

ABSTRACT

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The purpose of this study was to evaluate the effect of different interval training magnitudes on measures of training intensity. It was hypothesized that the session rating of perceived exertion (RPE) in relation to summated heart rate (HR) score, blood lactate (HLA), and oxygen consumption (VO_2) would increase as the deviation from the mean power output of the interval was increased. Subjects consisted of $n=6$ female and $n=6$ male well trained individuals accustomed to cycling exercise. A VO_2 max test, as well as 4 additional tests were performed on an electrically braked cycle ergometer. Blood lactate was collected during the VO_2 max test to determine the individual anaerobic threshold (IAT). A steady state (SS) ride at 90% IAT as well as 1 min intervals at 10, 25, and 50% above and below 90% IAT, all 30 min in duration, were performed. Session RPE and summated HR were calculated for each exercise session and compared to each other. Steady state conditions were observed in all individual comparisons for HR, RPE, VO_2 , and HLA for each interval session. The relationship between session RPE score and summated HR score for each exercise session was similar. This relationship indicates that these two variables are essentially the same regardless of the type of exercise intervention, providing a means of quantifying the intensity of interval exercise.

THE EFFECT OF DIFFERENT INTERVAL MAGNITUDES
ON MEASURES OF EXERCISE INTENSITY

A MANUSCRIPT STYLE THESIS PRESENTED

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THE GRADUATE FACULTY
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MASTER OF SCIENCE DEGREE

