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MONITORING OF TRAINING AND RACING OF LONG DISTANCE RUNNERS USING HEART RATE MONITORS

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ABSTRACT

Aim

The aim of this thesis was to contribute to a better understanding of heart rate during exercise with the aim of improving the precision with which heart rate can be used to measure intensity during running. Accordingly, heart rate responses were examined in long distance runners during different types of training and racing. The thesis also examined the effects of environmental and body temperature on heart rate during submaximal and maximal running.

Study 1

Ten male provincial and national class road runners ($VO_2max = 67.1 \pm 3.8\ mlO_2.kg^{-1}.min^{-1}$) were recruited for the study. All the subjects completed questionnaires on their training history and recorded their training sessions in their diaries. The subjects wore heart rate monitors during training and racing. There was no convincing evidence that competitive runners who train at higher intensities have a better running performance. A poor relationship was found between $\%VO_2max$ and %HRmax. Finally, heart rate during races was higher compared to heart rates during training. The cause of the elevated heart rate during races was not clear.

Study 2

The relationship between heart rate and running speed during competition was not well understood. Accordingly, an elite long distance male runner (25 years, $VO_2max = 71\ mlO_2.kg^{-1}.min^{-1}$) was studied over a 5 month period during which time he participated in 9 races (5 km - 28 km). The subject wore a heart rate monitor which measured his heart rate throughout the race and his split running times each kilometre. The subject underwent a field test during which the heart rate/running speed relationship was determined under non-competitive conditions ($r = 0.99$). However, in the race situation there was no relationship between heart rate and running speed ($r = 0.02$). It was concluded that during competition there was no relationship between heart rate and running speed, whereas in a non-competitive situation heart rate was proportional to running intensity.

Study 3

With a poor relationship found between heart rate and running speed during races in the previous study, other factors like environmental conditions and core temperature were hypothesised to have effects on heart rate. Accordingly, twelve highly trained distance runners were recruited for the study. Each subject ran on a treadmill (30 minutes at 70% peak treadmill running speed, followed by 8 km time trial) in different ambient temperatures (15°C, 25°C and 35°C) with humidity (60%) and wind speed (15 $km.h^{-1}$) kept constant. Heart rate, RPE and

T_{re} were recorded every 5 minutes during the submaximal and the maximal trials. When subjects were exercising at 70% of peak treadmill running speed at 15°C, no cardiovascular drift was observed, at least for 30 minutes. However, during the same exercise test at 25°C and 35°C there was a significant increase in heart rate. In the maximal exercise test the average heart rate was significantly higher during the trial at 35°C compared to the trials at 15°C and 25°C. It was concluded that heart rate can be used as an accurate measure of running intensity in cooler (15°C) ambient temperature.

In summary, this thesis described the practical use of heart rate monitors during training and competition and at different temperatures. Data are provided which suggest that heart rate can accurately assess exercise intensity providing factors which affect the heart rate/running speed relationship are controlled.

DECLARATION

I, **Ziphelele Mbambo**, do hereby declare that the ideas and experiments presented in this thesis were mainly conceived by my supervisor and executed by myself.

Neither the substance nor part of this thesis has been submitted in the past, or is being, or is to be submitted for a degree in the University or any other University.

This thesis is presented in fulfilment of the requirements for the degree of Master of Science, Exercise Science.

I hereby grant the University of Cape Town permission to reproduce this thesis in part or whole, for the purpose of research.

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Date:________________________

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LIST OF ABBREVIATIONS

%HRmax	percentage of the maximum heart rate
BLC	blood lactate concentration
ECG	electrocardiogram
HR	heart rate
LT	lactate threshold
OBLA	onset of blood lactate accumulation
PTRS	peak treadmill running speed
PV	Plasma volume
RER	respiratory exchange ratio
RPE	rate of perceive exertion
T_{re}	rectal temperature
V_E	minute ventilation
VO_2	oxygen consumption
VO_2max	maximum oxygen uptake

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PUBLICATIONS

Sections of this work have been published in the following journals.

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Chapter 1

Motivation and aims of the Study

1.1 Introduction:

In general there is a linear relationship between oxygen consumption (VO2) and work load and between oxygen consumption and heart rate (Åstrand and Rodahl, 1986). Therefore, heart rate reflects the metabolic and contractile activity of the large muscle groups engaged in the physical activity and has been used to estimate exercise intensity (Sharkey, 1991).

With the advent of telemetric heart rate monitors which have the capability of storing heart rate data for subsequent analysis, the task of accurately measuring heart rates during exercise training has become possible (Tulppo et al., 1998). Indeed, heart rate monitors have been used to monitor exercise intensity in a variety of sports such as cycling (Hopkins and Hawley, 1989; Palmer et al, 1994) , soccer (Ali and Farrally, 1991), tennis (Therminarias et al., 1991), orienteering (Bird et al., 1993), swimming (Mougios and Deligiannis, 1993); basketball (Terrados et al., 1995), skiing (Gilman, 1996; Karvonen et al., 1987) and running (Billat et al., 1994; Selley et al., 1995; Adkisson and Nethery, 1995; Lambert et al., 1998).

There are suprisingly little data analysing training intensity in long distance runners using the measurement of heart rate as a marker of training intensity. The only study addressing this question was done by Robinson et al. (1991) who monitored the training intensity of 13 nationally ranked male distance runners. Training heart rates, environmental factors and motivational factors were recorded throughout a 6 to 8 week period of normal training. During the study, subjects ran on a treadmill at 0% gradient. The heart rate recorded during these runs were used to convert the average heart rate during training sessions to training speeds. The results of this study however, could be misleading, as it has been shown that a 1% treadmill gradient most accurately reflects the energetic cost of outdoor running (Jones and Doust, 1996). Therefore, more data are required to fully understand the training intensity of male distance runners.

Heart rate may be affected by a number of factors which may reduce the accuracy of using heart rate as a measure of exercise intensity. For example, it is known that the heart rate may be affected by a number of factors such as environmental temperature (Galloway and Maughan, 1997), exercise duration (Potteiger and Weber, 1994), body temperature (Ekelund and Holmgren, 1964), diurnal changes (Reilly et al., 1984), plasma volume (Richardson et al, 1993), mental stress (Desharnais et al., 1995), autonomic nervous system (Hartley et al., 1970), and medication (ACSM, 1991). Recently, it has been shown that heart rate is increased during competition compared to running at the same speeds during non-competitive conditions (Selley et al., 1995). However, the effects of competition on heart rate has not been studied systematically and is not well understood.

In summary, there is a potential for heart rate to be used to monitor training intensity, particularly since heart rate monitors are relatively cheap, light-weight and can be worn comfortably during training and racing. Although guidelines for training intensity, based on heart rate have been reported (Edwards, 1993), these data are based on the experiences of coaches. To refine these recommendations, studies need to be conducted which monitor the training intensity of elite long distance runners during different phases of training. To further optimise the use of heart rate monitors, those factors which affect the heart rate/running speed relationship need to be fully investigated and understood.

1.2 Aims of the thesis

The aim of this thesis is to contribute to a better understanding of heart rate during exercise with the overall goal of improving the precision with which heart rate can be used to measure intensity during running. More specifically the thesis examines heart rate responses in long distance runners during different types of training and racing. In addition, the thesis also examines the effects of environmental and body temperature on heart rate during submaximal and maximal running.

Before the experimental section of the thesis (Chapter 3, 4 and 5) the literature pertaining to heart rate and exercise is discussed. Chapter 3 focuses on heart rate during different phases of training in a group of long distance runners. Chapter 4 studies the effect of competition on heart rate/running speed relationship and Chapter 5 studies the effects of body and environmental temperature on heart rate while running at submaximal and maximal running speeds. The main findings of these studies are discussed in Chapter 6 followed by recommendations for future research.

Chapter 2

Literature Review

2.1 Measurement of training intensity during long distance running.

2.1.1 Introduction

Coaches and athletes have used certain measures to quantify training volume and intensity. For example the training of athletes has been assessed by retrospective questionnaires, diaries, rating of perceived exertion (Birk and Birk, 1987; Williams and Eston, 1989) and physiological monitoring (oxygen uptake, blood lactate and heart rate) (Hopkins, 1991). These forms of monitoring have advantages and disadvantages in terms of practicality either in the laboratory or in the training field.

2.1.2 Retrospective questionnaires

Training data are obtained from the athletes by asking questions based on their previous training activities (retrospective questionnaires). A disadvantage of this technique is that an athlete could find it difficult to recall the training sessions done over a long period of time which would lead to inaccurate data. According to Hopkins (1991) most of the questionnaire methods which have been used to obtain data on training have not been validated.

The successful usage of retrospective questionnaires is based primarily on how the questions are constructed. Questions should be properly worded for easy comprehension, provide a structured response for selection and with a final instruction which urges the respondent to check back for mistakes (Hopkins, 1991).

Despite some disadvantages of using retrospective questionnaires as a method of quantifying training, they are relatively easy and cheap to administer. Moreover, they have the least problems with athlete and coach compliance compared to other forms of training monitoring (Hopkins, 1991). Hewson and Hopkins (1996) validated six-month retrospective questionnaires which were completed by 119 females and 234 male coached distance runners for relationships between specificity of training and best performance in a summer season. The data revealed that the better runners in the study did not necessarily have greater training specificity than the other runners. The compliance ideally, for this form of data collection should be above 70% to increase the scientific validity (Hopkins, 1991).

In another study by Hewson and Hopkins (1995), training data collected using questionnaires revealed a disparity in the reporting of training as prescribed by coaches for their athletes and the training reported by athletes themselves. The correlation between training prescribed by coaches and training reported by athletes was $r = 0.2 - 0.6$. In summary, these data show that retrospective questionnaires need to be validated and administered in such a way as to improve compliance. The low relationship between prescribed and reported training suggests that the data obtained from these questionnaires should be interpreted with caution.

2.1.3 Training diaries

Most athletes record the details of their training sessions in diaries or logbooks. The data collected using diaries is likely to be more valid than data collected using retrospective questionnaires. The advantage of the training diary is that the training data are recorded immediately after the training session and is therefore likely to be more accurate than when the data are recorded retrospectively.

To improve compliance in the use of diaries, the diaries should be kept short and simple (Hopkins, 1991). If an athlete updates the diary everyday, there is little reason to determine test-retest reliability because of the close proximity of the data collected (Hopkins, 1991). Diaries are good at reflecting training volumes and different modes of training which are likely to be correlated with injuries or illness. However, it is not as clear how training diaries can be used to investigate relationships between training intensity and running performance (Hopkins, 1991).

In the studies of Foster (1983) and Hagan et al. (1981) diaries were used to record training pace in distance runners ranging from 1 500 m to 42.2 km. Relatively low inverse correlations (r = -0.20 to -0.40) were found between training intensity and running performance. The subjects kept daily exercise records for training volume (distance, time and intensity).

In summary, diaries can generate vast amounts of data for training sessions over a period of time, but data recorded may lack the sensitivity to track change in exercise intensity between training sessions.

2.1.4 Physiological monitoring.

(a) Oxygen consumption

During exercise, all the energy systems are involved at certain levels in generating energy (Åstrand and Rodahl, 1986). Mitochondria in the muscle cells consume oxygen to resynthesize adenosine triphosphate (ATP) from adenosine diphosphate (ADP) (Cain and Davies, 1962). When the intensity of exercise or running speed is increased, metabolic rate can be increased by 15 - 20 times above the resting values of about 3.6 mlO2 $kg^{-1}.min^{-1}$ (Gollnick and King 1969; McArdle et al., 1991).

The metabolic rate, measured as oxygen uptake (VO2) during running, can also be described as running economy. Running economy, is defined as the steady state oxygen uptake (VO2) for a given running velocity (Morgan et al., 1989) and is an important factor in determining running performance in endurance events (Svedenhag and Sjodin, 1984; Joyner, 1991; Svedenhag, 1995). Generally, a better running economy (i.e. less VO2 at a submaximal running speed) is associated with improved running performance (Noakes, 1991).

There is a linear relationship between oxygen consumption and exercise intensity (Rejeski, 1985). Oxygen consumption (VO_2) has been measured to assess exercise intensity for many years (Londeree, 1986). Fay et al. (1989) found a moderate inverse relationship ($r = -0.40$ to -0.63) between the oxygen cost (VO_2) of running and race pace. In some studies, the maximal treadmill speeds achieved in a VO_2max test were the better predictors of running performance ($r = 0.72$) than VO_2max *per se* ($r = 0.54$) (Scrimgeour et al., 1986; Noakes et al., 1990). These data were supported by the study of Morgan et al. (1989) who concluded that in well trained male subjects with similar VO_2max, there was a strong relationship between 10 km run time and running velocity at VO_2max.

Yoshida et al. (1993) suggested that running velocity at VO_2max could be used as a non-invasive predictor of distance running performance. Yoshida et al. (1993) found a strong correlation ($r = 0.75$) between running velocity in a 3000 m race and velocity at VO_2max. This was further confirmed by Billat and Koralsztein (1996) that velocity at VO2max is a useful variable that combines VO_2max and economy into a single factor which can identify aerobic differences between various runners.

Jones (1998) suggested that an improvement in the running performance in a world class 3000 m female runner was not caused by an increase in VO_2max, but rather by the extensive training programme together with physical maturation which resulted in the improvements in submaximal fitness factors such as running economy and lactate threshold.

According to Morgan and Craib (1992) and Daniels (1985) running economy is influenced by physiological and environmental aspects which include intra-individual variability, body temperature, heart rate, ventilation, muscle fibre type, gender, body weight, age, state of fitness, training, fatigue, air and wind resistance, altitude, and running surface. However, the influence of training on VO2max and to some extent on the running economy appears to be limited by genetic factors (Sjodin and Svedenhag, 1985).

In summary, maximal and submaximal oxygen consumption are one of the objective methods of measuring exercise intensity (Hopkins, 1991). However, the main disadvantage of measuring oxygen consumption to assess exercise intensity is that laboratory based equipment is needed, making it difficult to apply these measurements during training outside the laboratory.

(b) Blood lactate

During exercise of light and moderate intensity, the energy demands are primarily met by chemical reactions that use oxygen (oxidative pathway). However, when the exercise intensity increases, the energy requirement is met by anaerobic glycolysis (non-oxidative pathway) which results in the accumulation of blood lactate (Katz and Sahlin, 1988). In the glycolytic pathway, blood glucose is metabolised to pyruvate, which may either enter the mitochondria or be converted into lactate. The point where a systematic increase of blood lactate concentration occurs is called the "onset of blood lactate accumulation" (OBLA). OBLA is usually defined as the exercise intensity which coincides with a blood lactate concentration of 4 $mmol.l^{-1}$ (Heck et al., 1985; Yoshida et al., 1987; Dotan et al., 1989; Ekes et al., 1990).

In highly trained male endurance athletes OBLA is often observed at about 80% of the maximal oxygen uptake (VO2max) (Wasserman et al., 1973). The rate of blood lactate accumulation is influenced by a number of factors which include exercise intensity during training (Billat, 1996; Fujitsuka et al., 1982), state of physical fitness, diet, drugs, site of blood sampling, ambient temperature, changes in the body's acid base balance prior to exercise (Jacobs, 1986), type and duration of the exercise (Gollnick et al., 1986) and the rate of blood lactate clearance (Gass et al., 1981).

Some studies have shown a high inverse correlation between blood lactate accumulation and running performance (Farrell et al., 1979; Yoshida et al. 1987; Tanaka et al., 1984; Coetzer et al., 1993). Some exercise physiologists use the blood lactate profile as a method of assessing the athlete and setting a basis for exercise prescription or training intensity (Foster et al., 1995).

OBLA levels tend to differ greatly between individuals and should only be interpreted on an intra-individual basis (Anderson and Rhodes, 1991). Furthermore, factors that influence blood lactate concentrations need to be controlled to standardise the accuracy in measuring exercise intensity.

Taking this into account, Pfitzinger and Freedson (1998) studied different measures of lactate threshold (treadmill velocity, oxygen consumption and heart rate) and found the coefficient of variation to be between 1.2 and 2.9%. This suggest that the determination of the lactate threshold is reliable if conditions are controlled.

Although OBLA as a single variable is not very accurate in determining running performance, when coupled with running economy it becomes more significant (Daniels, 1974). For example, Costill et al. (1973) found that at all running speeds above 70% VO_2max, the faster runners accumulated less blood lactate than slower runners at similar speeds. This suggests that variables such as running economy combined with blood lactate concentrations are better predictors of running performance than blood lactate concentrations alone.

In summary, there are data which suggest that blood lactate concentrations may be related to exercise intensity, providing factors which affect lactate production and clearance are controlled.

(c) Heart rate

The linear relationship between heart rate and oxygen uptake (VO_2) between 60 and 90% of maximum oxygen uptake (VO_2max) makes it possible to use heart rate as predictor of training intensity (Åstrand and Rodahl, 1986; Ballarin et al., 1996; Conconi et al., 1996; Gilman, 1996). However, at high exercise intensities (> 90% VO_2max) an increase in the exercise intensity exceeds the rate of increase in heart rate (Bunc et al., 1988).

Heart rate, when used as a measure of exercise intensity, is often expressed as a percentage of the maximum heart rate (%HRmax) (Arts and Kuipers, 1994). Heart rate is measured accurately with radiotelemetry, continuous ECG recording and with portable heart rate monitors which have computer downloadable memory for later analyses (Karvonen and Vuorimaa, 1988; Robinson et al., 1991; Laukkanen and Virtanen, 1998).

