completed on visit two.

Visit8:
Participants will complete the same maximal aerobic test on treadmill that was completed on their first visit.

To participate in this study you must:

- Be between the age of 18-55 years
- Have been running regularly for a minimum of one year
- Must have completed 6 hours per week in the three months prior to the study.
- Have no medical condition that will impair your ability to perform all tests
- Have no known heart conditions or diabetes
- Have no diagnosed with metabolic syndrome
- Be a non-smoker
- Not be using any performance enhancing substances or be willing to suspend their consumption for the duration of testing including
- Be without injury or illness
- Not be taking any performance enhancing substances (excluding caffeine)

Prior to all visits you will be expected to:

- Avoid participation in any strenuous exercise for 48 hours (above regular training intensities)
- Avoid drinking alcohol and caffeinated drinks (i.e. coffee, tea, and cola) for 24 hours
- Consume the same breakfast or lunch a minimum of 2 hours prior to testing
- In the 2 hours before the testing session consume no food or energy drinks and drink only plain water (aim to consume around 1 litre of water prior to testing)
- Bring appropriate running shorts, T-shirt and running trainers

Advantages of taking part
A benefit of taking part in this study is that you will receive feedback, with explanations, on your cardio-respiratory fitness (e.g. maximal heart rate, maximal oxygen uptake and efficiency) and time-trial performance.

Disadvantages of taking part
For some participants, a disadvantage of taking part in this study could relate to time commitment. To complete all aspects of the 12 week study you will be required to attend the lab on eight (six if you are in the single session group) occasions and complete two outdoor runs. This equates to about 15 hours of your time, 1/1.5 hours per visit. Although every effort will be made to keep time spent in the lab to a minimal, in the rare occasion that an equipment malfunction occurs you may be asked to re-attend sessions. There is the possibility of muscle soreness after testing; however, this should be no different to the feeling after an intense training session. You will also be required to complete the two prescribed training sessions per week in combination with your normal weekly training.

Additional information
You may at any time withdraw from the Study. You do not have to give any reason, and no one can attempt to dissuade you. If you ever require any further explanation, please do not hesitate to ask. If you refuse to give consent to participation in this study, or withdraw from it at a later time, it will not prejudice you in any way.

In addition, the following withdrawal criteria also apply:
- If you have any known injuries
- At the request of the researcher – Mr Phil Anthony, supervisor Dr Damian Coleman or Dr Jim Wiles
- Failure of the equipment to record

Any personal information obtained during this Study will remain confidential and comply with the data protection act 1989. You have right of access to your records at any time. Data collected which cannot be identified with you, will be published or presented at meetings with the aim of benefiting others. The results of this study will be published as part fulfilment of a PhD thesis with intent to submit the research at conference and as a journal article. You have a right to obtain copies of all papers, reports, transcripts, summaries, and other material published or presented, on request to the researcher or their supervisor, if appropriate.
A full scientific protocol for this Study has been approved by Canterbury Christ Church University Research Ethics Committee. Further details of the approval will be provided to you if you wish and you have a right to have a copy of the full protocol to retain, if you so request of the researcher.

Appendix 4: Health and Fitness Questionnaire for day of testing

Department of Sport Science, Tourism and Leisure

Sport Science Health and Fitness Questionnaire for day of testing

Name: …….

Date of Birth: …… **Age: ……** **Sex: ……..**

Please answer the following questions by ***circling*** the appropriate response and if necessary providing extra information in the spaces provided.

ANY INFORMATION CONTAINED HEREIN WILL BE TREATED AS CONFIDENTIAL

1. How would you describe your present level of fitness?

Untrained / Moderately trained / Trained / Highly trained

2. Average number of hours spent exercising in the past 4 weeks

…….……per wk

3. Average numbers of hour sleep in the past week **…….**

4. Do you currently have any form of muscle or joint injury?

Yes / No

If you have answered **yes**, please give details:

……

5. Have you had to suspend your normal training/physical activity in the last two

weeks? **Yes / No** if you have selected **Yes** please give details:

……

6. How would you describe your present bodyweight?

Underweight / Ideal / Slightly overweight / Very overweight

7. How would you describe your alcohol intake?

Never Drink / An occasional drink / A drink every day / More than one drink a day

(Note 1 drink = 1 unit)

8. Have you had to consult your doctor within the last six months?

Yes / No

If you have answered **yes**, please give

details:**…….**

9. Are you presently taking any form of medication?

Yes / No

If you have answered **yes**, please give details:

……

10. Do you suffer or have you ever suffered from any of the following?

a. Diabetes **Yes / No** b. Asthma

Yes / No

c. Epilepsy **Yes / No** d. Bronchitis

Yes / No

e. Any form of heart complaint **Yes / No** f. Serious Back or Neck Injury

Yes / No

g. High blood pressure **Yes / No** h. Aneurysm [1] or Embolism[2]

Yes / No

1: Arterial wall weakness causing dilation. 2: Obstruction in the Artery.