BY

JESSICA A. FLORHAUG

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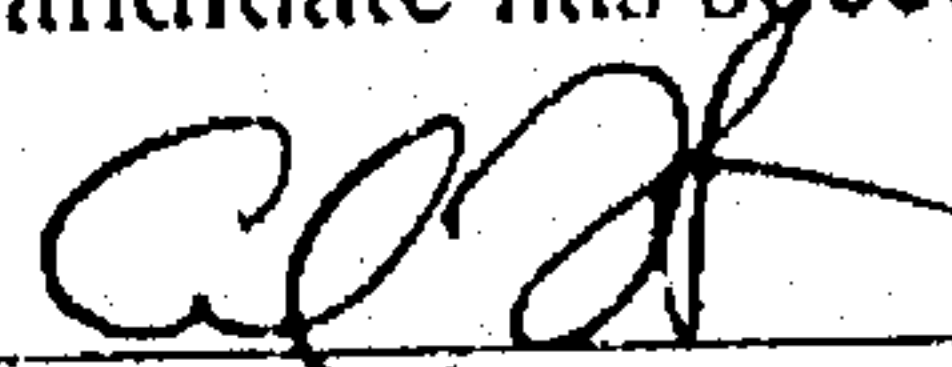
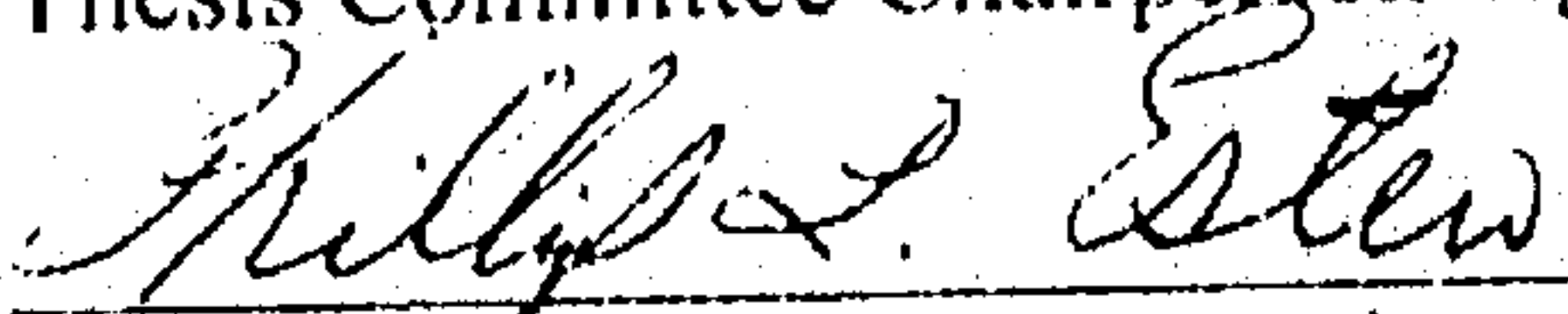
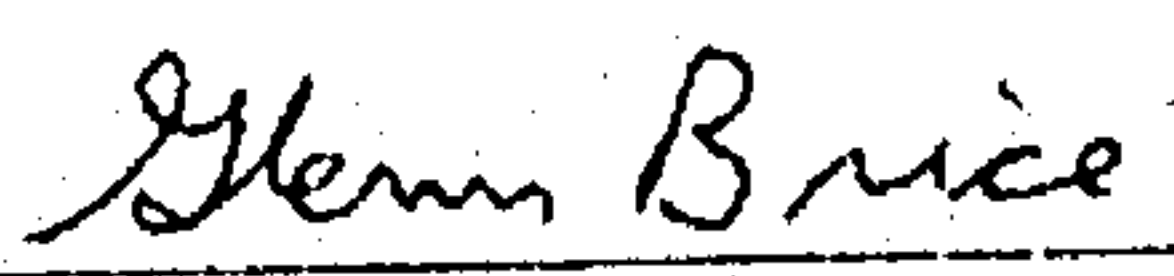
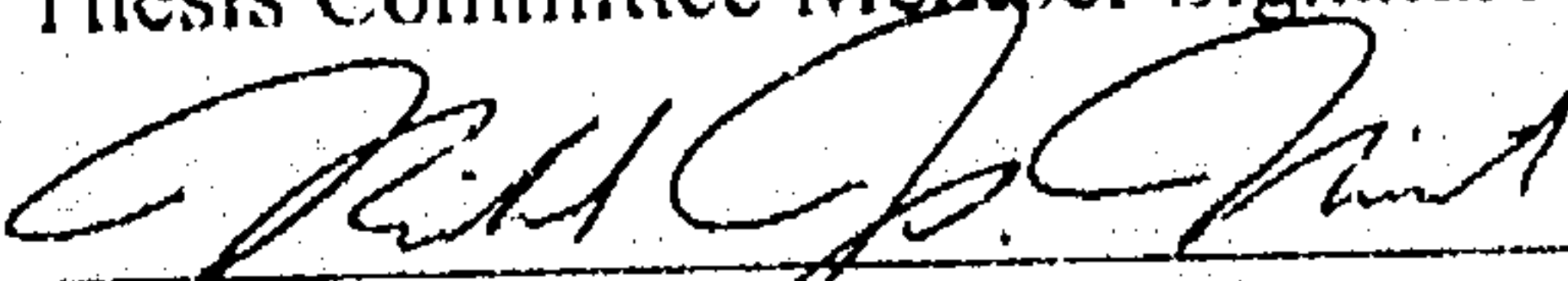