Some studies have validated portable telemetric heart rate monitors. For example, Léger and Thivierge (1988) and Seaward et al. (1990) found strong relationships (r = 0.998) between heart rate measured simultaneously with portable heart rate monitors and ECG. This, together with the fact that heart rate monitors have evolved to be lightweight with the capacity to store heart rate data for later retrieval, has made the measurement of heart rate during training and races accurate and practical (Hopkins, 1991, Robinson et al., 1991; Ritchie and Hopkins, 1991, Gilman and Wells, 1993; Laukkanen and Virtanen, 1998).

Although heart rate provides a precise measure for training intensity (Karvonen and Vuorimaa, 1988), factors which affect heart rate need to be controlled.

Factors affecting heart rate

(i) Temperature

In warmer conditions heart rate increases at any given exercise intensity with increasing environmental temperature. Galloway and Maughan (1997) reported a significantly ($P < 0.05$) higher heart rate during exercise at 31°C than at 4°, 11° and 21°C. The differences in heart rate occurred from 35 minutes to the end of a 55 minute bout of exercise. Claremont et al. (1975) reported that cyclists cycling for 30 to 60 minutes at 52 to 59% VO2max at either 0° or 35°C had an average increase in heart rate of 13 beats.min^{-1} in the warmer environment.

Increases in heart rate observed during exercise in the heat are likely caused by increases in skin blood flow and the redistribution of blood volume towards the periphery, resulting in a reduction in stroke volume (Rowell et al., 1968). This thermal stress could be reduced by improved fitness and acclimatisation (Gisolfi and Copping, 1974; Fortney and Vroman, 1985).

(ii) Diurnal changes

Circadian rhythms refer to changes in physiological variables (i.e. rectal temperature, heart rate. oxygen uptake and urinary excretion of potassium and catecholamines) that recur every 24 hours (Winget, et al., 1985; Åstrand and Rodahl, 1986; Atkinson and Reilly, 1996). A significant circadian rhythm occurs in resting heart rate, with peak heart rates occurring at 15:00 h (Reilly et al., 1984) and low heart rates at 03:00 h. Heart rate also has diurnal changes which exist during submaximal and maximal exercise (Reilly et al., 1984). Tests of work capacity based on heart rate in the morning can be misleading because the heart rate responses to exercise are minimal at this time (Atkinson and Reilly, 1996).

Other studies have reported the heart rate rhythm peaks at around 17:00 h, with a range of 15-30% heart rate beats.min^{-1} (Reilly and Brooks, 1982; Reilly et al., 1984; Walker et al., 1981). During maximal exercise the heart rate rhythm peak may occur between 07:00 and 22:00 h (Cohen, 1980; Ilmarinen et al., 1975; Reilly et al., 1984).

However, a study by Dalton et al. (1997) showed that circadian rhythms had no effect on cycling performance in a 15 minute time trial. Seven subjects underwent a series of four tests; one VO2max test and three 15 minute maximal performance tests at different times (08:00-10:00; 14:00-16:00 and 20:00-22:00 h) during a 24 h period. Although, total work (kJ) and average power output (W) recorded in the morning were higher than the afternoon, the differences were not significant ($P = 0.10$).

Dalton et al. (1997) suggested that the ability to perform and train at various times of the day has an adaptive response which appears to over-ride these inherent circadian rhythms. This was shown earlier by Hill et al. (1989), whose subjects cycle trained either in the morning or in the afternoon. They showed that the effects of training were independent of the time of day of training as training lowered their heart rates, VE and RPE during submaximal exercise irrespective of whether the subjects trained in the morning or in the evening.

In summary, it is important to consider the circadian rhythm in heart rate during exercise when heart rate is used as a measure of fitness or as a marker of exercise intensity or during prolonged exercise training.

(iii) Medication

There are many effects of medication on heart rate at rest and during exercise. For example, beta-receptor blockers and anti-adrenergic agents without selective blockade of peripheral receptors, decrease heart rate at rest and during exercise, while antidepressants, major tranquillisers, nicotine and alcohol may not affect heart rate at rest and during exercise (ACSM, 1991). Amphetamines exert the same effects as catecholamines, causing an increase in blood pressure, heart rate, metabolic rate and plasma free fatty acids (Puffer, 1986). Even though the general effects of these drugs are known, there are individual responses in heart rates and also changes in heart rate as a result of the placebo effect (Clarkson and Thompson, 1997).

(iv) Cardiac drift

Cardiac drift can be defined as a progressive increase in heart rate, decreases in stroke volume and mean arterial pressure, and a maintained cardiac output during prolonged exercise (Shaffrath and Adams, 1984; Kindermann et al., 1979).

There seems to be a general consensus among exercise physiologists that cardiovascular drift is caused by progressive dehydration which leads to a reduction in blood volume. To test this hypothesis, Hamilton et al. (1991) recruited 10 endurance trained cyclists who cycled on two occasions for 2 hours at 22°C starting at 70 % of VO_2max. In one trial there was fluid replacement and in the other trial there was no fluid replacement. Within 20 - 120 minutes of no fluid replacement, stroke volume and cardiac output declined 15% and 7% while heart rate and VO_2 uptake increased by 10% and 6% respectively. However, during the fluid replacement trial stroke volume was maintained, heart rate

As the mechanism for cardiac drift is not entirely clear, some investigators sought to determine the effect of hydration on cardiovascular drift during exercise. In a study by Heaps et al. (1994), subjects were euhydrated while hypohydrated before exercise. Then they cycled at 65% of peak oxygen consumption at 21°C. This exercise induced dehydration and there after a 2 hour rest/rehydration period was observed. The observations indicated that the cardiovascular drift during exercise in 21°C environment is graded in proportion to hydration not due to reduction in blood volume.

(v) Plasma volume

The relationship between plasma volume and heart rate during sub-maximal and maximal exercise has been studied by Convertino (1983). Subjects cycled 2 $h.d^{-1}$ for 8 days at 65% VO2max during which VO2max increased 8%, HRmax decreased by 4% and plasma volume increased by 12%. This percentage change (% delta) in plasma volume was correlated with % delta HR at 65% VO_2max (r = -0.89) and % delta HRmax (r = -0.82). This indicates that an increase in plasma volume may be necessary for the cardiovascular and thermoregulatory adaptations accompanying chronic exercise. A similar increase in plasma volume and decrease in heart rate was observed by Green et al. (1990) observed after subjects had cycled $2h.d^{-1}$ for three days at 65% VO_2max. Also, in other cycling studies of high intensity (90-95% of VO_2max and intermittent work 120% VO_2max), an increase plasma volume and reduction in maximal heart rate were observed (Green, et al., 1984; Richardson, et al., 1996).

In summary, an increase in plasma volume as a result of exercise training results in a decrease in submaximal heart rate. This will clearly affect the relationship between heart rate and running speed and will have implications for using heart rate as a measure of exercise intensity.

(vi) Competition

Selley et al (1995) found that runners' heart rate during 10- and 21- km were higher than their heart rates at similar running speeds during non-competitive training. A recent study had similar findings in 10, 21 and 42 km races (Tucker et al., 1998). In another study performed on cyclists, six out of seven subjects recorded higher peak heart rates while racing than during the maximal laboratory test (Palmer et al., 1994). Collectively these studies show that further data are required on the effect of competition on heart rate.

(vii) State of training

One of the consequences of endurance training is that the resting heart rate decreases (Pollock, 1973). The extent of the decrease in heart rate varies. For example, resting heart rate decreased to 10 beats.min^{-1} after 12 weeks of endurance training (Byrd et al., 1974) and decrease 5 beats.min^{-1} after 30 weeks of jogging training (Seals and Chase, 1989).

To date, the physiological mechanism responsible for decreased resting heart rate at rest after training is not well understood. Researchers have attributed the decrease in resting heart rate to a reduction in the intrinsic heart rate (Lewis et al., 1980; Katona et al., 1982), an increase in vagal tone (Seals and Chase, 1989), or a combination of a decrease in intrinsic heart rate, an increase in parasympathetic autonomic control and a decrease in sympathetic autonomic control (Smith et al., 1989).

In summary, since there is lack of agreement on the magnitude of decrease in heart rate with training and uncertainty on the underlying physiological mechanism causing the decrease in resting heart rate, resting heart rate should be used with caution as a marker of endurance training.

2.1.5 Rating of perceived exertion

As discussed previously, physiological measurements such as maximum oxygen consumption, blood lactate concentrations and heart rate provide an objective training intensity profile. A rating of perceived exertion (RPE) has also been used to assess exercise intensity (Borg, 1982). RPE has been used as a proxy for heart rate and oxygen consumption as they all increase linearly with the increase of workload (Birk and Birk, 1987). The advantage of RPE as a method of estimating exercise training intensity is that an athlete does not have to stop during the exercise session to take measurements as may be the case when measuring blood lactate concentration. Also, an athlete has immediate feedback and can make pace adjustments while exercising, based upon the perception of effort (Glass et al., 1992).

RPE increases with increasing heart rate (r = 0.83) (Birk et al., 1983) and with blood lactate concentrations (r = 0.79 to 0.98) (Steed et al., 1993). However, two contrasting studies on physiological responses and RPE, have been noted. The aim of the study by Thomson and West (1998) was to compare the accuracy of relating RPE to blood lactate concentrations and heart rate in a non-laboratory setting and to examine the relationship between those variables measured in the laboratory. They found that the heart rate and blood lactate concentrations obtained outdoors were significantly higher than the values obtained in the laboratory at the same RPE.

In contrast, Ceci and Hassem (1991) found that when subjects were asked to exercise at the same level of intensity according to RPE while running on the treadmill and in the field, their heart rates, blood lactate concentration and running velocity were not significantly different in the field.

Stoudemire et al. (1996) examined the validity of regulating blood lactate concentrations during running by adjusting speed according to RPE. The study was performed indoors and RPE used in a 30 minutes run was able to produce corresponding lactate concentrations of 2.5 $mmol.l^{-1}$ and 4.0 $mmol.l^{-1}$.

Glass et al. (1992) indicated that RPE can be used to accurately regulate exercise intensity during treadmill running. They used an RPE intensity which was calculated as 75% of heart rate reserve from a graded exercise test on a treadmill. Then 48 hours later, subjects ran for 10 minutes on a level treadmill at the prescribed RPE. After about 6 minutes there were no significant differences between the graded exercise test and the level exercise test for VO2 and VE. Dunbar et al. (1992) concluded that RPE provides a psychologically valid method of regulating exercise intensity. This was after they had used the RPE equivalent to 50% and 70% of VO_2max estimated by using standard clinical protocols on treadmill and cycle ergometre.

Koltyn and Morgan (1992) compared the effective use of RPE and heart rate in monitoring exercise intensity during aerobic dance. In the study, training effect was measured as the distance run in 15 minutes. They found that the aerobic dance group that only used RPE to monitor exercise intensity improved endurance 11% (274 m) while the group that used heart rate monitors to monitor intensity had an endurance improvement of 6% (166 m). However, in the study of Potteiger and Weber (1994) where nine cyclists performed the same task under three temperature conditions (14°C, 22°C and 30°C), heart rate was found to be a more valid marker of exercise intensity than RPE. This was in contrast to a study by Eston et al. (1987) who showed that RPE was as good as heart rate as a predictor of exercise intensity during treadmill running.

Evans and Potteiger (1995) conducted a study aimed at using heart rate, central RPE and peripheral RPE values, obtained from the graded exercise test, to produce a similar metabolic intensity during a 5 km run in trained athletes. They concluded that using heart rate from the graded exercise test was better than using RPE values for maintaining exercise intensity at blood lactate level of > 4 $mmol.l^{-1}$ during a 5 km field run.

The above studies show that, in most cases, the RPE accurately measures exercise intensity. Based on these studies, the American College of Sports Medicine has advocated the use of RPE as a tool for prescribing and monitoring exercise intensity (Dishman, 1994; Williams and Eston, 1989). However, based on some of the above studies conducted in the laboratories, heart rate is more accurate than RPE as a measure of exercise intensity, provided the factors which affect heart rate are controlled.

2.1.6 Summary

Since training is important in determining levels of performance in competitive sports, a number of quantitative measures (ranging from invasive, perceived exertions to pulse counting) have been used by athletes, coaches and exercise physiologists. While it is known that there is a positive relationship between heart rate and exercise intensity, the practical application of this relationship is not known. Also, with the development of portable heart rate monitors there is much potential for measuring exercise intensity based on heart rate.

Chapter 3

Quantification of training and racing intensity in long distance runners.

3.1 Introduction

Although training intensity is an important variable associated with improving performance in long distance running (Mikesell and Dudley, 1984; Fohrenbach et al., 1987; Bosch et al., 1990; Robinson et al., 1991; Ritchie and Hopkins, 1991; Pollock, 1992; Morgan et al., 1989), there are little data measuring training intensity precisely during the training of high performance long distance runners. Measurements of exercise intensity such as oxygen uptake (Foster, 1983), heart rate recordings from ECG (Karvonen and Vuorimaa, 1988) and blood lactate concentration (Heck et al., 1985; Costill et al., 1973) are frequently used in the laboratory to quantify exercise intensity (Hopkins, 1991). These methods, however, are not practical for measuring training intensity in the field.

Some studies have inferred that runners train at more than 80% VO_2max and compete at an even higher percentage VO_2max (Coetzer et al., 1993; Bosch et al., 1990). The data on the training intensity in these studies were inferred by asking the subjects to report on their perceived training intensity. However, with the development of radiotelemetric heart rate monitors it has become possible to accurately measure and store heart rate data during a training session (Léger and Thivierge, 1988, Treiber et al., 1989, Laukkanen et al., 1998). This has enabled coaches, exercise scientists and athletes to measure heart rate accurately while running and has increased the precision of prescribing exercise intensity, based on heart rate (Gilman, 1996).

Few studies, however, have objectively quantified either the training or racing intensity of runners using heart rate monitors (Robinson et al., 1991; Karvonen and Vuorimaa, 1988; Ritchie and Hopkins, 1991; Gilman and Wells, 1993; Selley et al., 1995). As a result, there is little consensus on the training intensity of high performance long distance runners in different types of training or compared to the intensity during competition. Thus, the aim of this study was to quantify training intensity of high performance long distance runners during different types of training and racing using heart rate as a measure of exercise intensity.

3.2 <u>Materials and Methods</u>

3.2.1 Subjects

Ten male provincial and national class road runners were recruited for the study (Table 1). Subjects gave their informed consent after the testing protocol was explained. The study was approved by the Ethics and Research Committee of the University of Cape Town.

3.2.2 Study design

Training diaries

During the first week of the study subjects were invited to the laboratory for orientation and familiarisation with running on the treadmill. During this visit they completed questionnaires on their training history and were given diaries in which they had to record details about their training sessions. Details in the diaries included date of training session, heart rate, type and duration of a training session, average running pace, terrain and a score (6 - 20) from a Borg Scale for a rating of intensity during training (Borg, 1982).

Treadmill familiarisation

During the first week of the study subjects underwent a 10 minute familiarisation run on the treadmill at approximately 12 $km.h^{-1}$ and were instructed on the use of heart rate monitors (Sports Tester, Polar Electro, Finland).

Anthropometric assessment

In the second week runners underwent anthropometric assessment with measurements of body mass, stature, and seven skinfold thickness (biceps, triceps, subscapular, suprailiac, abdomen, calf and mid-thigh). The skinfolds were measured according to procedures described by Ross and Marfell-Jones (1991) and body fat was calculated according to the procedure of Durnin and Womersley (1974).

VO_2max test

In the third week subjects underwent a maximum oxygen consumption (VO_2max) test on a treadmill. Each subject warmed up on the treadmill (Quinton Tiernay Electrical, Seattle, WA) for 5 minutes running at 14 $km.h^{-1}$ followed by general stretching for about five minutes. The subjects then started running at 12 $km.h^{-1}$ and the treadmill speed was subsequently increased by 0.5 $km.h^{-1}$ every 30 seconds. The gradient of the treadmill was maintained at 1% throughout the test to ensure that the intensity at any speed was similar to the intensity while running outside on the track or road (Jones and Doust, 1996).

The treadmill test continued until the subjects were unable to maintain the speed of the treadmill. Oxygen consumption (OxyconSigma, Minjihart, Netherlands) and heart rate (Sports Tester, Polar Electro, Finland) were measured continuously during the test. VO_2max and maximum heart rate (MHR) were defined as the highest values for these parameters which were recorded during the test.

Diarised training

From the fourth week the runners started recording training sessions in their diaries. Details of training were recorded intermittently for a minimum of 17 to a maximum of 227 days. The number of training sessions recorded by each subject differed. This was attributed to varying compliance of the subject.

In some cases runners only used diaries at the beginning of the monitoring period then later used both the diaries and heart rate monitors. In other cases runners used both the heart rate monitors and diaries at the beginning of their monitoring phase. This was determined by the availability of the heart rate monitors when the subjects started the study. Diaries and heart rate monitors were distributed to, and collected from, subjects randomly at different periods. This was done to get a representative sample of training and racing. Runners were instructed to train at an intensity that was planned for that training session and not to be influenced by the presence or absence of a heart rate monitor. Training sessions, particularly high intensity training (HIT) sessions, were preceded by a 2 km warm up, followed by stretching of major muscles.

Racing

Each runner, except subject 5, used a heart rate monitor in at least one race, either on the track or on the road race (up to a full marathon, 42.2 km). During the race runners were instructed to record their time split for each kilometre by pressing the appropriate button on the heart rate monitor receiver. The average heart rate and average speed was calculated for each km during the race. Only league standard races were used to ensure correct measurement of distance covered during races.