11. Is there a history of heart complaint in your family?

Yes / No

If you have answered **yes**, please give details:

……

12. Do you have any allergies?

Yes / No

If you have answered **yes**, please give details:

……

Appendix 5: Health and Fitness screening for day of testing

Department of Sport Science, Tourism and Leisure

Sport Science Health and Fitness screening for day of testing

Name: …….

Date of Birth: …… **Age: ……** **Sex: ……..**

Please answer the following questions by ***circling*** the appropriate response and if necessary providing extra information in the spaces provided.

ANY INFORMATION CONTAINED HEREIN WILL BE TREATED AS CONFIDENTIAL

Height ……	
Mass ……	
Resting Blood pressure ……	
Resting Heart rate ……..	

Signature of Participant: ……..

Signature of Sport Scientist: ……..

Date: ……

Appendix 6: CONSENT FORM

CONSENT FORM

Title of Project: A comparison between indoor and outdoor running measures

Name of Researcher: Philip Christopher Anthony

Participant contact details:

Address:	
Tel:	
Email:	

Please initial box

1.	I confirm that I have read and understand the information sheet for the above study and have had the opportunity to ask questions.	
2.	I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason.	
3.	I understand that any personal information that I provide to the researchers will be kept strictly confidential	
4.	I agree to take part in the above study.	

_____	_____	_____
Name of Participant	Date	Signature
_____	_____	_____
Name of Person taking consent (if different from researcher)	Date	Signature
_____	_____	_____
Researcher	Date	Signature

Copies:1 for participant and1 for researcher

Appendix 7: Participant food and training record sheet

Participant food and training record sheet

Day Month Year

Day……day Date: / / Day Order:

Please use a separate line for each item eaten; write in weight of plate; leave a line between different 'plate' entries.

A	B		C	D	E	F	**Office Use**
Time	Food eaten		Brand name of each item (except fresh food)	Full description of each item including: -whether fresh, frozen, dried, canned -cooked: boiled, grilled, fried, roasted. -what type of fat food fried in	Weight Served	Weight of Leftovers	Actual Weight
am/pm	home	away			(gms)	(gms)	(gms)

GENERAL COMMENTS:

TRAINING TYPE & DURATION:

Appendix 8: Athlete and coach training guide

The influence of Continuous vs Split training protocols on Endurance Performance: Key Elements for Runners and Coaches

Reports of twice daily training being used routinely by elite level endurance runners during the foundational (base) stage of training can be traced back to the 1960s. Coaches and runners have engaged in training protocols that split the long, low intensity run session into two sessions performed twice daily, in order to maintain volume of exercise (aligned with a single, long LIT session).

Despite this, few studies to date have explored the training response of a single day, or the long-term adaptations to 'twice daily training'. There is an assumption of parallel benefits of once daily training versus twice daily training based on total volume of exercise accumulated, however, this assumption has not been tested.

The primary aim of this research was therefore to investigate the effects of once daily and twice daily training, performed during the foundational (also known as base) stage of training, on factors associated with running performance.

This resource highlights the key findings and gives practical examples of how to apply these findings

Key findings

- Splitting your long run into two shorter runs, performed 6-8 hours apart, for 6 weeks leads to greater gains in 5km performance, compared with performing the long run as a continual long run.

- For example, rather than running for 1 hour at low intensity, try running for 30 minutes in the morning and 30 minutes in the evening. Both of these runs should be performed at the same intensity (70-75%)

- This type of training has been shown to increase Carbohydrate use during the run, which is the predominant fuel source used for 5km race efforts.

- Runners in the trials, trained five days per week. Four of these training days were low intensity runs. Twice daily training was performed on two of these low intensity training days. The fifth session was an interval training session.

- For athletes wishing to predict 5Km performance, this research also developed the following user friendly equation:

Predicted 5Km time in seconds = (Peak treadmill velocity x - 64.977) + 2270.636

- To determine your Peak Treadmill Velocity, after a warm up, and with the gradient of the treadmill set to 1%, start at an easy pace, and then increase the speed by 1kph every 4 minutes until you can no longer continue. Record the speed that you finish on as your peak treadmill velocity.

- Using a predicted 5km time allows a runner to determine how they have responded to a period of training.

For more information, please contact Phil Anthony.