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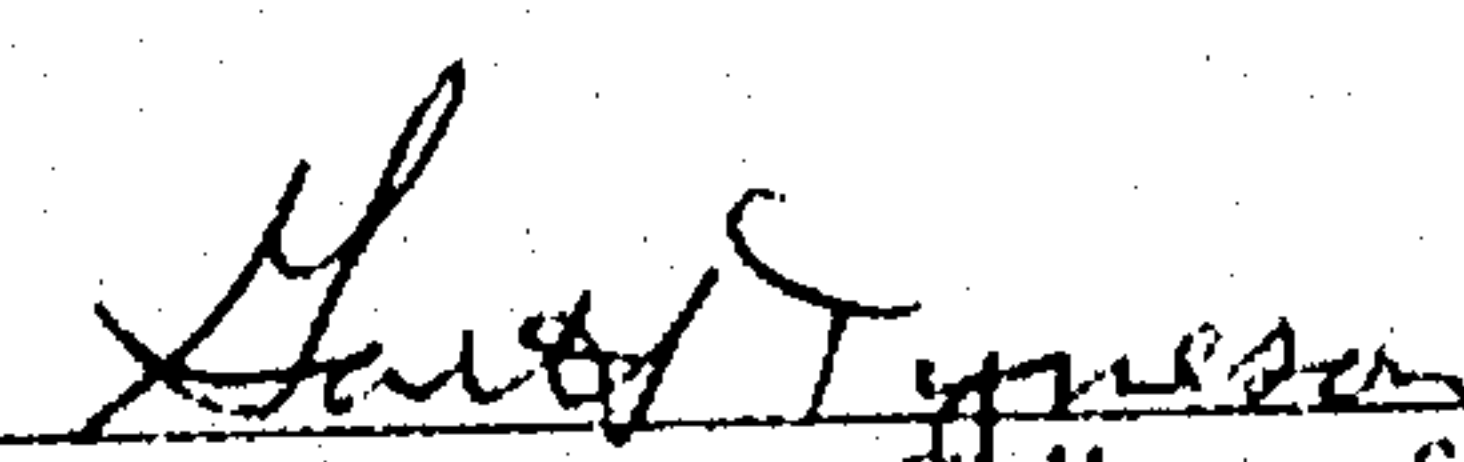
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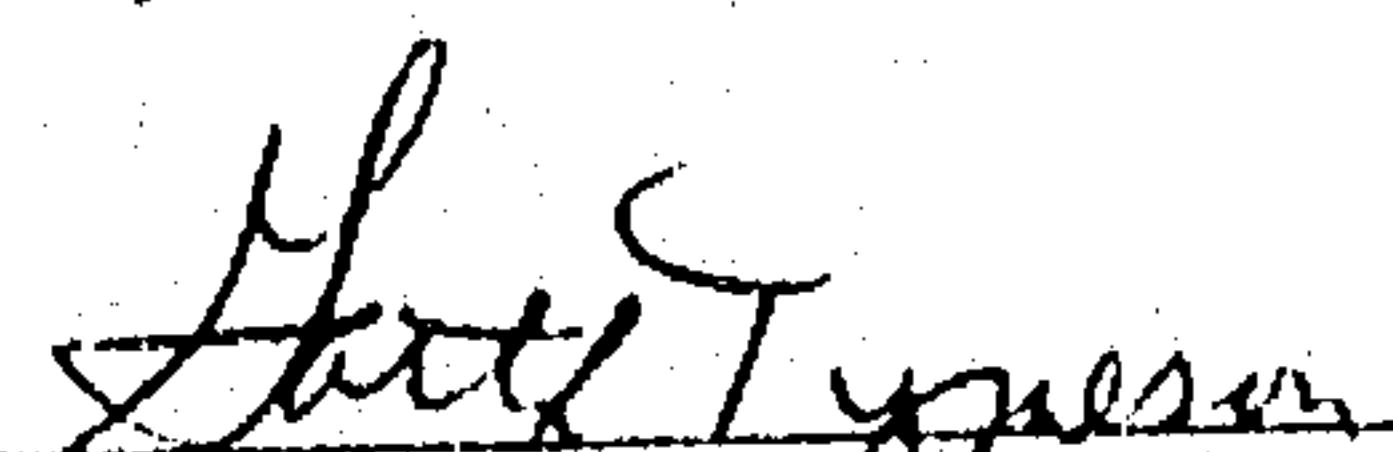
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INTRODUCTION