Heart rate recording

Heart rate during training and racing were recorded and stored every 15 seconds. The heart rate monitors stored heart rate data every 15 seconds. When subjects visited the laboratory to return their heart rate monitors, heart rate data were transferred to a computer for analysis using an interface (Polar Electro, Finland). The heart rate data were expressed as total average time spent at the heart rate intervals of 120 - 129, 130 - 139, 140 - 149, 150 - 159, 160 - 169, 170 - 179, 180 - 189, 190 - 199 and 200 - 210 beats.min^{-1}.

3.2.3 Statistics

The paired t-test was used to compare training sessions without heart rate monitors and training with heart rate monitors. An analysis of variance with repeated measures was used to compare the average duration of heart rate within each zone for long slow distance training intensity (LSD), high intensity training (HIT) and racing. Statistical significance was accepted when $P < 0.05$. Spearman's rank order correlation coefficient was used to determine the relationship between % of time spent above 80% VO_2max and running proficiencies (10 km time) in national, provincial and average runners.

3.3 Results

3.3.1 Subject characteristics

The characteristics of the subjects are shown in Table 1. All subjects specialised in the long distance running events. The average best 10 km time for the subjects was 31:15 ± 1:28 min:s (n = 10) and the average best time for all those subjects who raced a marathon (42.2 km) was 2:30 ± 0:10 h:min (n = 4). Three subjects were classified as national class runners (subjects 1, 2, 10); five subjects were classified as provincial runners (subjects 4, 5, 6, 8, 9) and two subjects as average runners (subjects 3 and 7).

3.3.2 Training

The subjects trained an average of 6 - 7 days per week. Besides long slow distance runs (LSD) for "aerobic base" (Wells and Pate, 1988), their training programmes included quality interval sessions or high intensity training (HIT). Five subjects (3 national and 2 provincial class) trained twice a day at least 6 days per week. All subjects' training programmes emphasised both endurance and high intensity components.

The duration of training runs, distance covered and rating of perceived exertion (RPE) during the training without heart rate monitors are compared to the training sessions where the subjects wore heart rate monitors (Figures 1, 2 and 3 respectively). There were no differences in any of these measurements in 8 subjects. However, subjects 1 and 10 had a slightly higher RPE while training with heart rate monitors compared to the training sessions before they were given heart rate monitors (Figure 3; $P < 0.05$). Although the RPE measurements were marginally higher in these two subjects while they were training with heart rate monitors, discussions with subjects indicated that their training with heart rate monitors was representative of their normal training and not a type II error of wearing the heart rate monitor.

The duration of training sessions in which the subjects wore heart rate monitors are broken into 4 categories: LSD, HIT, racing and total time for training and racing (Table 2). The average duration for LSD, HIT and racing are shown in table 3. Subjects 1, 3, 4, 5, 6, 9 and 10 spent more than 40 minutes on average for each LSD training session.

There was no significant difference in average duration during LSD, HIT, or racing (Table 3). Subject 4 had more racing duration because he raced a marathon (42.2 km during the study). While other subjects raced shorter races of 5,10, 12, and 15 km. Subjects 8 and 9 participated in half marathons (21.1 km) during the study.

Table 4 and 5 shows the total time (min) spent at heart rate intervals of 10 beats.min^{-1} ranging from 120 - 210 beats.min^{-1} for LSD and HIT training respectively. Table 6 shows the total time spent at each heart rate interval while racing. Tables 7, 8 and 9 show the average time spent at the same heart rate interval for LSD, HIT training and racing respectively. Various significant differences are also shown in tables 7, 8 and 9. Tables 10, 11 and 12 show the percentage time spent at the heart rate intervals for LSD and HIT training and racing respectively. The average oxygen consumption and heart rate corresponding to 80% VO_2max was 52.0 ± 5.2 mlO2.kg-^{1}·min-^{1} and 152 ± 14 beats.min^{-1} respectively (Table 13). Table 14 shows the percentage of VO_2max at 70, 80 and 90% of maximum heart rate respectively. There was a wide variation in % VO_2max at 70% MHR (45 - 81% VO_2max), 80% MHR (63 - 88% VO_2max) and 90% MHR (79 - 94% VO_2max).

Table 15 shows time and percentage of the total time spent above 80% VO_2max. Subject 6 showed very low levels of training intensity in all sessions (LSD, HIT and racing). Amongst the subjects, percentage of total time above 80% differed. For LSD the range is 3 - 96%, for HIT is 0 - 85% and for racing is 22 - 100% excluding subject 5 who did not race.

3.4 Discussion

This is the first study that has monitored and quantified training and competition intensity according to heart rate in runners. Although studies acknowledge the role of training intensity in running performance (Robinson et al., 1991; Wells and Pate, 1988; Hopkins and Hawley, 1989; Mahler and

Jacob, 1985; Pollock, 1992; Mikesell and Dudley, 1984) no studies have monitored the same athletes while undergoing different forms of training and during competition. Accordingly, this study attempted to objectively quantify training and racing intensity based on heart rate and then to relate this to running performance.

The novel aspect of this study was that the subjects were representative of national, provincial and "average" class runners. All runners were trained by the same experienced senior national coach and the study was conducted when athletes were in different stages of periodisation (build-up, overload and taper) (Hopkins, 1993). These phases of training were characterised by routine aerobic training (LSD), high intensity aerobic race-pace simulations, time trials, anaerobic interval sessions and competition.

This study calculated subject's oxygen consumption levels at 80% VO_2max and heart rate at 80% VO_2max (Table 13), and then the % VO_2max corresponding to 70, 80 and 90% of maximum heart rate (Table 14). These relative exercise intensities were chosen because training is often prescribed as a % of maximum heart rate (Edwards, 1993). Table 14 shows that there is much variation in exercise intensities based on % VO_2max with a range of 45 - 81% VO_2max for 70% maximum heart rate, 63 - 88% VO_2max for 80% maximum heart rate and 79 - 94% VO_2max for 90% maximum heart rate. There was also much variation in oxygen consumption, (range 44.7 - 58.2 $mlO_2.kg^{-1}.min^{-1}$) and heart rate (range 130 - 163 $beats.min^{-1}$) at 80% VO_2max (Table 13).

The time spent training above 80% VO_2max also varied considerably for LSD (3 - 96% of the time spent training LSD), HIT (0 - 85% of the time spent training HIT) and racing (22 - 100% of the time spent racing). There was no relationship between the time spent above 80% VO_2max, for any of the types of training, and running performance. Therefore, this study showed no conclusive evidence that competitive runners who train at higher intensities, either during LSD or HIT training, have a better running performance. Also, there was no relationship between intensity during a race and training performance, which is in agreement with the data of Selley et al. (1995).

Robinson et al. (1991) studied elite athletes and suggested that intensity of training may only have a very small effect on performance in this group. But they went on to say that among elite athletes, even small improvements in performance can be highly significant. In other studies examining the relationship between training intensity and performance, weak correlations were found ($r = -0.20$ to -0.40) (Hagan et al., 1981 and Foster, 1983).

In terms of training volumes, Coetzer et al. (1993) found that national class middle and long distance runners trained consistently at intensities greater than 80% VO_2max. But heart rate monitors were not used to quantify those high levels of training intensity. Rather, the information provided by the subjects was subjective and based on the runners' perceptions. In this study, the % of the total time spent above 80% VO_2max during total training was only $52.6 \pm 30.1\%$ compared to $80.9 \pm 27.0\%$ of the total time above 80%

VO_2max during racing. This suggests that the subjective training intensity data should be interpreted with caution.

The intensity during training was not as high as the intensity during racing and this raises questions about the appropriateness of the specificity of their training. Another interpretation of these data is that the intensity, as measured by heart rate during racing, is falsely elevated (Selley et al., 1995).

Subjects were monitored with and without heart rate monitors. The reason for this was to reduce the risk of the subjects training any differently with heart rate monitors compared to training without heart rate monitors. In most cases the perception of effort was similar when subjects trained with or without heart rate monitors. Two subjects (subjects 1 and 10) had higher average perceived exertions while training with heart rate monitors compared to their training sessions without. Although this suggests that the subjects were training harder while using heart rate monitors, this may be a spurious finding. The subjects were interviewed when they returned the heart rate monitors and neither gave any impression that they had trained uncharacteristically harder while wearing the heart rate monitor. Furthermore, the heart rate values of subjects 1 and 10 were within the range of values of all the subjects in the study (Tables 7, 8 and 9), supporting the fact that the interpretation of the data are valid.

For all high intensity training (HIT), subjects trained together as a group. This introduced a certain amount of competition into their training which may have accounted for a higher than expected training intensity. But this "competition" occurred whether or not the subjects were wearing heart rate monitors. LSD training sessions were often done individually. In general, subjects in the study did more quality training (average of three time a week) than racing. In this study subject 5 did not race and subject 6 spent no time above 80% VO_2max during HIT training (Table 15). Furthermore, subjects in the study consistently trained at a lower intensity compared to racing (Table 7, 8 and 9).

In conclusion, the runners in this study trained at different intensities and this was not related to running performance (10km time). There was a particularly wide range of training intensity, according to % VO_2max when training was examined at different intensities (70, 80 and 90% maximum heart rate). This has important practical applications as coaches often prescribe exercise as % of maximum heart rate (Edwards, 1993). Another finding was that, the heart rate during races was consistently higher than the heart rate during either LSD training or HIT training. Whether this was indeed the case or whether this is an artefact of using heart rate as a measure of exercise intensity during competition remains to be determined. The answer to this question has important implications for training prescription.

Table 1: Means (± SD) for the characteristics of the 10 subjects who took part in the study.

variable	(mean ± SD)	Range minimum	Range maximum
Age (years)	26.0 ± 3.5	22.0	30.0
Mass (kg)	61.8 ± 7.0	54.4	73.6
Stature (cm)	174.2 ± 5.0	168.2	186.0
Percent fat	9.6 ± 2.5	6.7	13.9
Sum of 7 skinfolds (mm)	38.3 ± 10.1	29.8	64.0
VO_2max ($mlO_2.kg^{-1}.min^{-1}$)	67.1 ± 3.8	58.0	70.7
* MHR ($beats.min^{-1}$)	185 ± 6	174	196
* PTRS ($km.h^{-1}$)	20.1 ± 0.7	20.0	22.0
* RER	1.08 ± 0.07	0.93	1.19
Best 10 km time (min:s)	31:15 ± 1.28	29:04	33:48
Best 42.2 km time (h:min) (n = 4)	2:30 ± 0:10	2:22	2:44

* MHR - maximum heart rate

* PTRS - peak treadmill running speed

* RER - respiratory exchange ratio coinciding with exhaustion in the VO_2max test

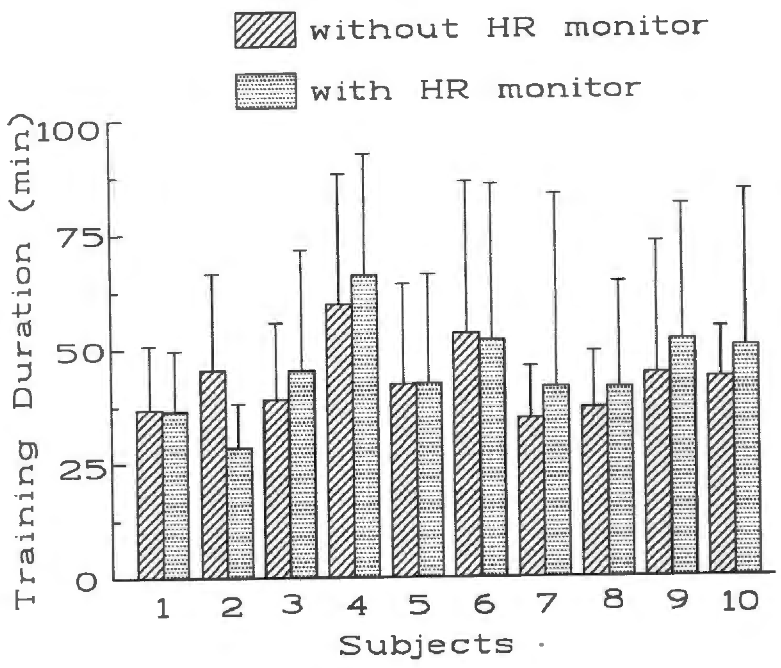


Figure 1. Duration of training runs (min) while subjects trained without and without the heart rate monitors. The number of training runs for each subject is shown below.

Subject	number of training runs without a heart rate monitor	number of training runs with a heart rate monitor	duration of study (days)
1	14	14	137
2	13	14	177
3	14	12	34
4	26	18	47
5	10	12	17
6	18	14	227
7	13	19	143
8	21	6	52
9	9	16	75
10	23	14	61

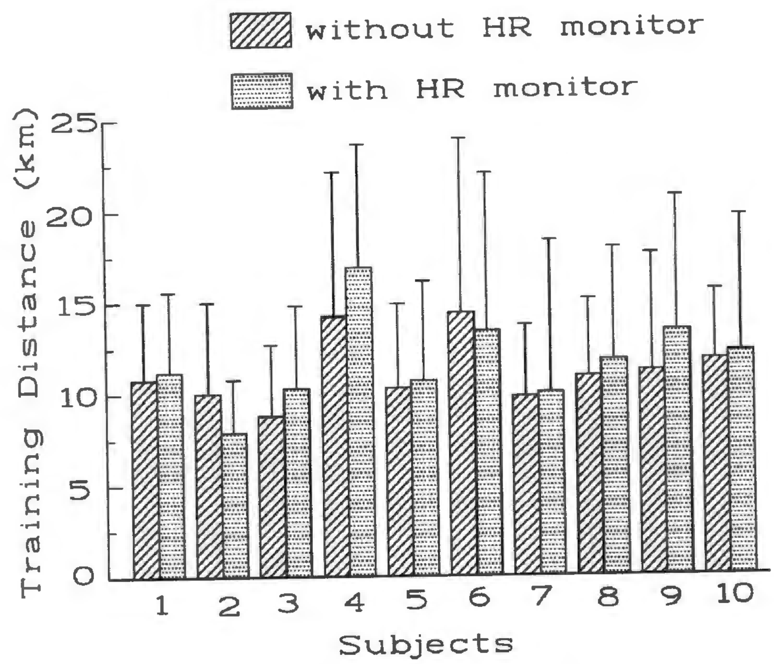


Figure 2. Distance of training runs (km) while subjects trained without and without heart rate monitors. The number of training runs for each subject is shown below.

Subject	number of training runs without a heart rate monitor.	number of training runs with a heart rate monitor	duration of study (days)
1	14	14	137
2	13	14	177
3	14	12	34
4	26	18	47
5	10	12	17
6	18	14	227
7	13	19	143
8	21	6	52
9	9	16	75
10	23	14	61

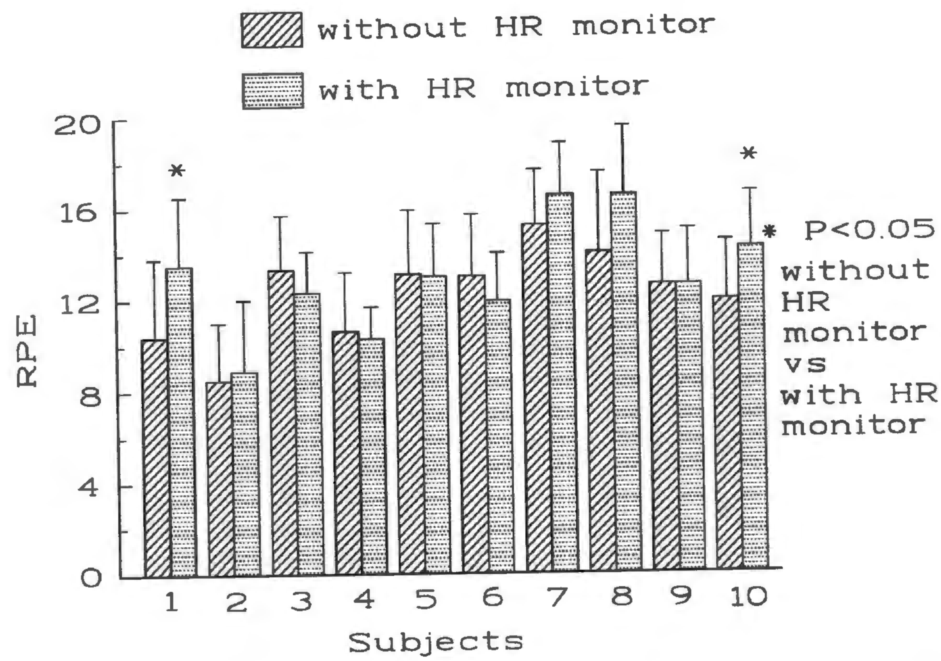


Figure 3. RPE of training runs while subjects trained without and with heart rate monitors. The number of training runs for each subject is shown below.

Subject	number of training runs without a heart rate monitor	number of training runs with a heart rate monitor	duration of study (days)
1	14	14	137
2	13	14	177
3	14	12	34
4	26	18	47
5	10	12	17
6	18	14	227
7	13	19	143
8	21	6	52
9	9	16	75
10	23	14	61

* $p < 0.05$ (without HR monitor vs with HR monitor)

Table 2: Duration (minutes) of long slow distance (LSD), high intensity training (HIT), racing and total running while subjects trained with heart rate monitors.

