

Research article

## Discrepancy between training, competition and laboratory measures of maximum heart rate in NCAA division 2 distance runners

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### Abstract

A percentage of either measured or predicted maximum heart rate is commonly used to prescribe and measure exercise intensity. However, maximum heart rate in athletes may be greater during competition or training than during laboratory exercise testing. Thus, the aim of the present investigation was to determine if endurance-trained runners train and compete at or above laboratory measures of 'maximum' heart rate. Maximum heart rates were measured utilising a treadmill graded exercise test (GXT) in a laboratory setting using 10 female and 10 male National Collegiate Athletic Association (NCAA) division 2 cross-country and distance event track athletes. Maximum training and competition heart rates were measured during a high-intensity interval training day (TR HR) and during competition (COMP HR) at an NCAA meet. TR HR ( $207 \pm 5.0$  b·min<sup>-1</sup>; means  $\pm$  SEM) and COMP HR ( $206 \pm 4$  b·min<sup>-1</sup>) were significantly ( $p < 0.05$ ) higher than maximum heart rates obtained during the GXT ( $194 \pm 2$  b·min<sup>-1</sup>). The heart rate at the ventilatory threshold measured in the laboratory occurred at  $83.3 \pm 2.5\%$  of the heart rate at VO<sub>2</sub> max with no differences between the men and women. However, the heart rate at the ventilatory threshold measured in the laboratory was only 77% of the maximal COMP HR or TR HR. In order to optimize training-induced adaptation, training intensity for NCAA division 2 distance event runners should not be based on laboratory assessment of maximum heart rate, but instead on maximum heart rate obtained either during training or during competition.

**Key words:** Competition, heart rate, laboratory, performance, running, training.

### Introduction

Successful performance in aerobic distance running is dependant on the athlete's ability to cover a fixed distance in the shortest time possible. To attain this objective, distance runners must train hard, yet intelligently, to maximize the physiological adaptations derived from training (Baechle and Earle, 2000). An effective distance runner's program must include an exercise prescription specifically developed for the individual athlete. In this regard, the regulation of exercise intensity is critical to the success of each training session and ultimately the entire training program since an exercise intensity set too low does not induce the desired physiological adaptations while an exercise intensity set too high results in fatigue and a premature end to training sessions (Potteiger and Weber, 1994).

There are many different techniques for measuring exercise intensity during endurance training, including speed, percentage of maximal oxygen consumption (VO<sub>2max</sub>), or a measurement of heart rate (Jeukendrup and Diemen, 1998). Heart rate is commonly used when prescribing aerobic exercise intensity due to the assumption of a linear relationship between heart rate and oxygen consumption (VO<sub>2</sub>) (Boulay et al., 1997). The load of the circulatory system during exercise is usually determined based on the difference between heart rate during exercise and at rest and the assumption is that 60% to 90% of maximum heart rate is equivalent to 50% to 85% of VO<sub>2max</sub> (American College of Sports Medicine, 1990; Brooke and Hamley, 1972; Hoffman et al., 2001). Furthermore, the use of telemetric heart rate monitors enables a simple, non-invasive, and convenient method for the continuous measurement of heart rate during exercise (Jeukendrup and Diemen, 1998; Lambert et al. 1998). During graded exercise testing there is frequently a divergence from the linear heart rate - workload relationship, called the heart rate deflection point (HRDP) (Bodner and Rhodes, 2000; Brooke and Hamley, 1972). Identifying the HRDP may be useful when prescribing exercise intensity. For instance, Conconi et al. (1982) observed that by monitoring the heart rate during incremental track running exercise one could estimate the lactate threshold by noting the change in the slope of the heart rate, but the accuracy of the HRDP for identifying the lactate threshold is debated (Bodner and Rhodes, 2000). With certain heart rate monitors the heart rate data from the exercise session can be conveniently transferred to a computer for post exercise evaluation and, if necessary, adjustments to the training program to achieve the appropriate exercise stimulus.

Testing of the athlete to determine individual physiological capabilities helps athletes and coaches identify areas in need of improvement and can be used in goal setting. Maximum heart rates may be predicted from many published equations such as age-predicted maximal heart rate equations in the absence of laboratory testing. Two such commonly used methods are the percentage of maximal heart rate method (American College of Sports Medicine, 1990) and the Karvonen method (Karvonen et al., 1957). However, such estimates of heart rate maximum have shortcomings when compared to laboratory testing due to factors including *inter alia*: age, pollution, medications, caffeine, smoking, certain disease conditions, mode of exercise and current fitness levels (O'Toole et al., 1998; Tsuji et al., 1996). In addition to

this, there is variability in maximal heart rate measures dependant on the test applied or even across different settings (Kunduracioglu et al., 2007). It has also been established that there can be considerable differences in heart rate between competition and training, even when the training pace and distance are the same (Lambert et al., 1998). In contrast, Zhou et al. (1997) observed that during a short course triathlon, the athletes exercised at a heart rate that corresponded to their laboratory measured ventilatory threshold, suggesting that the identification of the heart rate corresponding to the ventilatory threshold can be used to determine an effective training and competition strategy. Furthermore, the relationship between running speed and heart rate can be easily established and monitored throughout a training period, and can be effectively used to monitor the effectiveness of the training program (Selley et al., 1995). However, the use of heart rate to determine exercise intensity is frequently based on a measurement of maximum heart rate, and there may be some disagreement between the measurement of maximal heart rate when performed in a laboratory compared to training or competition setting (Jeukendrup and Diemen, 1998; Lambert et al., 1998). Thus, the aim of the present investigation was to ascertain if endurance-trained runners train and compete at or above laboratory measures of maximum heart rate when compared to a high-intensity interval training day and during competition at a National Collegiate Athletic Association (NCAA) meet.

## Methods

Ten female (mean age: 20.1 years  $\pm$  7.8) and 10 male (mean age: 19.9 years  $\pm$  6.2) NCAA division 2 cross-country and distance event track athletes were sampled from the University of Nebraska at Kearney. Prior to participation in the investigation, all volunteers gave written informed consent and underwent a screening history and physical examination and were allowed to discontinue the study at any time. This investigation was approved by the Institutional Review Board at the University of Nebraska at Kearney.

For descriptive purposes, the body composition was assessed on each subject using hydrostatic weighing. Body mass was measured to the nearest 0.01 kilogram (kg) using a digital platform scale (PS6600, Befour Inc, Saukville, WI, USA) and body height was measured to the nearest 0.25 centimetres (cm) measured using a stadiometer (216, SECA, Hanover, MD, USA). Underwater mass was recorded to the nearest 25 grams with an Autopsy Scale (Chatillion, Kew Gardens, NY, USA). Subjects performed six trials with the mean of the three highest mass trials used for subsequent calculations of body composition. Residual volume was measured in duplicate immediately before underwater weighing using an Nitrogen Gas Analyzer (Exertech, Dresbach, MN, USA) using the techniques of Wilmore et al. (1980) and the subjects exhaled to residual volume during the underwater weighing. After the determination of body density, percent body fat was calculated with the Brozek equation (Siri, 1961)

Laboratory maximum heart rates were measured utilising a treadmill (2300, Sensor Medics, Yorba Linda, California, USA) graded exercise test (GXT) during