Subject	total duration of LSD (min)	total duration of HIT (min)	total duration of racing (min)	total time for training and racing (min)
1	n = 7 286.83	n = 7 242.22	n = 4 171.34	n = 18 700.39
2	n = 4 123.38	n = 10 274.25	n = 9 435.51	n = 23 833.14
3	n = 9 454.61	n = 3 89.32	n = 2 47.63	n = 14 591.56
4	n = 14 1024.66	n = 4 277.40	n = 2 192.37	n = 20 1494.43
5	n = 7 300.61	n = 5 213.08	0	n = 12 513.69
6	n = 11 619.73	n = 3 125.66	n = 2 114.91	n = 16 860.30
7	n = 12 454.01	n = 7 256.71	n = 6 603.47	n = 25 1314.19
8	n = 4 155.33	n = 2 93.03	n = 1 66.67	n = 7 315.03
9	n = 7 423.39	n = 9 360.78	n = 1 66.97	n = 17 851.14
10	n = 8 328.66	n = 6 324.01	n = 3 143.94	n = 17 796.61
Average	417.12 ± 259.52	225.65 ± 94.60	204.76 ± 189.74	827.04 ± 352.33

Table 3: The average duration per session (mean ± SD) for long slow distance (LSD), high intensity (HIT) training and racing.

Subject	average LSD duration (min)	average HIT duration (min)	average racing duration (min)
1	n = 7 41.0 ± 10.2	n = 7 32.0 ± 14.8	n = 4 42.8 ± 17.5
2	n = 4 30.8 ± 19.6	n = 10 27.4 ± 9.6	n = 9 48.4 ± 22.9
3	n = 9 50.5 ± 27.7	n = 3 29.8 ± 15.9	n = 2 23.8 ± 15.3
4	n = 14 73.2 ± 37.7	n = 4 69.3 ± 15.6	n = 2 100.7 ± 76.8
5	n = 7 42.9 ± 22.2	n = 5 42.6 ± 28.3	0
6	n = 11 56.3 ± 36.4	n = 3 41.9 ± 32.7	n = 2 57.5 ± 23.7
7	n = 12 37.8 ± 13.1	n = 7 36.7 ± 18.8	n = 6 79.9 ± 76.4
8	n = 4 38.8 ± 8.0	n = 2 46.5 ± 43.2	n = 1 66.7
9	n = 7 60.5 ± 42.3	n = 9 30.1 ± 18.9	n = 1 67.0
10	n = 8 41.1 ± 10.9	n = 6 54.0 ± 37.4	n =3 46.5 ± 17.7
Average	50.3 ± 29.3	40.0 ± 23.2	57.4 ± 47.7

Table 4: Total time (minutes) spent at heart rate intervals of 10 beats.min^{-1} for long slow distance (LSD).

Subject		t 120 -129 beats.min^{-1}	t 130 -139 beats.min^{-1}	t 140-149 beats.min^{-1}	t 150-159 beats.min^{-1}	t 160-169 beats.min^{-1}	t 170-179 beats.min^{-1}	t 180-189 beats.min^{-1}	t 190-199 beats.min^{-1}	t 200-210 beats.min^{-1}	Total time training
1	N = 7	10.48	31.78	78.23	125.96	28.14	10.83	1.41	0.00	0.00	286.83
2	N = 4	5.90	17.82	22.53	8.01	9.05	10.81	49.26	0.00	0.00	123.38
3	n = 9	9.34	27.07	83.23	182.72	110.63	40.38	1.24	0.00	0.00	454.61
4	n = 14	491.52	316.34	137.83	50.56	24.05	0.00	0.00	0.00	4.36	1024.66
5	n = 7	17.80	83.54	132.24	52.99	13.47	0.37	0.00	0.20	0.00	300.61
6	n = 11	92.15	192.35	175.48	84.79	45.04	14.21	13.96	1.75	0.00	619.73
7	n = 12	15.11	33.46	43.12	88.03	141.85	93.72	33.60	5.12	0.00	454.01
8	n = 4	2.64	5.67	12.82	31.96	31.17	37.06	29.11	4.90	0.00	155.33
9	n = 7	2.72	23.67	59.47	102.93	145.38	70.92	17.16	1.14	0.00	423.39
10	n = 8	24.34	86.95	122.50	82.91	1.14	10.40	0.42	0.00	0.00	328.66
mean		67.20 ± 151.40	81.87 ± 99.09	86.75 ± 53.91	81.09 ± 49.84	54.99 ± 55.67	28.87 ± 31.67	14.62 ± 17.51	1.31 ± 2.04	0.44 ± 1.38	417.12 ± 259.52

Table 5: Total time (min) spent at heart rate intervals of 10 beats.min^{-1} for high intensity training (HIT) training.

Subject		t 120 -129 beats.min^{-1}	t 130 -139 beats.min^{-1}	t 140-149 beats.min^{-1}	t 150-159 beats.min^{-1}	t 160-169 beats.min^{-1}	t 170-179 beats.min^{-1}	t 180-189 beats.min^{-1}	t 190-199 beats.min^{-1}	t 200-210 beats.min^{-1}	Total time training
1	n = 7	21.03	14.97	42.42	58.54	23.24	24.84	25.77	13.28	0.00	242.22
2	n = 10	12.10	15.11	17.07	58.76	40.93	70.61	58.16	1.51	0.00	274.25
3	n = 3	0.85	7.55	15.05	26.50	26.22	8.30	4.85	0.00	0.00	89.32
4	n = 4	88.47	52.18	41.37	43.41	36.68	10.67	0.00	0.00	4.62	277.40
5	n = 5	32.09	46.48	42.88	22.51	34.63	31.32	2.23	0.94	0.00	213.08
6	n = 3	10.77	23.90	31.17	40.47	19.35	0.00	0.00	0.00	0.00	125.66
7	n = 7	24.44	19.53	22.59	32.13	19.33	38.35	69.86	30.48	0.00	256.71
8	n = 2	6.75	6.46	10.31	3.22	7.58	20.28	30.98	6.83	0.62	93.03
9	n = 9	20.77	31.20	48.94	56.36	63.32	74.77	53.42	12.00	0.00	360.78
10	n = 6	46.48	77.51	74.93	64.93	54.46	5.70	0.00	0.00	0.00	324.01
Mean		26.38 ± 25.47	29.49 ± 22.78	34.67 ± 19.56	40.68 ± 19.71	32.57 ± 17.05	28.48 ± 26.16	24.53 ± 27.39	6.5 ± 9.87	0.52 ± 1.45	225.65 ± 94.60

Table 6: Total time (minutes) spent at heart rate intervals of 10 beats.min^{-1} for racing.

Subject		t 120 -129 beats.min^{-1}	t 130 -139 beats.min^{-1}	t 140-149 beats.min^{-1}	t 150-159 beats.min^{-1}	t 160-169 beats.min^{-1}	t 170-179 beats.min^{-1}	t 180-189 beats.min^{-1}	t 190-199 beats.min^{-1}	t 200-210 beats.min^{-1}	Total time racing
1	n = 4	7.95	2.96	2.53	2.40	4.44	27.69	77.66	45.71	0.00	171.34
2	n = 9	1.00	0.00	0.18	1.38	19.41	91.83	318.00	3.71	0.00	435.51
3	n = 2	0.00	0.00	0.16	0.00	7.18	29.69	10.50	0.00	0.00	47.63
4	n = 2	32.01	14.38	3.49	42.23	104.22	5.04	0.00	0.00	0.00	192.37
5		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	n = 2	0.74	0.00	0.41	8.45	80.05	19.16	2.85	2.44	0.81	114.91
7	n = 6	21.45	27.80	25.26	32.33	100.83	74.67	91.54	104.59	1.25	603.47
8	n = 1	5.83	0.00	0.00	0.00	5.83	19.17	35.84	0.00	0.00	66.67
9	n = 1	0.00	0.00	0.00	0.00	0.00	1.34	45.54	20.09	0.00	66.97
10	n = 3	0.00	4.51	0.00	0.66	41.23	97.54	0.00	0.00	0.00	143.94
Mean		6.78 ± 11.09	5.19 ± 9.20	3.28 ± 7.85	9.45 ± 15.43	39.86 ± 42.72	37.60 ± 37.31	56.03 ± 97.27	14.54 ± 33.89	0.23 ± 0.45	204.76 ± 189.74

Table 7: Average time (minutes) spent at heart rates for long slow distance (LSD) training.

Subject		t 120 -129 beats.min^{-1}	t 130 -139 beats.min^{-1}	t 140-149 beats.min^{-1}	t 150-159 beats.min^{-1}	t 160-169 beats.min^{-1}	t 170-179 beats.min^{-1}	t 180-189 beats.min^{-1}	t 190-199 beats.min^{-1}	t 200-210 beats.min^{-1}	Average time training
1	n = 7	n = 2 5.2 ± 0.8	n = 6 5.3 ± 5.2	n = 7 11.2 ± 4.9	n = 7 18.0 ± 9.9	n = 5 5.6 ± 3.3	n = 2 5.4 ± 1.0	n = 1 1.4 ± 0	-	-	41.0 ± 10.2
2	n = 4	n = 2 2.9 ± 2.0	n = 3 5.9 ± 4.8	n = 3 7.5 ± 4.9	n = 2 4.0 ± 5.0	n = 1 9.0 ± 0	n = 1 10.8 ± 0	n = 1 49.3 ± 0	-	-	30.8 ± 19.6
3	n = 9	n = 5 1.9 ± 1.2	n = 7 3.9 ± 3.1	n = 9 9.2 ± 10.9	n = 9 20.3 ± 21.0	n = 9 12.3 ± 6.7	n = 6 6.7 ± 6.7	n = 1 1.2 ± 04	-	-	50.5 ± 27.7
4	n = 14	n = 14 35.1 ± 14.7	n = 13 24.3 ± 13.4	n = 11 12.5 ± 11.5	n = 4 12.6 ± 11.5	n = 3 8.0 ± 2.6	-	-	n = 1 4.4 ± 0	n = 1 4.4 ± 0	73.2 ± 37.7
5	n = 7	n = 5 3.6 ± 2.5	n = 7 12.0 ± 11.4	n = 7 18.9 ± 11.8	n = 7 7.6 ± 4.9	n = 4 3.4 ± 1.0	n = 1 0.3 ± 0	-	n = 1 0.2 ± 0	-	42.9 ± 22.2
6	n = 11	n = 11 8.4 ± 84	n = 11 17.5 ± 15.4	n = 10 17.5 ± 12.0	n = 8 10.6 ± 9.0	n = 5 9.0 ± 10.3	n = 2 7.1 ± 7.8	n = 1 14.0 ± 0	n = 1 1.7 ± 0	-	56.3 ± 36.4
7	n = 12	n = 8 1.9 ± 3.1	n = 6 5.6 ±10.5	n = 11 4.0 ± 7.3	n = 12 7.3 ± 7.0.	n = 11 12.9 ± 7.8	n = 11 8.5 ± 6.7	n = 5 6.7 ± 6.5	n = 2 2.6 ± 1.2	-	37.8 ± 13.1
8	n = 4	n = 3 .9 ± .4	n = 4 1.4 ± 1.4	n = 4 3.2 ± 2.3	n = 4 8.0 ± 11.7	n = 4 7.8 ± 10.8	n = 4 9.3 ± 9.2	n = 3 9.7 ± 8.2	n = 1 4.9 ± 0	-	38.8 ± 8.0
9	n = 7	n = 3 .9 ± .7	n = 6 3.9 ± 3.6	n = 7 8.5 ± 7.4	n = 7 14.7 ± 11.0	n = 7 20.8 ± 18.9	n = 5 14.2 ± 10.6	n = 3 5.7 ± 3.6	n = 1 1.1 ± 0	-	60.5 ± 42.3
10	n = 8	n = 5 4.8 ± 3.5	n = 7 12.4 ± 7.8	n = 8 15.3 ± 10.2	n = 6 13.8 ± 12.0	n = 1 1.1 ± 0	n = 4 2.6 ± 2.2	n = 1 0.4 ± 0	-	-	41.1 ± 10.9
Mean		n = 58 11.6 ± 15.8	n = 70**a** 11.7 ± 12.5	n = 77**a, b** 11.3 ± 10.3	n = 66 12.3 ± 11.9	n = 50**b** 11.0 ± 10.3	n = 36 8.0 ± 7.2	n = 16**d** 9.1 ± 12.2	n = 7 2.5 ± 1.7	n = 1 4.4 ± 0	50.3 ± 29.3

a $p < 0.05$ LSD vs HIT
b $p < 0.05$ LSD vs Racing
d $p < 0.0001$ LSD vs Racing

Table 8: Average time (minutes) spent at heart rates for high intensity training (HIT) training.

Subject		t 120 -129 beats.min^{-1}	t 130 -139 beats.min^{-1}	t 140-149 beats.min^{-1}	t 150-159 beats.min^{-1}	t 160-169 beats.min^{-1}	t 170-179 beats.min^{-1}	t 180-189 beats.min^{-1}	t 190-199 beats.min^{-1}	t 200-210 beats.min^{-1}	Average time training
1	n = 7	n = 4 5.3 ± 5.3	n = 5 3.0 ± 3.4	n = 6 7.1 ± 5.5	n = 6 9.8 ± 8.71	n = 7 3.3 ± 2.2	n = 6 4.1 ± 3.2	n = 4 6.4 ± 5.3	n = 3 4.4 ± 2.3	-	32.0 ± 14.8
2	n = 10	n = 7 1.7 ± 1.1	n = 8 1.9 ± 1.6	n = 10 1.7 ± 1.7	n = 9 6.5 ± 7.7	n = 10 4.1 ± 2.2	n = 8 8.8 ± 5.2	n = 7 8.3 ± 2.5	n = 1 1.5 ± 0	-	27.4 ± 9.6
3	n = 3	n = 2 0.4 ± 0.3	n = 2 3.8 ± 5.0	n = 3 5.0 ± 6.6	n = 3 8.8 ± 5.4	n = 3 8.7 ± 4.2	n = 2 4.2 ± 1.0	n = 1 4.9 ± 0	-	-	29.8 ± 15.9
4	n = 4	n = 4 22.1 ± 11.9	n = 4 13.0 ± 5.9	n = 4 10.3 ± 1.8	n = 3 14.5 ± 4.5	n = 3 12.2 ± 4.4	n = 1 10.7 ± 0	-	-	n = 1 4.6 ± 0	69.3 ± 15.6
5	n = 5	n = 3 10.7 ± 7.5	n = 3 14.4 ± 9.9	n = 4 10.7 ± 8.1	n = 5 4.5 ± 3.7	n = 5 6.9 ± 5.3	n = 5 6.3 ± 5.3	n = 2 1.1 ± 1.1	n = 1 0.9 ± 0	-	42.6 ± 28.3
6	n = 3	n = 3 3.6 ± 5.2	n = 3 8.0 ± 6.2	n = 3 10.4 ± 9.0	n = 3 13.5 ± 6.3	n = 2 9.7 ± 4.4	-	-	-	-	41.9 ± 32.7
7	n = 7	n = 7 3.5 ± 3.0	n = 6 3.3 ± 2.1	n = 7 3.2 ± 2.4	n = 7 4.6 ± 3.0.	n = 6 3.2 ± 3.4	n = 7 5.4 ± 3.4	n = 7 10.0 ± 6.2	n = 6 5.1 ± 4.9	-	36.7 ± 18.8
8	n = 2	n = 2 3.4 ± 4.4	n = 1 6.5 ± 0	n = 1 10.3 ± 1.0	n = 2 1.6 ± 1.4	n = 2 3.8 ± 2.7	n = 2 10.1 ± 2.4	n = 2 15.5 ± 19.9	n = 2 3.4 ± 1.0	n = 1 1.0 ± 0	46.5 ± 43.5
9	n = 9	n = 8 2.6 ± 1.7	n = 9 3.5 ± 2.5	n = 9 5.4 ± 5.9	n = 9 6.2 ± 5.3	n = 9 7.0 ± 6.2	n = 9 8.3 ± 7.2	n = 6 8.9 ± 7.5	n = 3 4.0 ± 0.5	-	30.1 ± 18.9
10	n = 6	n = 6 7.7 ± 8.9	n = 6 13.0 ± 11.7	n = 6 12.5 ± 5.6	n = 6 10.8 ± 12.3	n = 3 18.2 ± 13.1	n = 2 2.9 ± 2.4	-	-	-	54.0 ± 37.4
mean		n = 46 5.7 ± 7.7	n = 47a 6.2 ± 6.9	n = 53a 6.5 ± 5.9	n = 53 7.7 ± 7.2	n = 50 6.5 ± 6.0	n = 42c 6.8 ± 5.0	n = 29e 8.5 ± 6.8	n = 16c 4.1 ± 3.2	n = 2 2.6 ± 2.8	40.0 ± 23.2

a $p < 0.05$ HIT vs LSD
c $p < 0.05$ HIT vs Racing
e $p < 0.000003$ HIT vs Racing

Table 9: Average time (minutes) spent at heart rates for racing.