which the subjects ran at a self reported comfortable pace ( $12.9 \text{ km}\cdot\text{h}^{-1} \pm 0.8$ ) and the grade increased by 2.5% every two minutes, a graded exercise protocol similar to that used by Costill and Fox (1969) and Maskud and Coutts (1971) for evaluating  $\text{VO}_{2\text{max}}$  in well trained runners. Ratings of Perceived Exertion (RPE) and heart rates were recorded every minute and when the subjects reached volitional exhaustion. Oxygen consumption was measured continuously throughout the graded exercise testing using a metabolic cart (2900, Sensor Medics, Yorba Linda, CA, USA) and the data for oxygen consumption was averaged over 15-second intervals. The ventilatory threshold for each subject was determined by noting the point where an abrupt increase in  $\text{VE}\cdot\text{VO}_2^{-1}$  occurred without a concomitant increase in  $\text{VE}\cdot\text{VCO}_2^{-1}$  as a measure of the lactate threshold (Haverty et al. 1988) and the heart rate measured at this point was considered to be the heart rate at ventilatory threshold. Under all conditions, heart rates were measured with heart rate monitors (610, Polar Electro, Oy, Finland) that measured heart rate continuously and averaged the data over five-second intervals. Maximum training heart rates (TR HR) were measured after warm-ups and during a 400 metre indoor (temperature of 23.9 degrees Celsius) interval training workout in which the subjects were instructed to run eight sets of 400 metres at a pace that was approximately five seconds faster per kilometre than their race pace with one minute of active recovery between each interval. The competition heart rates were measured during competition (COMP HR) at an outdoor NCAA meet (temperature of 22.8 degrees Celsius) with distances of six kilometres for the females and 10 kilometres for the males. Heart rates were measured first in the laboratory, then during competition, then in training and the subjects were prevented from observing their heart rate throughout all trials by covering the face of the wristwatch part of the heart rate monitor receiver with black tape.

Independent T-tests were used to evaluate gender differences in age, body height, body mass, body composition,  $\text{VO}_{2\text{max}}$ , and heart rate at ventilatory threshold. The maximum heart rate data from laboratory, training, and competition were analyzed via a two-factor (gender by condition) repeated measures analysis of variance (ANOVA) using commercial software (SigmaStat 3, Systat Inc, Point Richmond, CA, USA) at a significance level of 95% or  $p \leq 0.05$ . When significant interactions were observed, specific mean differences were identified using a Newman-Keuls multiple comparison test. Data are presented as means  $\pm$  SEM.

## Results

The subject descriptive data are presented in Table 1. During the laboratory testing, the heart rate at the ventilatory threshold occurred at  $83.3 \pm 2.5\%$  of  $\text{VO}_{2\text{max}}$  with no differences between the men and women. The women completed their six kilometre competition trial in 23.28 minutes ( $\pm 0.56$ ) and the men completed their 10 kilometre competition in 34.4 minutes ( $\pm 0.61$ ).

There were no gender-related differences in measured maximum heart rates) from TR HR, COMP HR or maximum heart rates obtained during the GXT (Table 2).

**Table 1.** Subject descriptive data. Data are means ( $\pm$  standard deviation).

	Men (n = 10)	Women (n = 10)
Age (years)	19.9 (.5)	20.1 (.7)
Body mass (kg)	68.3 (2.5)	56.3 (1.8) *
Body height (m)	1.79 (.02)	1.64 (.01) *
Percent body fat	11.1 (1.1)	17.5 (1.6) *
VO <sub>2max</sub> (ml·kg <sup>-1</sup> ·min <sup>-1</sup> )	78.3 (4.0)	64.3 (2.4) *
Heart rate at ventilatory threshold (beats·min <sup>-1</sup> )	159 (2)	158 (3)

\* indicates difference between males and females ( $p < 0.05$ ). The ventilatory threshold for each subject was determined by noting the point where an abrupt increase in VE·VO<sub>2</sub><sup>-1</sup> occurred without a concomitant increase in VE·CO<sub>2</sub><sup>-1</sup> as a measure of the lactate threshold (Haverty et al., 1988) and the heart rate measured at this point was considered to be the heart rate at ventilatory threshold.