Subject		t 120 -129 beats.min^{-1}	t 130 -139 beats.min^{-1}	t 140-149 beats.min^{-1}	t 150-159 beats.min^{-1}	t 160-169 beats.min^{-1}	t 170-179 beats.min^{-1}	t 180-189 beats.min^{-1}	t 190-199 beats.min^{-1}	t 200-210 beats.min^{-1}	Average time
1	n = 4	n = 3 2.6 ± 2.6	n = 1 3.0 ± 0	n = 1 2.5 ± 0	n = 2 1.2 ± 0.7	n = 2 2.2 ± 0.4	n = 4 6.9 ± 9.2	n = 4 19.4 ± 13.2	n = 3 15.2 ± 13.2	-	42.8 ± 17.5
2	n = 9	n = 1 1.0 ± 0	-	n = 1 0.2 ± 0	n = 2 0.7 ± 0.3	n = 8 2.4 ± 3.7	n = 9 10.2 ± 9.3	n = 9 35.3 ± 12.9	n = 2 1.9 ± 0.5	-	48.4 ± 22.9
3	n = 2	-	-	n = 1 0.2 ± 0	-	n = 2 3.6 ± 3.9	n = 2 14.8 ± 12.0	n = 1 10.5 ± 0	-	-	23.8 ± 15.3
4	n = 2	n = 1 32.0 ± 0	n = 1 14.4 ± 0	n = 1 3.5 ± 0	n = 1 42.2 ± 0	n = 1 104.2 ± 0	n = 1 5.0 ± 0	-	-	-	100.7 ± 76.8
5		-	-	-	-	-	-	-	-	-	-
6	n = 2	n = 1 1.0 ± 0	-	n = 1 0.4 ± 0	n = 2 4.2 ± 1.4	n = 2 40.0 ± 28.4	n = 2 9.6 ± 2.0	n = 1 2.9 ± 0	n = 1 2.4 ± 0	n = 1 0.8 ± 0	57.5 ± 23.7
7	n = 6	n = 5 4.2 ± 2.8	n = 4 7.0 ± 9.0	n = 4 6.3 ± 9.4	n = 2 16.2 ± 22.2	n = 4 25.2 ± 47.4	n = 5 14.9 ± 21.7	n = 5 18.3 ± 10.3	n = 4 26.1 ± 29.0	n = 1 1.3 ± 0	79.9 ± 76.4
8	n = 1	n = 1 5.8	-	-	-	n = 1 5.8	n = 1 19.2	n = 1 35.8	-	-	66.7
9	n = 1	-	-	-	-	-	n = 1 1.3	n = 1 45.5	n = 1 20.1	-	67.0
10	n = 3	-	-	-	n = 1 0.7 ± 0	n = 3 13.7 ± 10.8	n = 3 32.5 ± 15.6	-	-	-	46.5 ± 17.7
mean		n = 12 5.7 ± 8.6	n = 6 7.5 ± 8.0	n = 9b 3.6 ± 6.4	n = 10 8.7 ± 15.2	n = 23b 15.8 ± 29.7	n = 28c 13.1 ± 13.8	n = 22 26.5 ± 15.1	n = 11c 16.0 ± 19.7	n = 2 1.0 ± 0.3	57.4 ± 47.7

b $p < 0.05$ Racing vs LSD
c $p < 0.05$ Racing vs HIT
d $p < 0.00001$ Racing vs LSD
e $p < 0.000003$ Racing vs HIT

Table 10: Percentage of the time spent at heart rates for long slow distance (LSD) training.

Subject	p120 – 129 beats.min^{-1}	p 130 - 139 beats.min^{-1}	p140 - 149 beats.min^{-1}	p150 - 159 beats.min^{-1}	p160 - 169 beats.min^{-1}	p170 - 179 beats.min^{-1}	p180 - 189 beats.min^{-1}	p190 - 199 beats.min^{-1}	p200 - 210 beats.min^{-1}
1	n = 2 3.7	n = 6 11.1	n = 7 27.3	n = 7 43.9	n = 5 9.8	n = 2 3.8	n = 1 0.5	-	-
2	n = 2 4.8	n = 3 14.4	n = 3 18.3	n = 2 6.5	n = 1 7.3	n = 1 8.8	n = 1 39.9	-	-
3	n = 4 2.1	n = 4 6.0	n = 6 18.3	n = 6 40.2	n = 6 24.3	n = 6 8.9	n = 3 0.3	-	-
4	n = 11 48.0	n = 10 30.9	n = 10 13.5	n = 3 4.9	n = 2 2.3	-	-	-	n = 1 0.4
5	n = 5 5.9	n = 7 27.8	n = 7 44.0	n = 7 17.6	n = 4 4.5	n = 1 0.1	-	n = 1 0.1	-
6	n = 11 14.9	n = 11 31.0	n = 10 28.3	n = 8 13.7	n = 5 7.3	n = 1 2.3	n = 1 2.3	n = 1 0.3	-
7	n = 7 3.3	n = 6 7.4	n = 10 9.5	n = 11 19.4	n = 10 31.2	n = 10 20.6	n = 4 7.4	n = 2 1.1	-
8	n = 3 1.7	n = 4 3.7	n = 4 8.3	n = 4 20.6	n = 4 20.1	n = 4 23.9	n = 3 18.7	n = 1 3.2	-
9	n =4 0.6	n = 7 5.6	n = 8 14.0	n = 8 24.3	n = 8 34.3	n = 6 16.8	n = 4 4.1	n = 1 0.3	-
10	n = 4 7.4	n = 6 26.5	n = 7 37.3	n = 5 25.2	n = 1 0.3	n = 3 3.2	n = 1 0.1	-	-
mean	n = 53 9.2 ± 14.2	n = 64 16.4 ± 11.3	n = 72 21.9 ± 12.0	n = 61 21.6 ± 12.7	n = 46 14.1 ± 12.4	n = 31 9.8 ± 8.6	n = 18 10.4 ± 13.9	n = 5 1.0 ± 1.3	n = 1 0.4

Table 11: Percentage of the time spent at heart rates for HIT training.

Subject	p120 – 129 beats.min^{-1}	p 130 - 139 beats.min^{-1}	p140 - 149 beats.min^{-1}	p150 - 159 beats.min^{-1}	p160 - 169 beats.min^{-1}	p170 - 179 beats.min^{-1}	p180 - 189 beats.min^{-1}	p190 - 199 beats.min^{-1}	p200 – 210 beats.min^{-1}
1	n = 4 8.7	n = 5 6.2	n = 6 17.7	n = 6 17.5	n = 7 24.2	n = 6 9.6	n = 4 10.6	n = 3 5.5	-
2	n = 7 4.4	n = 7 5.5	n = 9 6.2	n = 8 21.4	n = 9 14.9	n = 8 25.7	n = 7 21.2	n = 1 0.6	-
3	n = 2 1.0	n = 2 8.5	n = 3 16.8	n = 3 29.7	n = 3 29.4	n = 2 9.3	n = 1 5.9	-	-
4	n = 3 31.9	n = 3 18.8	n = 3 14.9	n = 3 15.6	n = 3 13.2	n = 1 3.8	n = 1 1.7	-	-
5	n = 2 15.1	n = 2 21.8	n = 3 20.1	n = 4 10.6	n = 4 16.3	n = 4 14.7	n = 2 1.0	n = 1 0.4	-
6	n = 2 8.6	n = 2 19.0	n =2 24.8	n = 2 32.2	n = 1 15.4	-	-	-	-
7	n = 6 9.5	n = 5 7.6	n = 6 8.8	n = 6 12.5	n = 5 7.5	n = 6 14.9	n = 6 27.2	n = 6 11.9	-
8	n = 2 7.3	n = 1 6.9	n = 1 11.1	n = 2 3.5	n = 2 8.1	n = 2 21.8	n = 2 33.3	n = 2 7.3	n = 1 0.7
9	n = 6 5.8	n = 6 8.6	n = 6 13.6	n = 6 15.6	n = 6 17.6	n = 6 20.7	n = 4 14.8	n = 2 3.3	-
10	n = 5 14.3	n = 5 23.9	n = 5 23.1	n = 5 20.0	n = 3 16.8	n = 2 1.8	-	-	-
mean	n = 39 10.7 ± 8.6	n = 38 12.7 ± 7.3	n = 44 15.7 ± 6.0	n = 45 17.9 ± 8.6	n = 43 16.3 ± 6.6	n = 37 13.6 ± 8.2	n = 27 14.5 ± 11.9	n = 15 4.7 ± 4.4	n = 1 0.7

Table 12: Percentage of the time spent at heart rates for racing.

Subject	p120 – 129 beats.min^{-1}	p130 - 139 beats.min^{-1}	p140-149 beats.min^{-1}	p150-159 beats.min^{-1}	p160-169 beats.min^{-1}	p170-179 beats.min^{-1}	p180-189 beats.min^{-1}	p190-199 beats.min^{-1}	p200-210 beats.min^{-1}
1	n = 3 4.6	n = 1 1.7	n = 1 1.5	n = 2 1.4	n = 2 2.6	n = 4 16.2	n =4 45.3	n = 3 26.7	
2	n = 1 0.2	-	n = 1 0.04	n = 2 0.3	n = 8 4.5	n = 9 21.1	n = 9 73.0	n = 2 0.9	-
3	-	-	n = 1 0.2	-	n = 2 15.1	n = 2 62.5	n = 1 22.1	-	-
4	n = 1 12.0	n = 1 7.5	n = 1 1.8	n = 1 22.0	n = 1 54.2	n = 1 2.6	-	-	-
5	-	-	-	-	-	-	-	-	-
6	n = 1 0.6	-	n = 1 0.4	n = 2 7.4	n = 2 69.7	n = 2 16.7	n = 1 2.5	n = 1 2.1	n = 1 0.7
7	n = 4 3.6	n = 3 4.6	n = 3 4.2	n = 1 5.4	n = 3 16.7	n = 4 12.4	n =5 15.2	n =4 17.3	n = 1 20.7
8	n = 1 8.7	-	-	-	n = 1 8.7	n = 1 28.8	n =1 53.8	-	-
9	-	-	-	-	-	n = 1 2.0	n =1 68.0	n = 1 30.0	-
10	-	n = 1 3.1	-	n = 1 0.5	n = 3 28.6	n = 3 67.8	-	-	-
mean	n= 11 5.0 ± 4.6	n = 5 4.2 ± 2.5	n = 8 1.4 ± 1.6	n= 9 6.2 ± 8.3	n = 22 25.0 ± 24.5	n = 27 25.6 ± 24.0	n = 22 40.1 ± 27.3	n = 11 15.4 ± 13.5	n = 2 10.7 ± 14.1

Table 13: Oxygen consumption and heart rate at 80% VO_2max

Subject	O_2 consumption at 80% VO_2max ($mlO_2.kg.min^{-1}$)	HR at 80% VO_2max ($beats.min^{-1}$)
1	44.7	130
2	57.7	156
3	44.7	159
4	55.0	159
5	53.4	126
6	45.8	167
7	53.6	155
8	55.5	162
9	58.2	163
10	51.0	147
Mean	52.0 ± 5.2	152 ± 14

Table 14: Percentage VO_2max corresponding to 70, 80 and 90% of maximum heart rate.

Subject	% VO_2max at 70% MHR	% VO_2max at 80% MHR	% VO_2max at 90% MHR
1	81	84	88
2	48	68	79
3	45	63	81
4	48	67	86
5	81	88	94
6	49	66	82
7	60	73	88
8	55	71	86
9	56	70	82
10	61	74	88
Mean	58 ± 13	72 ± 8	85 ± 5

Table 15: Percentage time spent above 80% VO_2max.

Subject	LSD		HIT		Racing	
	Time (min) spent above 80% VO_2max	% of the total time above 80% VO_2max	Time (min) spent above 80% VO_2max	% of the total time above 80% VO_2max	Time (min) spent above 80% VO_2max	% of the total time above 80% VO_2max
1	276.4	96	203.1	84	163.4	95
2	69.1	56	171.2	62	433.0	99
3	152.3	34	39.4	44	47.4	100
4	28.4	3	52.0	19	109.3	57
5	282.8	94	181.0	85	-	-
6	29.9	5	-	-	25.3	22
7	362.3	80	190.2	74	405.2	67
8	102.2	66	66.3	71	60.8	91
9	234.6	55	203.5	56	67.0	100
10	94.9	29	125.1	39	139.4	97
Mean	163 ± 118	52 ± 34	137 ± 68	59 ± 22	161 ± 153	81 ± 27

Chapter 4

Variations in the heart rate of an elite long distance runner during races of varying distances

4.1 Introduction

Since the invention of reliable lightweight heart rate monitors, a variety of sports such as skiing (Gilman 1996), orienteering (Bird et al, 1993), cycling (Hopkins and Hawley, 1989; Palmer et al, 1995), tennis (Therminarias et al, 1991), soccer (Ali and Farrally, 1991) and running (Selley et al, 1995) have used them to monitor exercise intensity.

In the previous study on training/competition quantification (Chapter 3), disparities were observed in training versus competition intensity. Results showed that runners general trained at lower intensities but competed at higher intensities. Although Selley et al (1995) observed the same phenomenon with regards competition. In their study runners' heart rates during 10 and 21.1 - km road races were consistently higher than their heart rates while running non-competitively at the same speeds. However, this aspect of a higher heart rate during competition compared to the heart rate at the same running speed under non-competitive conditions has not been studied systematically.

Accordingly, the aims of this study were to monitor the heart rate of an elite long distance runner over varying race distances (5 km to 28 km) on the road and on the track, and to determine the extent which the heart rate/running speed relationship may vary under competitive conditions.

4.2 Materials and Methods

4.2 1 Subject

An elite male long distance runner who was planning to race over a 6-month period was recruited for the study.

4.2.2 Study design

Laboratory test

The subject followed the same anthropometric assessment, maximum oxygen consumption (VO_2max) test and submaximal indoor track test as explained in the quantification of training and racing study (Chapter 3).

Competitive track and road races

The subject competed in nine races over a 6 month period. Two races were on the track (5 000 m and 1 hour); three races were 15 km; one race was 28 km; one race was 21.1 km and two races were 10 km road races. The subject wore the heart rate monitor (Sport Tester, Polar Electro, Finland) during each race and was instructed to press the appropriate button every kilometre during the race to record his split time for that kilometre. Recording the time for each kilometre enabled the calculation of the average running speed for each kilometre during the race.

4.2.3 Results

The subject was 25 years old, weighed 55.7 kg and was 170.3 cm tall at the time of the laboratory testing. The sum of 7 skinfolds was 33.2 mm. The subjects' peak treadmill running speed was 22 $km.h^{-1}$. His VO_2max and maximum heart rate were 71 $ml.O_2.kg^{-1}.min^{-1}$ and 183 $beats.min^{-1}$ respectively.

The subjects' average weekly training distance and personal best times for the preceding 6 months are shown in Table 1. Table 2 shows data derived from the 9 races the subject participated in during the study. Although the subject did not set any personal best times in the races during the study, he was only 27 seconds slower than his best time for the preceding 6 months in the 5 km track race and 28 seconds slower in the 10 km race (Table 1 and 2). His lowest heart rate (59 $beats.min^{-1}$) was recorded at the start of the 15 km race and his highest heart rate was 193 $beats.min^{-1}$ recorded during the 5 km track race. In all races the subject's maximum heart rate was higher than his maximum heart rate determined in the laboratory test (183 $beats.min^{-1}$). The coefficient of variation [(Standard deviation ÷ mean) x 100] for the average heart rate during the races ranged from 3 to 6%.

<u>Table1:</u> Average weekly training distance and personal best times for races during six months preceding the start of the study.

Average training distance ($km.wk^{-1}$)	80 km
Best times 5 km (track)	14:20 min:s
10 km	29:25 min:s
15 km	45:19 min:s
21.1 km	64:12 min:s

Table 2: Race distance (km), time (min), average running speed (m.min^{-1}), average heart rate (beats.min^{-1}) and heart rate range of 9 races listed in chronological order. Average speed and average heart rate are expressed as $\pm$ standard deviation.

Race Distance (km)	Time (min)	Average speed (m.min^{-1})	Average heart rate (beats.min^{-1})	Heart rate range (beats.min^{-1})		Average heart rate coefficient of variation (%)	Average HR as a % MHR determined in laboratory
				Min	Max		
15	48:33	309 ± 8	181 ± 8	101	189	4%	99%
15	46:55	320 ± 22	182 ± 6	77	189	3%	99%
28	91:56	305 ± 26	178 ± 7	73	187	4%	97%
21	66:48	316 ± 26	180 ± 7	89	187	4%	98%
10	29:53	335 ± 26	183 ± 7	102	190	4%	100%
19.4 (1 hour track race)	60:00	323 ± 9	183 ± 6	82	189	3%	100%
5 (track)	14:47	338 ± 16	183 ± 10	82	193	6%	100%
15	45:42	328 ± 14	178 ± 10	59	188	6%	97%
10	30:12	331 ± 16	183 ± 7	92	191	4%	100%

The average heart rate and average running speed for each kilometre in all races are shown in figure 1. The average heart rate and the average running speed in the non-competitive field test are also shown in figure 1 (open circles). The relationship between heart rate and running speed determined in the field test was r = 0.99 ($P < 0.001$). There was no significant relationship between heart rate and running speed (r = 0.02) during the races ($P > 0.05$). Figure 1 shows that at 338 $m.min^{-1}$ the heart rate varied from 148 - 193 $beats.min^{-1}$ and that the greatest difference in running speed (278 - 403 $m.min^{-1}$) occurred when the heart rate was 162 $beats.min^{-1}$.

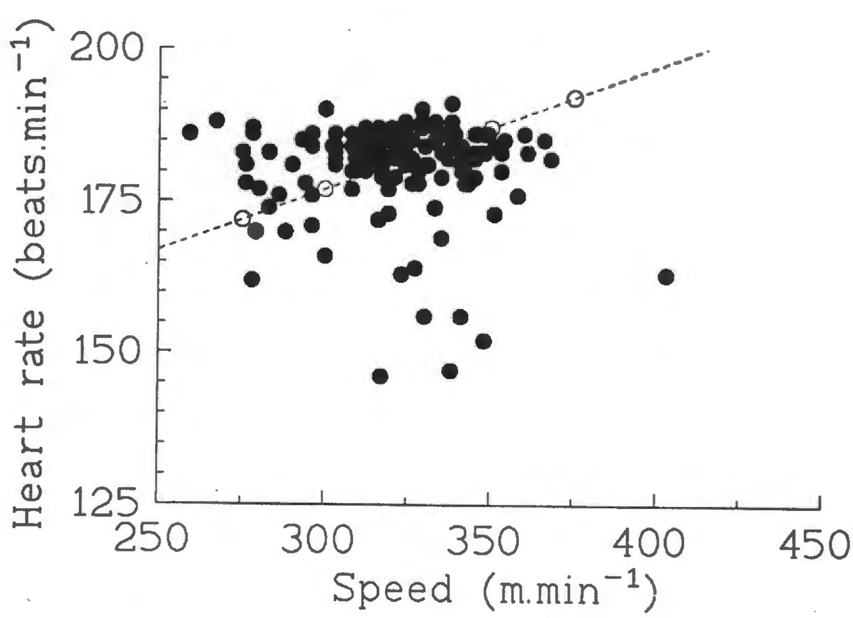


Figure1: Average heart rate plotted against average running speed for each kilometre during the 9 races (5 – 28 km). The dashed line represents the relationship between heart rate and running speed derived during the non-competitive field test. (0 - heart rate during non-competitive field test).