However, TR HR ( $207 \pm 5$  b·min<sup>-1</sup>; presented as pooled data for all subjects) and COMP HR ( $206 \pm 4$  b·min<sup>-1</sup>) were significantly higher than maximum heart rates obtained during the GXT ( $194 \pm 2$  b·min<sup>-1</sup>) ( $p = 0.035$  and  $p = 0.021$ , respectively).

## Discussion

The primary finding of this experiment is that the maximal heart rate measured during a treadmill graded exercise test is considerably lower than the maximal heart rate obtained during either competition or during endurance interval training in distance runners. These data suggest that the exercise setting in which heart rates are measured should be considered when maximal heart rates are used for prescribing training intensity.

Similar to the present findings, Boudet et al. (2002) observed that 13 of 16 male endurance athletes attained higher maximal heart rates in a field or competition setting than in a laboratory setting, and that the intra-individual variation in maximal heart rate was  $\pm 6$  beats·min<sup>-1</sup>. Furthermore, Vergès, Flore and Favre-Juvin (2003) observed that the blood lactate concentration at a given heart rate during a field test was higher than during a laboratory setting. Therefore, a laboratory based value of maximal heart rate may not be the optimal choice for designing a training program for enhancing endurance performance.

Rather than prescribing an exercise intensity based on a percentage of maximal heart rate for optimal endurance performance adaptations, other submaximal measures of heart rate could be used. For instance, there is the Conconi method (Conconi, 1982) for identifying the HRDP which may accurately reflect the lactate threshold in some athletes. Hofmann et al. (2001) further clarified the issue of the application of heart rate for prescribing an exercise intensity for endurance athletes when they observed that in many athletes, the heart rate – workload curve can be irregular and must be evaluated carefully in order to correctly identify which measure of heart rate (e.g. percentage of maximal, or HRDP) should be used. Finally, Boudet et al. (2004) observed that during high intensity running, such as during competition or intense

training, it may be better to prescribe the running intensity based on running speed rather than heart rate. Thus, the utility of heart rate for optimizing training adaptations in athletes requires very careful consideration and evaluation of many factors and measurements, and not simply a single measurement of maximal heart rate.

The present observation that the maximal heart rate measured in a laboratory based treadmill exercise test is considerably lower than the maximal heart rate measured during training or competition is of considerable importance for athletes and coaches when designing a training program. For instance, if the laboratory based maximal heart rates from the present investigation were used for prescribing an exercise intensity of 85% of heart rate reserve (American College of Sports Medicine, 1990) the intensity would be only ~79% of the heart rate reserve based on the training or competition maximal heart rates. Similarly, if the laboratory based maximal heart rates were used to identify the ventilatory or lactate thresholds for training purposes, the athletes would be exercising at a heart rate that does not correspond to the lactate threshold during training or competition situations (Zhou et al., 1997). The considerably lower training intensity based on treadmill maximal heart rate compared to training or competition based maximal heart rate could reduce the adaptations to training and impair performance (Potteiger and Weber, 1994).

A possible reason for the athletes obtaining higher heart rate maximum levels during the high-intensity interval training day and during competition when compared to the treadmill GXT in a laboratory setting could be due to differences in temperature during test conditions (Potteiger and Weber, 1994). In this regard, temperature is always a controlling factor for chemical reactions and since heart rate is a function of chemical processes, when temperatures increase upward from 21 degrees Celsius, heart rate increases in a correlative manner by about one beat per minute. In the case of laboratory testing, the temperatures during the testing were controlled at between 23 and 25 degrees Celsius whereas during training and competition, the temperatures were not as controlled

**Table 2.** Maximal heart rates measured during a laboratory based treadmill graded exercise test, during an endurance interval running training session, and during competition in NCAA division 2 endurance runners. Data are means ( $\pm$  SEM).