The environmental conditions during the race are shown in Table 3.

Table 3: Temperature and humidity data during the races.

Date	Race Distance (km)	Starting Time	Finishing Time	Temperature (°C)	Humidity (%)
26/10/1996	15	6:30 a.m.	7:20 a.m.	17.0 – 18.0	84 – 72
02/11/1996	15	6:30 a.m.	7:20 a.m.	18.0	72
10/11/1996	28	6:30 a.m.	8:04 a.m.	15.0 – 18.0	78 – 58
30/11/1996	21.1	6:00 a.m.	7:12 a.m.	15.1 18.0	88 – 64
11/12/1996	10	6:00 p.m.	6:30 p.m.	16.4 – 16.2	92 – 90
19/01/1997	19.4 (1 hour track race)	7:10 p.m.	8.10 p.m.	18.5 – 18.4	70
25/01/1997	5 (track)	6:00 p.m.	6.15 p.m.	20.0	82
15/02/1997	15	6:30 a.m.	7.18 a.m.	20.0 – 22.2	62 – 52
23/03/1997	10	7:00 a.m.	7:30 a.m.	19.0 – 20.2	82 – 72

Discussion

The main finding of this study was that there was no relationship between the heart rate and running speed during the races (r = 0.02). In contrast, the relationship between heart rate and running speed during a non-competitive field test was linear (r = 0.99). These data showed that a competitive race causes the heart to respond differently to increasing exercising intensity compared to a non-competitive situation.

Although temperature may affect the heart rate/running speed relationship, this is unlikely to have explained the results in this study. The study of Potteiger and Weber (1994) showed that heart rate may be affected by about 10 beats.min^{-1} when the temperature increased from 15° to 30°C. However, in this study the temperatures ranged from 15.1°C and 22.2°C and therefore cannot explain the differences in heart rate (Table 3).

Diurnal changes in heart rate also need to be excluded as a reason for the differences in heart rate. In this study the field test was conducted at 5:48 p.m., and all the races with the exception of the 5 km track race and 1 hour track race were held in the morning. Although the resting heart rate may have increased by about 5 beats.min^{-1} from morning to evening (Reilly and Brooks, 1982), this difference is overcome once the exercise intensity increases. Further, in the races run at similar speeds in the morning and evening 338 ± 16 vs 335 ± 26 m.min^{-1} (a.m. vs p.m.) and 320 ± 22 vs 323 ± 9 m.min^{-1} (a.m.

vs p.m.) the average heart rates were very similar (Table 2), suggesting that diurnal changes were not significant in the study.

The subjects' state of training and running performance remained fairly constant throughout the study (Table 2) and therefore cannot explain the difference in heart rate at different running speeds in the races.

The most likely explanation for the lack of relationship between heart rate and running speed is the increased sympathetic arousal associated with competition. This, however, is speculation and will have to be investigated in a study designed to identify mechanisms.

In all the races the subjects' average heart rate was very close (97 - 100%) to the maximum heart rate determined in the laboratory (Table 2). It may be argued that the maximum heart rate measured during the treadmill test in the laboratory was not a true maximum. But, the subject was clearly exhausted at the end of the test and could not have continued any longer and therefore his heart rate was maximum for the laboratory conditions. A study on cyclists (Palmer et al., 1994) also showed that maximum heart rates determined in the laboratory were lower than the heart rate determined in a competitive cycling situation. These data therefore suggest that errors may be incurred if data generated in an exercise test in the laboratory are extrapolated directly to a race situation.

In conclusion, this study shows that in a race situation there is no relationship between heart rate and running speed, suggesting that heart rate monitors should be used with caution as a gauge of exercise intensity during competition.

Chapter 5

Heart rate during running in three different environmental temperatures (15°, 25°, 35°C) during a 30 minute steady state run and the 8 km time trial.

5.1 Introduction

The main finding of the previous study was that there was no relationship ($r = 0.02$) between heart rate and running speed during the races. Although environmental conditions under which races took place (Table 3, Chapter 4) varied, this could not account for the lack of relationship between heart rate and running speed during races. This relationship was not measured during training and therefore no conclusion can be reached on the effect of temperature on heart rate. Also the core temperature of the subject was not measured during the study and therefore no conclusions can be drawn between heart rate, running speed and core temperature. Therefore the purpose of this study was to evaluate the effect of cool (15°C) moderate (25°C) and high (35°C) ambient temperature on heart rate and running performance. The relative humidity were controlled at 60 % and wind speed at 15 $km.h^{-1}$ respectively.

5.2 Materials and Methods

5.2 1 Subjects

Twelve highly trained (Table 1) distance runners were recruited for the study. None of the subjects had specifically adapted for heat or cold prior to the study. All testing procedures were explained to the subjects before commencing the experiment. Thereafter, subjects signed informed consent forms. The study was approved by the Ethics and Research Committee of the University of Cape Town Medical School.

5.2.3 Study design

Laboratory test

On a first visit to the laboratory, subjects were weighed on a precision balance (Seca, Germany) for body mass (to the nearest 0.1kg) and stature was measured with a stadiometer (Seca, Germany) (to the nearest 0.1mm). An anthropometric assessment, as explained in the previous studies, (Chapter 4) was conducted on each subject.

Maximal oxygen consumption and peak treadmill running speed

The subjects underwent an incremental test to exhaustion to determine maximal oxygen consumption (VO_2max) and peak treadmill running speed (PTRS). This was preceded by a 10 minute treadmill familiarisation at a steady speed of 12 $km.h^{-1}$. The tests were conducted inside the environmental chamber (Scientific Technology Corporation, South Africa) under thermoneutral conditions where the temperature was 21°C, relative humidity 60% and the wind speed was 15 $km.h^{-1}$.

During the incremental treadmill running test, the subjects wore a nose-clip and breathed through a mouthpiece connected to an Oxycon Alpha automated gas analyser (Jaeger, Netherlands). Before each test the analyser was calibrated with a Hans Rudolph 3 litre syringe (Vacuumed, Ventura, USA) and standard gases.

Treadmill speed was increased progressively as explained in the previous studies (Chapters 3 and 4) and peak treadmill running speed (PTRS) was determined. PTRS, VO_2max and maximum heart rate were defined as the highest mean values recorded during the test.

Steady state trials

After 3 days of VO_2max test, subjects then visited the laboratory on 3 separate occasions for a 30 minute submaximal test at 70% peak treadmill running speed and a 8 km time trial. The tests were done at either 15°C, 25°C or 35°C. Subjects were allowed to drink up to 300 ml of water during the 30 minutes.

Temperature and humidity

The ambient temperatures (15°C, 25°C and 35°C) were randomly set for the tests. Humidity (60%) and wind speed (15 $km.h^{-1}$) which were kept constant throughout the experiments. Both the submaximal test and running performance were randomised such that they were completed in not less than 3 days and not more than 14 days apart. All the trials were performed in the environmental chamber (Scientific Technology Corporation, South Africa).

8 km Time trials

After 30 minutes of submaximal run, subjects had a 5 minute rest. Then subjects had to start their 8 km running performance trial. Subjects were instructed to complete this distance as quickly as possible. They were able to regulate their running speed by adjusting the speed of the treadmill themselves. During this trial subject were not allowed to read the treadmill speed and accumulated distance. The running performance trial was terminated after the subject covered the required distance of 8 km or when the subject signalled unwillingness to carry on running as a result of fatigue.

Temperature monitoring

During the experimental trials (submaximal and maximal performance) a rectal Mon-a-therm thermistor probe (Mallinckrodt, OH, USA) was inserted into each subject's rectum to a depth of 10 cm for the measurement of rectal temperature. The rectal probe was connected to the YSI Tele-thermometer (Simpson Electric CO. OH, USA). T_{re} was recorded every 5 minutes during the experimental trials.

Heart rate monitoring and perceived exertion

During the testing heart rate was monitored and recorded at the end of each minute with a Sports Tester heart rate monitor (Polar Electro, Finland). Subjects were asked to rate their perceived exertion using the 20-point Borg scale (Borg, 1982) every 5 minutes.

5.2.4 Statistics

All data are expressed as the mean ± standard deviation. Differences between trials were determined using an analysis of variance with repeated measures. Significant main effects were analysed with Scheffe's post hoc-test. Statistical significance was accepted when $P < 0.05$. Relationships between variables were determined by using the Pearson's product moment correlation coefficient.

5.2.5 Results

The physical characteristics of the subjects (n = 12) are shown in Table 1. An * indicates that subjects did not complete the 8 km time trial in the test at 35°C.

Table 1: General characteristics of the subjects (n = 12).

Subject	Age (yrs)	Body mass (kg)	Stature (cm)	Body fat %	Body surface area (m^2)	Peak treadmill running speed ($km.h^{-1}$)	VO_2max ($mlO_2.kg.min^{-1}$)
1	25	57.2	170	8.6	1.66	23	74.7
2	22	55.2	168	9.4	1.62	22	67.4
3 *	26	56.7	167	9.2	1.63	22	67.1
4	22	63.3	178	9.7	1.79	21	68.8
5	23	65.5	169	14.0	1.75	20	59.8
6 *	19	59.0	170	9.5	1.68	20	67.7
7	28	58.8	168	7.5	1.67	22	73.5
8	26	83.6	192	15.4	2.13	21	60.0
9 *	29	65.0	172	9.8	1.77	23	68.4
10	22	55.0	159	15.7	1.55	20	61.2
11	19	76.2	174	17.0	1.95	21	58.3
12	29	74.3	176	12.8	1.90	21	59.1
Mean ± SD	24.2 ± 3.5	64.2 ± 9.3	172 ± 8	11.6 ± 3.2	1.80 ± 0.20	21 ± 1	65.5 ± 5.7

Running performance

Table 2 shows the times taken by the subjects to run the 8 km time trial on the treadmill. This trial was run 5 minutes after the 30 minute submaximal run at 70% of peak treadmill speed. Three subjects did not finish the 8 km time trial at the ambient temperature of 35°C. These subjects ran for 14.62, 18.28 and 23.95 minutes respectively before stopping the test. The average time for the remaining 9 subjects who finished the 8 km time trial was 31.16 ± 3.17 minutes at 35°C which was significantly slower than the time at 15°C (27.17 ± 1.64 minutes; $P < 0.000002$) and 25°C (27.82 ± 1.53 minutes; $P < 0.00002$).

There was no significant difference in average time for the 8 km time trial at 15°C and 25°C. Peak treadmill running speed determined in the VO_2max test was significantly correlated to performance in the 8 km time trial at 15°C ($r = -0.85$; $P < 0.05$). There was, however no relationship between peak treadmill running speed and 8 km performance at 25°C or 35°C. Also, % body fat was related to the 8 km time trial at 15°C ($r = 0.77$; $P < 0.05$), but there was no relationship between these variables at 25°C or 35°C.

The 8 km time trial times for the subjects who did not complete the trial at 35°C (n = 3) compared to the subjects who completed the 8 km time trial at 35°C (n = 9) were not different at either 15°C (26.94 ± 1.64 minutes vs 28.1 ±

1.19 minutes; finishers vs non-finishers or 25°C, 27.63 ± 1.70 vs 28.00 ± 1.52 minutes; finishers vs non-finishers.

Table 2: Time (minutes) to complete 8 km time trial on the treadmill at 15°C, 25°C and 35°C.

subject	15°C	25°C	35°C
1	24.07	25.23	27.57
2	25.25	26.72	30.25
3 *	28.88	28.10	(23.95)
4	28.15	30.27	35.78
5	27.00	26.67	27.47
6 *	28.67	29.47	(14.62)
7	24.90	25.75	27.45
8	28.40	29.22	32.47
9 *	26.72	27.72	(18.28)
10	28.88	29.00	34.83
11	27.68	27.68	32.47
12	27.43	27.98	32.12
mean	n = 12 27.17 ± 1.64	n = 12 27.82 ± 1.53	n = 9 31.16 ± 3.17

* did not finish the 8 km time trial

Heart rates

There were significant main effects for the trial X temperature ($P < 0.0003$) and duration ($P = 0.0000001$) and there was a significant interaction of trial X duration ($P = 0.0000001$). There was no cardiovascular drift when subjects ran for 30 minutes at 70% PTRS at 15°C. But when the subjects ran at 25°C there was a significant increase in heart rate from 20 minutes onwards (Table 3, Figure 1). During the submaximal trial at 35°C there was a significant increase in heart rate at 15 minutes (Table 3, Figure 1). The heart rate increased by an average of 19 beats.min^{-1} (12%) after 20 minutes in this trial.

When the trials (15°C, 25°C and 35°C) were analysed as a main effect there were significant differences between average heart rates at 15°C vs 35°C ($P = 0.003$) and 25°C and 35°C ($P = 0.02$).

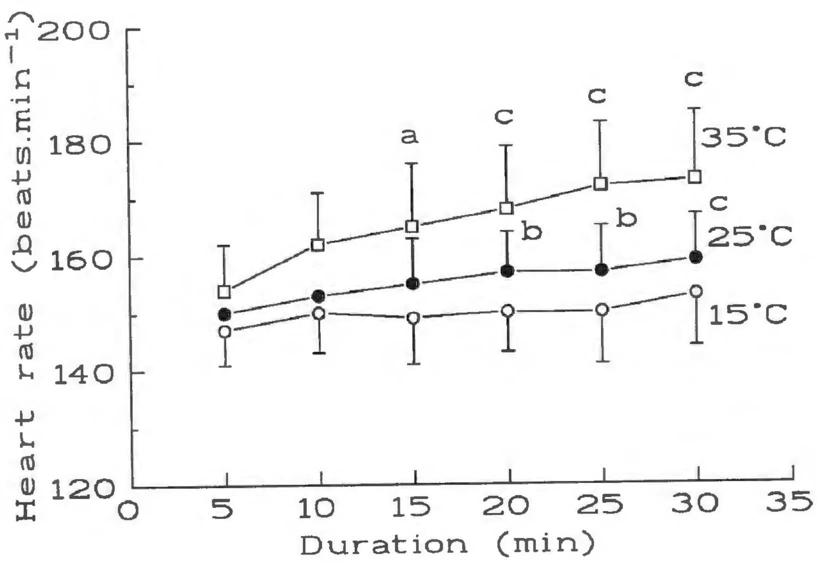
Table 3: Heart rate (beats.min^{-1}) for all subjects (finishers and non-finishers) (n = 12) at different temperatures during a 30 minute steady state run.

Temperature °C	HR at rest (beats.min^{-1})	HR at 5 min (beats.min^{-1})	HR at 10 min (beats.min^{-1})	HR at 15 min (beats.min^{-1})	HR at 20 min (beats.min^{-1})	HR at 25 min (beats.min^{-1})	HR at 30 min (beats.min^{-1})
15	63 ± 9	147 ± 6	150 ± 7	149 ± 8	150 ± 7	150 ± 9	153 ± 9
25	60 ± 12	150 ± 8	153 ± 8	155 ± 8	157 ± 7[b]	157± 8[b]	159 ± 8[c]
35	70 ± 22	154 ± 8	162 ± 9	165 ± 11[a]	168 ± 11[c]	172 ± 11[c]	173 ± 12[c]

a P = 0.001 (vs HR at 5 minutes)

b P = 0.003 (vs HR at 5 minutes)

c P = 0.000001 (vs HR at 5 minutes)



a	P = 0.001	(vs HR at 5 minutes)
b	P = 0.003	(vs HR at 5 minutes)
c	P = 0.000001	(vs HR at 5 minutes)

Figure 1. Heart rate (beats.min^{-1}) for all subjects (finishers and non-finishers) (n = 12) at different temperatures during a 30 minute steady state run.

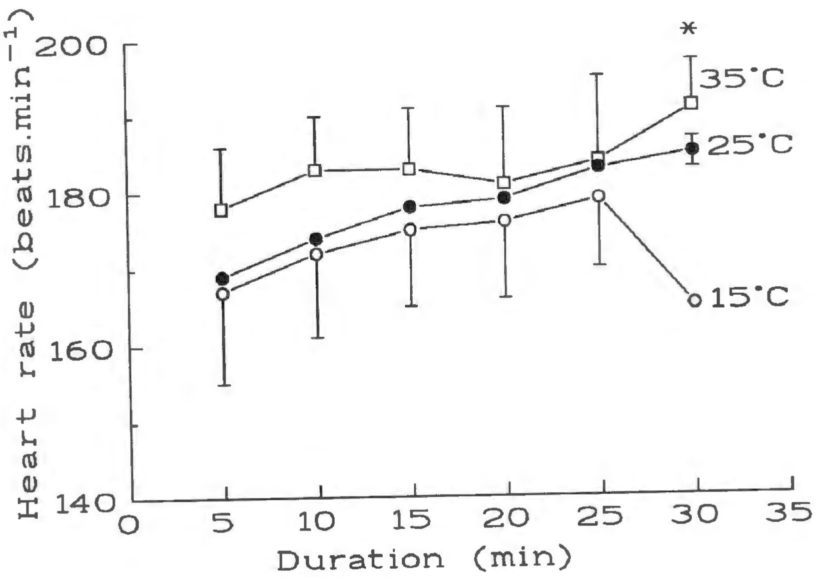
There was no cardiovascular drift in the 8 km time trial as there was no significant increase in heart rate over time during the 8 km trial at either 15, 25 or 35°C. However, the average heart rate was consistently higher at 35°C compared to at 15°C (P = 0.0004) and 25°C compared to at 15°C (P = 0.003) (Table 4, Figure 2).

Table 4: Heart rate (beats.min^{-1}) for all subjects (finishers and non-finishers) (n = 12) at different temperatures during an 8 km time trial.

Temperature	HR at 5 min	HR at 10 min	HR at 15 min	HR at 20 min	HR at 25 min	HR at 30 min
15°C	n = 12 167 ± 12	n = 12 172 ± 11	n = 12 175 ± 10	n = 12 176 ± 10	n = 12 179 ± 9	n = 1 165 ± 0
25°C *	n = 12 169 ± 12	n = 12 174 ± 12	n = 12 178 ± 9	n = 12 179 ± 9	n = 12 183 ± 8	n = 4 185 ± 2
35°C **	n = 12 178 ± 8	n = 12 183 ± 7	n = 11 183 ± 8	n = 10 181 ± 10	n = 9 184 ± 11	n = 6 191 ± 6

* P = 0.0004 15°C vs 35°C

* P = 0.003 15°C vs 25°C



At 30 minutes n = 1 (15°C), n = 4 (25°C) and n = 6 (35°C).

*	P = 0.0004	15°C vs 35°C
*	P = 0.003	15°C vs 25°C

Figure 2. Heart rate (beats.min^{-1}) for all subjects (finishers and non-finishers) (n = 12) at different temperatures during an 8 km time trial.

The subjects were divided into those subjects that completed all the trials (finishers; n = 9) and subjects who did not complete the 8 km time trial (non-finishers; n = 3) for analysis. The heart rates of the finishers and non-finishers in the 30 minute submaximal run are shown in Table 5. There were no significant differences in heart rates between subjects who finished all the trials and the subjects who did not complete the 8 km time trial at 35°C.

Table 5: Heart rate (beats.min^{-1}) for finishers (n = 9) and non-finishers (n = 3) at different temperatures during a 30 minute steady state run.

Temperature	HR at rest	HR at 5 min	HR at 10 min	HR at 15 min	HR at 20 min	HR at 25 min	HR at 30 min
15°C (finishers)	65 ± 10	147 ± 7	150 ± 9	149 ± 9	151 ± 8	151 ± 10	154 ± 10
15°C (non-finishers)	60 ± 6	148 ± 2	149 ± 2	146 ± 2	146 ± 3	148 ± 6	151 ± 2
25°C (finishers)	61 ± 13	151 ± 8	155 ± 8	156 ± 9	158 ± 8	159 ± 9	161 ± 9
25°C (non-finishers)	55 ± 1	145 ± 5	147 ± 6	151 ± 3	152 ± 4	151 ± 3	154 ± 6
35°C (finishers)	64 ± 12	155 ± 11	163 ± 10	166 ± 12	170 ± 12	173 ± 11	176 ± 12
35°C (non-finishers)	84 ± 40	152 ± 9	157 ± 8	161 ± 8	164 ± 8	166 ± 9	169 ± 11

Table 6 shows the heart rates of the finishers and non-finishers during the 8 km time trial at 15 and 25°C and up to 10 minutes in the time trial at 35°C. Although there was a tendency for the heart rates to be lower at each time interval and at each temperature in the non-finishers compared to the finishers, there were no significant differences.

Table 6: Heart rate (beats.min^{-1}) for finishers (n = 9) and non-finishers (n = 3) at different temperatures during an 8 km time trial.

Temperature	HR at 5 min	HR at 10 min	HR at 15 min	HR at 20 min	HR at 25 min	HR at 30 min
15°C (finishers)	171 ± 11	176 ± 9	177 ± 8	180 ± 8	183 ± 6	-
15°C (non-finishers)	153 ± 2	158 ± 3	166 ± 11	166 ± 10	168 ± 9	165 ± 0
25°C (finishers)	175 ± 7	180 ± 6	181 ± 8	182 ± 8	186 ± 7	186 ± 2
25°C (non-finishers)	153 ± 9	158 ± 9	168 ± 8	170 ± 4	173 ± 2	183 ± 0
35°C (finishers)	179 ± 7	184 ± 7	184 ± 8	182 ± 11	184 ± 11	191 ± 6
35°C (non-finishers)	172 ± 10	178 ± 9	-	-	-	-

Rectal temperature

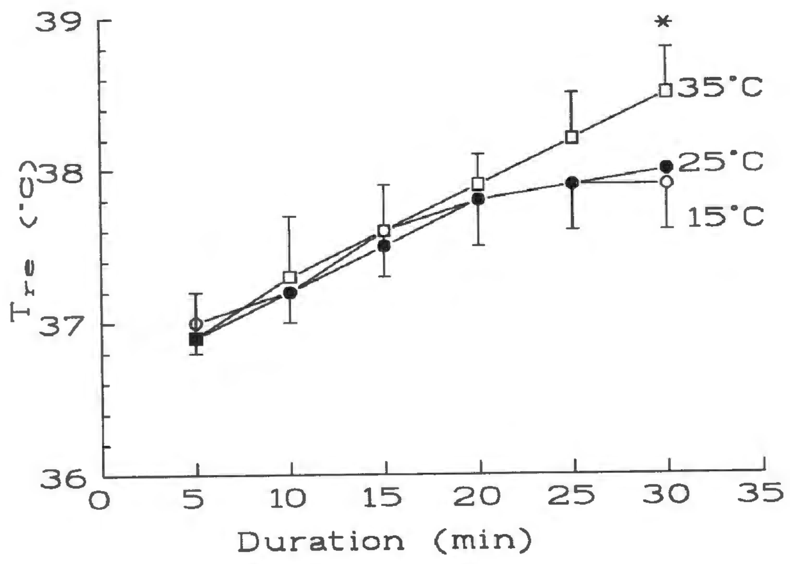
During the 30 minute submaximal run the T_{re} increased as the duration of the trial increased ($P < 0.0000001$). However, the magnitude of the this increase in T_{re} was the same for each trial (Table 7, Figure 3).

Table 7: T_{re} (°C) for all subjects (finishers and non-finishers) (n = 12) at different temperatures during a 30 minutes steady state run.

*

Temperature	T_{re} at rest	T_{re} at 5 min	T_{re} at 10 min	T_{re} at 15 min	T_{re} at 20 min	T_{re} at 25 min	T_{re} at 30 min
15°C	36.8 ± 0.2	37.0 ± 0.2	37.2 ± 0.3	37.6 ± 0.3	37.8 ± 0.3	37.9 ± 0.3	37.9 ± 0.3
25°C	36.8 ± 0.2	36.9 ± 0.2	37.2 ± 0.2	37.5 ± 0.3	37.8 ± 0.3	37.9 ± 0.3	38.0 ± 0.3
35°C	36.7 ± 0.3	36.9 ± 0.3	37.3 ± 0.4	37.6 ± 0.3	37.9 ± 0.2	38.2 ± 0.3	38.5 ± 0.3

* temperature increased in all groups ($P < 0.0000001$)



* temperature increased in all groups (P < 0.0000001)

Figure 3. T_{re} (°C) for all subjects (finishers and non-finishers) (n = 12) at different temperatures during a 30 minutes steady state run.

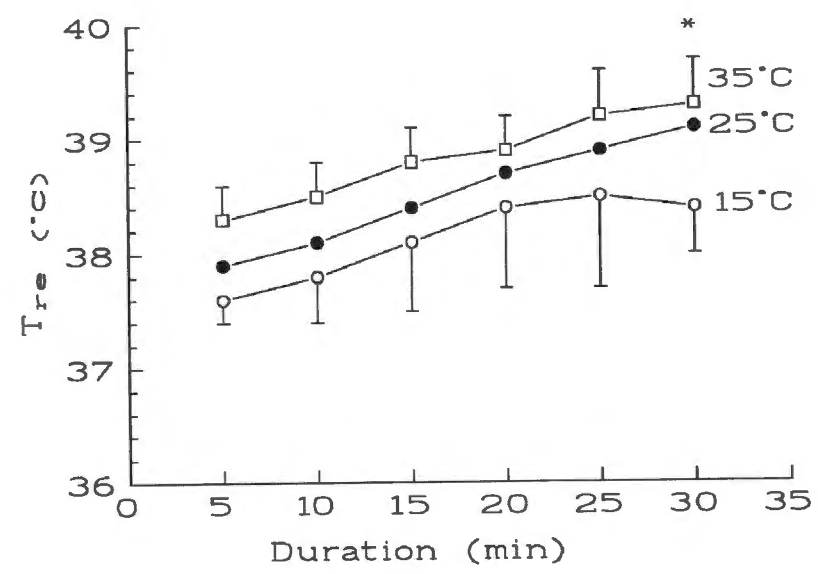
T_{re} increased significantly in all groups during the 8 km time trial (P < 0.0000001) (Δ T_{re} 15°C = 0.8°C; Δ T_{re} 25°C = 1.2°C; Δ T_{re} 35°C = 1.0°C). There was a significant effect of ambient temperature on the final T_{re}. The average T_{re} was lower at 15°C (38.1 ± 0.4) compared to T_{re} at 35°C (38.8 ± 0.4) (P < 0.006). There was no difference between T_{re} at 25°C (38.5 ± 0.4) compared to T_{re} at 35°C (38.8 ± 0.4).

Body surface area was not related to T_{re} in either the 30 minute submaximal run or the 8 km time trial at any temperature.

Table 8: T_{re} (°C) for all subjects (finishers and non-finishers) (n = 12) at different temperatures during an 8 km time trial.

Temperature	T_{re} at 5 min	T_{re} at 10 min	T_{re} at 15 min	T_{re} at 20 min	T_{re} at 25 min	T_{re} at 30 min
15°C *	n = 12 37.6 ± 0.3	n = 12 37.8 ± 0.4	n = 12 38.1 ± 0.6	n = 12 38.4 ± 0.7	n = 11 38.5 ± 0.8	n = 3 38.4 ± 0.4
25°C	n = 12 37.9 ± 0.2	n = 12 38.1 ± 0.3	n = 12 38.4 ± 0.4	n = 12 38.7 ± 0.5	n = 12 38.9 ± 0.6	n = 5 39.1 ± 0.5
35°C	n = 12 38.3 ± 0.3	n = 12 38.5 ± 0.3	n = 11 38.8 ± 0.3	n = 10 38.9 ± 0.3	n = 9 39.2 ± 0.4	n = 5 39.3 ± 0.4

* $P < 0.006$ average T_{re} at 15°C vs 35°C.



At 30 minutes n = 3 (15°C), n = 5 (25°C) and n = 5 (35°C).

* $P < 0.006$ average T_{re} at 15°C vs 35°C.

Figure 4. T_{re} (°C) for all subjects (finishers and non-finishers) (n = 12) at different temperatures during an 8 km time trial.

The subjects were divided into those who completed all the trials (finishers; n = 9) and subjects who did not complete the 8 km time trial (non-finishers; n = 3) for analysis. The T_{re} of the finishers and non-finishers in the 30 min submaximal run are shown in Table 9. There were no significant differences in T_{re} between the subjects who finished and the subjects who did not complete the 8 km time trial at 35°C.

Table 9: T_{re} (°C) for finishers (n = 12) and non-finishers (n = 3) at different temperatures during a 30 minutes steady state run.

Temperature	T_{re} at rest	T_{re} at 5 min	T_{re} at 10 min	T_{re} at 15 min	T_{re} at 20 min	T_{re} at 25 min	T_{re} at 30 min
15°C (finishers)	36.8 ± 0.3	36.9 ± 0.2	37.2 ±0.2	37.5 ± 0.3	37.7 ± 0.3	37.8 ± 0.3	37.9 ± 0.3
15°C (non-finishers)	37.0 ± 0.2	37.1 ± 0.2	37.4 ± 0.3	37.7 ± 0.3	37.9 ± 0.2	38.0 ± 0.2	38.0 ± 0.3
25°C (finishers)	36.8 ± 0.2	36.9 ± 0.2	37.2 ± 0.2	37.6 ± 0.3	37.8 ± 0.2	38.0 ± 0.3	38.1 ± 0.3
25°C (non-finishers)	36.8 ± 0.1	36.9 ± 0.1	37.1 ± 0.2	37.4 ± 0.2	37.6 ± 0.3	37.8 ± 0.3	37.9 ± 0.3
35°C (finishers)	36.6 ± 0.2	36.9 ± 0.2	37.2 ± 0.4	37.6 ± 0.3	37.9 ± 0.3	38.2 ± 0.2	38.4 ± 0.3
35°C (non-finishers)	36.8 ± 0.3	37.1 ± 0.3	37.5 ± 0.3	37.9 ± 0.1	38.0 ± 0.1	38.4 ± 0.3	36.3 ± 4.5

Table 10 shows the T_{re} of the finishers and non-finishers during the 8 km time trial at 15°C and 25°C and up to 20 minutes in the trial at 35°C. There were no significant differences in T_{re} between finishers and non-finishers at any stage of the run or at any temperature.

Table 10: T_{re} (°C) for finishers (n = 12) and non-finishers (n = 3) at different temperatures during an 8 km time trial.

Temperature	T_{re} at 5 min	T_{re} at 10 min	T_{re} at 15 min	T_{re} at 20 min	T_{re} at 25 min	T_{re} at 30 min
15°C (finishers)	37.5 ± 0.3	37.8 ± 0.4	38.1 ± 0.6	38.4 ± 0.8	38.6 ± 0.8	38.7 ± 0
15°C (non-finishers)	37.7 ± 0.3	37.9 ± 0.3	38.1 ± 0.3	38.3 ± 0.5	38.2 ± 0.4	38.3 ± 0.5
25°C (finishers)	38.1 ± 0.3	37.9 ± 0.2	38.2 ± 0.3	38.8 ± 0.4	39.1 ± 0.5	39.2 ± 0.7
25°C (non-finishers)	37.8 ± 0.3	38.0 ± 0.2	38.1 ± 0.2	38.2 ± 0.3	38.4 ± 0.3	38.9 ± 0.1
35°C (finishers)	38.2 ± 0.3	38.5 ± 0.3	38.8 ± 0.3	39.0 ± 0.3	39.2 ± 0.4	39.3 ± 0.4
35°C (non-finishers)	38.5 ± 0.4	38.6 ± 0.5	38.9 ± 0.3	38.8 ± 0	-	-

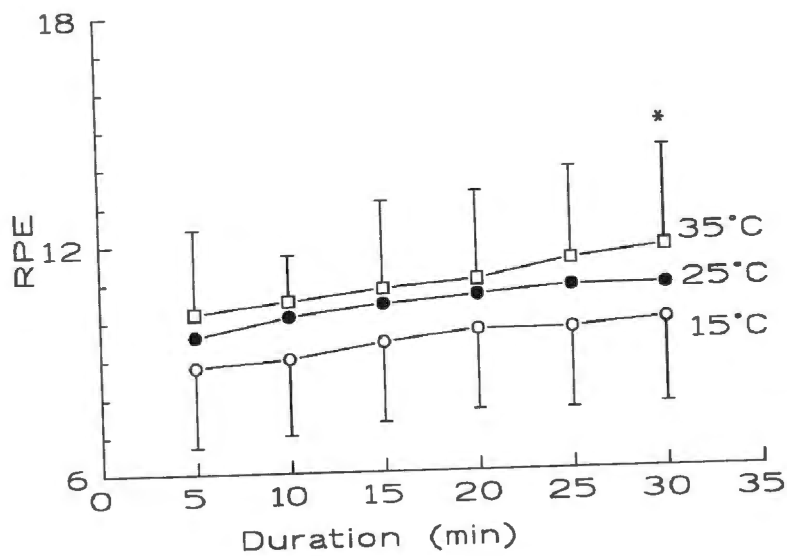
Rating of perceived exertion

RPE increased significantly in all trials during the submaximal run ($P < 0.0000001$), (Table 11, Figure 6). Although the average RPE tended to increase as the ambient temperature increased, this was not significant ($P = 0.90$). There was no interaction between ambient temperature and time.

Table 11: RPE for all subjects (finishers and non-finishers) (n = 12) at different temperatures during a 30 minutes steady state run.

Temperature	RPE at rest	RPE at 5 min	RPE at 10 min	RPE at 15 min	RPE at 20 min	RPE at 25 min
15°C	6.6 ± 1.4	8.8 ± 2.1	9.0 ± 2.0	9.4 ± 2.1	9.7 ± 2.1	9.7 ± 2.1
25°C	6.5 ± 0.9	9.6 ± 1.8	10.1 ± 0.6	10.4 ± 1.6	10.6 ± 1.6	10.8 ± 1.7
35°C	6.3 ± 0.5	10.2 ± 2.2	10.5 ± 1.2	10.8 ± 2.3	11.0 ± 2.3	11.5 ± 2.4

* $P < 0.0000001$ increase in RPE over time.



* P < 0.0000001 increase in RPE over time.