	Men (n = 10)	Women (n = 10)
Treadmill maximal heart rate (b·min <sup>-1</sup> )	193 (3)	195 (2)
Interval training maximal heart rate (b·min <sup>-1</sup> )	208 (7)	206 (8) *
Competition maximal heart rate (b·min <sup>-1</sup> )	210 (7)	203 (6) *

\* indicates different from treadmill ( $p < 0.05$ ).

or measured and may be much higher than during laboratory testing resulting in increased heart rate levels. However, the temperature in the training facility (23.9 degrees Celsius) was very similar to the temperature in the laboratory, so it seems unlikely that differences in temperature would account for the differences in maximal heart rate. For the same reasons as increased temperature, a higher relative humidity will increase maximal heart rate. Further, during training and competition, runners typically lose over one kilogram of water per hour. This results in blood volume decreases and less blood is pumped by the heart per beat. Specifically, for every 1% loss in body weight due to dehydration, heart rate increases by approximately seven beats per minute (Lambert et al., 1998).

The duration of the interval training session (~30 minutes, including warm up) was considerably longer than the duration of the typical treadmill test (~12 minutes). Thus, the cardiovascular drift (Frangolias et al., 2000) associated with the longer exercise times in the training and competition situations could be partially responsible for higher maximal heart rates observed in these conditions. However, the duration of the interval training session was between the time of competition for the women (~23 minutes) and the men (~34 minutes). Furthermore, the interval training session consisted of ~5 minutes of warming up at a low intensity followed by ~25 minutes of discontinuous exercise, both of which are unlikely to contribute to cardiovascular drift in a similar way as does continuous intense running, such as during the competition (Zavorsky et al., 1998). In the present investigation, the maximal heart rates attained during the first intense interval run were not different from subsequent intervals, and the maximal heart rates during the interval training were not different from the maximal heart rates during competition in spite of the more prolonged, intense effort required during competition. When evaluating the data from competition for each athlete the heart rate would occasionally increase by ~4-5 beats·min<sup>-1</sup>, presumably due to a burst of speed to pass a competitor or due to changes in terrain, and then decrease by the same amount, thus making it difficult to identify a slow component of cardiovascular drift. Therefore, the lack of difference between the maximal heart rates in the training and competition setting suggest that the differences in maximal heart rate between the laboratory and non-laboratory settings is not due to cardiovascular drift.

It is likely that the increased maximal heart rates observed during the high-intensity interval training day and during competition are due to an increased state of arousal during the uncertain and exciting training session and competitive meet. This uncertainty and excitement during training and competition could have then result in a heightened cardiac responsiveness (Johnston et al., 1990). The sympathetic nervous system plays a strong regulatory role in the increases in heart rate that occur during exercise (Kawada et al., 2006) and engaging in competition or high intensity training are strong activators of sympathetic nervous activity (Ruttkay-Nedecky, 1980). Simulated competition has been demonstrated to elicit oxygen consumption and heart rates higher than those

observed during laboratory fitness testing (Foster et al., 1993). Also, those who participate in competitive orienteering at international levels achieve higher heart rates than those at the club or local level (Bird et al., 2003). As such, the present data suggests that the level of psychological stimulation presented in a laboratory environment does not effectively mimic the stimulation level during intense training or competition.

## Conclusion

The findings of the present investigation cast doubt on the interchangeability of laboratory and field tests. Thus, in order to optimize training-induced adaptation, training intensity for NCAA division 2 distance event runners should not be based on laboratory assessment of maximum heart rate, but instead on maximum heart rate measures obtained either during training or during competition as these conditions better represent “real-life” situations than does a laboratory setting.

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## Key points

- A percentage of maximum heart rate is commonly used to prescribe and measure exercise intensity. However, maximum heart rate may be greater during competition or training than during laboratory exercise testing.
- Heart rates during training and competition were significantly higher than maximum heart rates obtained during laboratory exercise testing.
- To optimize training-induced adaptation, training intensity for NCAA division 2 distance event runners should not be based on laboratory assessment of maximum heart rate, but instead on maximum heart rate measure obtained either during training or during competition.

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