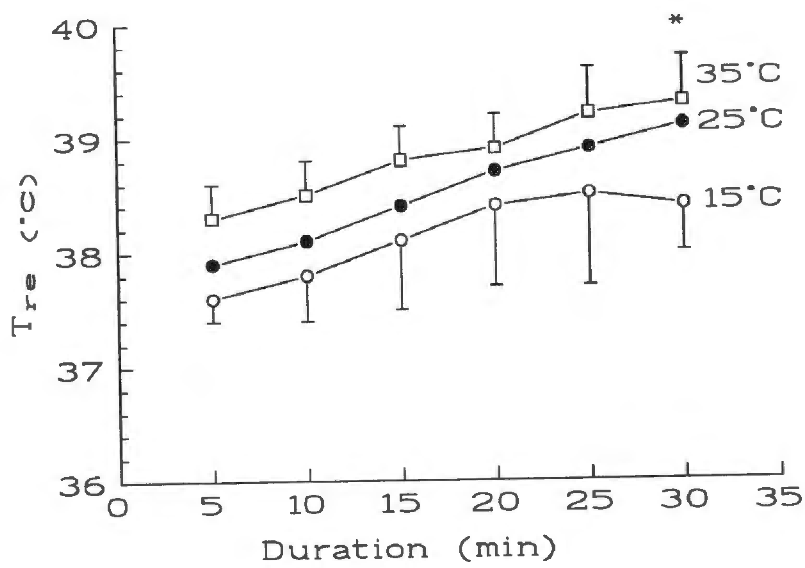
Figure 5. RPE for all subjects (finishers and non-finishers) (n = 12) at different temperatures during a 30 minutes steady state run.

During the 8 km time trial RPE increased significantly over time at all 3 ambient temperatures ($P < 0.0000001$) (Table 12, Figure 6). There was no significant difference in RPE between the tests at different temperatures ($P = 0.90$), nor was there a significant interaction between trials and duration of the test.

Table 12: RPE for all subjects (finishers and non-finishers) (n = 12) at different temperatures during an 8 km time trial.

Temperature	RPE at 5 min	RPE at 10 min	RPE at 15 min	RPE at 20 min	RPE 25 min	RPE at 30 min *
15°C	n = 12 11.4 ± 2.3	n = 12 12.6 ± 2.8	n = 12 13.0 ± 2.6	n = 11 13.9 ± 2.4	n = 10 14.7 ± 3.1	n = 2 13.5 ± 2.1
25°C	n = 12 11.6 ± 2.8	n = 12 12.7 ± 1.6	n = 12 12.9 ± 1.6	n = 11 13.9 ± 2.4	n = 8 14.9 ± 2.4	-
35°C	n = 12 12.3 ± 2.3	n = 12 13.7 ± 2.3	n = 11 14.8 ± 2.1	n = 10 15.1 ± 2.1	n = 9 15.3 ± 2.1	n = 3 16.3 ± 1.2

* $P < 0.0000001$ increase in RPE over time.



At 30 minutes n = 3 (15°C), n = 5 (25°C) and n = 5 (35°C).

* P < 0.0000001 increase in RPE over time.

Figure 6. RPE for all subjects (finishers and non-finishers) (n = 12) at different temperatures during an 8 km time trial.

The subjects were separated into those subjects that completed all the trials (finishers; n = 9) and subjects who did not finish the 8 km time trial (non-finishers n; n = 3). There were no significant differences in RPE between these subjects who finished all the trials and those who did not complete the 8 km time trial at 35°C trial. The RPE of finishers and non-finishers in the 8 km time trial is shown in Table 14. RPE was not related to T_{re} at either 15°C, 25°C or 35°C in submaximal or 8 km time trial.

Table 13: RPE for finishers (n = 12) and non-finishers (n = 3) at different temperatures during a 30 minutes steady state run.

Temperature	RPE at rest	RPE at 5 min	RPE at 10 min	RPE at 15 min	RPE at 20 min	RPE at 25 min
15°C (finishers) 15°C (non-finishers)	6.3 ± 0.5 6.3 ± 0.6	8.6 ± 2.1 9.7 ± 2.3	8.7 ± 2.1 10.0 ± 1.7	9.2 ± 2.3 10.0 ± 1.7	9.3 ± 2.2 10.7 ± 1.5	9.3 ± 2.2 10.7 ± 1.5
25°C (finishers) 25°C (non-finishers)	6.6 ± 1.0 6.3 ± 0.6	9.4 ± 1.9 10.0 ± 1.7	10.1 ± 1.6 10.0 ± 1.7	10.4 ± 1.7 10.3 ± 1.2	10.7 ± 1.7 10.3 ± 1.2	10.8 ± 1.8 10.7 ± 1.5
35°C (finishers) 35°C (non-finishers)	6.3 ± 0.5 6.0 ± 0	10.2 ± 2.1 10.0 ± 2.6	10.7 ± 1.6 10.0 ± 2.6	10.7 ± 2.3 11.0 ± 2.6	10.9 ± 2.5 11.3 ± 2.1	11.3 ± 2.6 12.0 ± 1.7

<u>Table 14:</u> RPE for finishers (n = 12) and non-finishers (n = 3) at different temperatures during an 8 km time trial.

Temperature	RPE at 5 min	RPE at 10 min	RPE at 15 min	RPE at 20 min	RPE at 25 min	RPE at 30 min
15°C (finishers)	11.9 ± 2.6	12.8 ± 3.2	13.1 ± 3.0	14.1 ± 2.9	15.0 ± 3.5	12.0 ± 0
15°C (non-finishers)	10.0 ± 1.7	12.0 ± 1.0	12.7 ± 0.6	13.3 ± 0.6	13.5 ± 0.7	15.0 ± 0
25°C (finishers)	11.4 ± 2.7	12.8 ± 1.4	13.1 ± 1.7	14.1 ± 2.3	15.3 ± 2.7	-
25°C (non-finishers)	12.0 ± 3.6	12.3 ± 2.5	12.3 ± 1.2	13.5 ± 0.7	13.5 ± 0.7	-
35°C (finishers)	12.1 ± 2.7	13.9 ± 2.4	15.0 ± 2.3	15.3 ± 2.0	15.6 ± 2.1	16.3 ± 1.2
35°C (non-finishers)	12.7 ± 2.5	13.3 ± 2.1	14.0 ± 1.7	14.5 ± 3.5	13.0 ± 0	-

5.2.6 Discussion

The subjects in this study were well trained (Table 1) with no particular heat acclimatisation. Most of the subjects (75%) completed the exercise task (8 km time trial) in the heat (35°C), albeit at a slower running speed. The subjects who did not complete the 8 km time trial were not different from the subjects who did complete the trial, at least for those parameters measured in this study (heart rate, T_{re} and RPE). Based on this, a likely explanation for the "non-finishers" is that they were less motivated to complete the trial in the hot conditions compared to the finishers.

The subjects who completed the 8 km time trial at 35°C were slower at 15°C and 25°C ($P = 0.000002$ and $P = 0.00002$) respectively. In the study of Galloway and Maughan (1997), subjects cycled to exhaustion at 70% VO_2max at various ambient temperatures and their exercise time was 81 minutes at 4°C, 94 minutes at 11°C, 81 minutes at 21°C and 52 minutes at 31°C. Clearly, cycle performance was impaired during the warm conditions (31°C) in this study. The extent of the impairment in cycle performance in warm weather conditions in this study was probably overestimated as they used a performance test with a poor test reliability (Jekendrup et al., 1996).

An increased core temperature may have been associated with a reduced performance in the 8 km time trial at 35°C. The T_{re} at 30 minutes at 35°C during the 8 km time trial was 39.4 ± 0.4°C (Table 8)which was similar to the T_{re} in runners immediately after a standard marathon (39.9 ± 0.6) run in moderate conditions (Noakes et al., 1991). Adams et al. (1975) suggested that the core temperature of marathon runners rarely rises much above 40°C. Whether the reduced 8 km time trial performance at 35°C is causally related to an increased T_{re} (39.4 ± 0.4°C) will have to be determined in the future study. It is also unlikely that dehydration caused an impaired performance in the 8 km time trial at 35°C as in all the running trials subjects were allowed to drink up to 300 ml of water *ad lib*. This amount of fluid would have reduced the risk of dehydration and minimised the rise in core temperature (Millard-Stafford, 1992; Montain et al., 1996).

Individuals with a smaller body mass and a higher ratio of surface area to body mass are likely to perform better in hot or humid conditions since their attributes are favourable for heat dissipation (Dennis and Noakes, 1999). Dennis and Noakes (1999) calculated that at 35°C and 60% relative humidity an athlete weighing 45 kg could maintain thermal balance by running a 2 h 23 minute marathon at 19. $km.h^{-1}$ while a 75 kg athlete could only run a marathon time of 3 h 28 minutes at 12.2 km. h^{-1}. Based on this calculation it is logical to assume a relationship between body surface area and T_{re} at the end of the 30 minute submaximal run or the 8 km time trial. In this study, the body surface area was not related to T_{re} in either the 30 minute submaximal run or the 8 km time trial at any temperature. That this relationship did not occur, can perhaps be explained by the fact that the range of body surface area of the subjects in the trial was only 1.55 to 2.13 m^2 and the coefficient of variation of T_{re} at the end of the 30 minute submaximal and 8 km time trial

(35°C) were 0.8% and 1.0% respectively. To test the theory of a relationship between body surface area and T_{re}, a future study will need to recruit subjects with a wide range of body surface areas.

Heart rate is influenced by exercise intensity and the ambient temperatures (Houmard et al., 1990). Other studies have examined the effects of different ambient temperatures on heart rate and exercise performance (Potteiger and Weber, 1994 (30°C); Booth et al., 1997 (31.6°C); Galloway and Maughan, 1997, 30.5°C). The data from these studies and the present study confirm that increasing ambient temperature above 30°C may increase heart rate during exercise and reduce exercise performance.

There was no cardiovascular drift when subjects ran for 30 minutes at 70% PTRS at 15°C in contrast to the trials at 25°C and 35°C where there was a cardiovascular drift (Table 3). Therefore, this shows that athletes may need to take special consideration when training at an ambient temperature of about 25°C and above if they use heart rate as a marker of exercise intensity.

Other studies, have also noted lower heart rates during submaximal exercise in cold air (Sink et al., 1989; Therminarias et al., 1989; Doubt 1991). This phenomenon is caused by peripheral vasoconstriction which puts less demand of blood flow from the working muscles.

At higher exercise intensities heart rate was more sensitive to higher ambient temperatures. This was shown during the 8 km time trial at 35°C where average heart rate was higher compared to the average heart rate at 15°C and 25°C. (Table 4). This may have been caused by increased activation of the sympathetic nerves which would increase the heart rate (Ekblom et al., 1973). In addition, under conditions of thermal stress the cardiac output has to be divided between oxygen delivery to the exercising muscles and the skin for heat dissipation (Nadel et al., 1979).

RPE increased significantly in all trials during the submaximal runs and also during the 8 km time trial. The increase in RPE was similar at all 3 temperatures (15°C, 25°C and 35°C) and RPE was not related to T_{re} at either 15°C, 25°C or 35°C in the 30 minute submaximal run and the 8 km time trial. This shows that there was a dissociation between RPE and heart rate at higher temperature. Although RPE values showed increasing trends with the increase in duration at all temperatures, these data indicate that RPE cannot be used an accurate indicator of exercise intensity (as measured by heart rate) as also shown by Potteiger and Weber (1994).

In conclusion, the range of temperatures, (25°C - 35°C) caused significant physiological effects on heart rate at submaximal intensity and at a higher exercise intensity, the heart rate increases more at 35°C than at 15°C and 25°C. Further studies should investigate the critical temperature between 25°C and 35°C above which the heart rate/running speed is changed. This study shows that exercising at 70% of peak treadmill running speed at 15°C elicit no cardiovascular drift at least for 30 minutes. Therefore in cooler conditions heart rate can be used as a more accurate measure of running intensity than in warmer conditions (25°C and above).

Chapter 6

Main findings of the studies and recommendations for future research

The aim of this thesis was to examine the heart rate response of long distance runners during different phases of training and competition. In addition, the thesis examined the effects of environmental and body temperature on heart rate during submaximal and maximal running. The following is a summary of the main findings of the studies, followed by the recommendations for future studies.

The aim of the first study was to quantify training intensity of long distance runners during different types of training and racing using heart rate as a measure of exercise intensity. The main finding was that there was no convincing evidence that competitive runners who train at higher intensities have a better running performance. The other important finding was that there was a poor relationship between %VO_2max and %HRmax. Lastly, heart rate during races was consistently higher compared to heart rate either during LSD training or HIT training. This raised the question of whether this was indeed a true finding or perhaps an artefact as a result of a "competition-induced" elevated heart rate.

The second study monitored the heart rates of an elite long distance runner over varying distances to determine the extent the heart rate/running speed relationship may vary under competitive conditions. The study found no relationship between heart rate and running speed during competition, in contrast to a linear relationship between these variables under non-competitive conditions.

The third and the last study of this thesis examined the effect of ambient temperature on heart rate during submaximal and maximal running. This factor was difficult to control during racing and training in the earlier studies. The main finding from this study was that exercising at 70% of peak treadmill running speed at 15°C elicits no cardiovascular drift, at least for 30 minutes. However, during the same exercise test at 25°C and 35°C, there was a significant increase in heart rate. During the high intensity test the average heart rate was higher at 35°C compared to the heart rate at 15°C and 25°C. This led to the conclusion that in cooler conditions heart rate can be used as an accurate measure of running intensity, however it should be used with caution in warmer conditions (25°C and above).

In summary, this thesis has undoubtedly highlighted the objective use of heart rate monitors in quantifying intensities of training (submaximal) and racing (performance trial) at different temperatures. However, further investigations are needed to fully understand the heart rate responses during exercise so that heart rate monitors can be used more accurately to monitor exercise intensity under a variety of conditions.

Seemingly, an obstacle to the simplification of data collected with heart rate monitors is the controlling of all factors (chapter 2) that affect heart rate and surely this will yield better interpretation of heart rate data. In general the effect of these factors on the heart rate/running speed need to be further investigated.

Future research in this field should include studies on the following topics:

1. Prediction of heart rate while running in warm conditions.

2. Prediction of heart rate during competition from a submaximal field test conducted under non-competitive conditions.

3. Further investigation is necessary to determine the effect of prolonged exercise (larger than 30 minutes) on heart rate in cool and warm conditions.

4. Investigation on the relationship between heart rate and running speed when the athlete is heat acclimatised.

The results from these studies will collectively improve the understanding of heart rate response during exercise which will allow heart rate monitors to be used to a greater potential during training and racing. With better interpretation of heart rate data, the athletes who use heart rate monitors during racing and competition will be at an advantage when competing against athletes who do not use heart rate monitors.

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APPENDIX A - TRAINING QUESTIONNAIRE

Please **print** and or make **"X"** where applicable.

PERSONAL DETAILS

Name:..

Postal address:..

....

....

....

Phone number: (Home) ....(Work) ....

Date of Birth: ....Age: ....(years)

What is your occupation? ....

HEALTH STATUS

When last was your medical check up? ☐ 6 months ago

☐ > than 6 months

Family history (blood relative) of heart attack? ☐ yes

☐ no

If yes, how old was he/she? ....(years)

Are you on medication? ☐ yes

☐ no

If yes, mention the medication and the reason.

....

TRAINING DETAILS

When did you start running competitively? .... (year)

Did you take part in any other sports before running? ☐ yes

☐ no

If yes, mention ....

DATA FOR THE LAST SIX MONTHS

Do you keep a training logbook? ☐ yes

☐ no

Do you train under a coach? ☐ yes

☐ no

How many times do you train a day? ☐ once

☐ twice

☐ more

How many days do you train per week? ....(days)

On average, how long are your weekly training sessions? ☐ < 30 min

☐ 31 - 60 min

☐ > than 60 min

At what pace do you run in your weekly training sessions? ☐ < 3:30 min/km

☐ 4:00-4:30 min/km

☐ > 4:30 min/km

On average, how long are your slow distance runs (LSD)? ☐ < 1:30 hours

☐ 1:30 - 2 hours

☐ > 2 hours

On average, at what pace is your LSD run(s)? ☐ < 4 min/km

☐ 4 - 4:30 min/km

☐ 4:30 - 5 min/km

☐ > 5 min/km

What distance do you run each week ? ☐ < 60 km

☐ 61 - 80 km

☐ more than 81 km

Do you do interval training? ☐ yes

☐ no

If yes, how many sessions do per week?.................

Do you do hill training? ☐ yes

☐ no

Do you do strength training? ☐ yes

☐ no

What is you best time(s) this year in the following race(s)? 10 km............

21.1 km........

Are you peaking for any race at the moment? ☐ yes

☐ no

If yes, when and what distance is the race?

..........................(date).................... (km)

Have you ever consulted a sports psychologist as part of your training?

☐ yes

☐ no

Have you ever consulted a sports scientist (exercise physiologist) as part of your training?

☐ yes

☐ no

What is your running highlight to date?..

What is your personal running ambition?...

APPENDIX B - VO_2MAX TEST

NAME: ....

DATE: ....

$VO_{2\,MAX}$ TEST @ 1% elevation

Time (min)	Treadmill Speed (km/h)	Heart rate (beats.min^{-1})	Respiratory Exchange Ratio (RER)	Rate of Perceived Exertion (RPE)

VO_2max:........................(mlO_2.kg.min^{-1})

APPENDIX E - ENVIRONMENTAL CHAMBER

NAME:.. DATE: ....

Ambient temperature 15°C 25°C 35°C

Wind Speed: 15 km/h Relative humidity: 60%

Body weight before:..............kg Body weight after:.............kg

Water ingested:..............ml

Time (min)	Treadmill speed	T_{re} (°C)	Heart rate (beats.min^{-1})	RPE
0				
1				
2				
3				
4				
5				
6				
7				
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