Background

Many studies have stressed the importance of training intensity in enhancing the effects of training on performance (9,14,16,19). These studies have shown that intensity rather than frequency or duration has the most profound effect on athletic performance. The specificity of the training program is also thought to significantly influence the training effect (10). This concept along with the importance of incorporating high intensity bouts into the training regimen has led to the development of interval training. Interval training can be used as a high intensity approach to training, the goal being to provide a method that allows a large volume of high intensity, specific training without incurring excessive fatigue.

Interval training, which allows for periods of rest between high intensity work-bouts, has been shown to be more effective than continuous, steady state (SS) training in increasing maximal oxygen uptake ($\text{VO}_2 \text{ max}$), heart rate (HR), and aerobic power. This mode of training is also effective in providing efficient utilization of glycogen and enhancing competitive performance (6,12,13,15). This would suggest that a longer, lower intensity SS work-bout can be replaced by a shorter but higher intensity interval work-bout while still achieving the same, if not greater, training effects.

Given the importance of interval training, there is a need to quantitate the effects of interval training on measures of training intensity. Foster et al. (11) expanded the

concept of the training impulse (TRIMPS) systems model developed and expanded by Banister, Calvert, Savage, and Bach (2), Fitze-Clarke, Morton, and Banister (7), and Morton, Fitze-Clarke, and Banister (17) by using a modified rating of perceived exertion (RPE) scale to replace the HR data on which the TRIMPS model depended. This provided a single number representation of the difficulty of a training session that corresponded with the physiological aspects of fatigue. However, this system of monitoring training was developed using mainly continuous SS exercise. The fact that little research has been done using this technique to monitor intermittent (interval) type exercise lead to this study.

The specific purpose of this study was to evaluate the effect of different interval training magnitudes on measures of training intensity. The intensity of each exercise session will be represented by the session RPE to determine how this single number representation of difficulty corresponds to the summated HR score for the same exercise session. It was hypothesized that the session RPE in relation to summated HR score, blood lactate level (HLA), and oxygen consumption (VO_2) would increase as the deviation from the mean power output of the interval was increased. By examining the effects of varying the magnitude of intervals on these physiological variables an athlete should be able to design a training program that effectively incorporates interval training. A related study examining the effect of increasing the duration of intervals on the same measures of training intensity was carried out in conjunction with this study.

METHODS AND PROCEDURES

Subject Selection

Twelve (6 female and 6 male) well-trained individuals accustomed to cycling exercise volunteered to participate in this study (see Table 1). All subjects participated in both parts of the study. Therefore, they underwent seven tests on a cycle ergometer over a period of approximately 20 days. All subjects had appropriate responses on a screening instrument designed to identify individuals at increased risk of cardiovascular disease (1). The specified protocol was approved by the Institutional Review Board at the University of Wisconsin La Crosse and all subjects provided written informed consent prior to participation.

Preliminary Test

Preliminary testing included anthropometric measurements (height, weight, and skinfold thickness), and a test to determine maximal oxygen consumption (VO_2 max). The VO_2 max test was conducted using an electrically braked cycle ergometer (Lode, Groningen, The Netherlands) and VO_2 was measured using open circuit spirometry (Q-Plex, Quinton Instruments, Seattle, WA). Power output was increased by 50 Watts for all males, 40 Watts for females weighing 60 kg or more, and 30 Watts for females under 60 kg every 3 min until fatigue, with VO_2 measured throughout the test. Heart rate and RPE were recorded during the last 30 s of each stage.

Table 1. Individual subject characteristics (mean \pm standard deviation)

Variable	Male (n=6)	Female (n=6)
Height (cm)	177.3 \pm 3.7	164.6 \pm 8.1
Weight (kg)	70.8 \pm 7.2	63.8 \pm 4.3
Age (years)	23.0 \pm 3.6	21.3 \pm 1.5
% Fat	11.1 \pm 4.8	20.9 \pm 2.7
LBW (kg)	61.6 \pm 6.8	50.4 \pm 2.8
Peak Watts	315 \pm 34	237 \pm 34
Peak Watts/kg	4.52 \pm 0.52	3.68 \pm 0.38
Peak VO ₂ (L/min)	3.84 \pm 0.30	2.94 \pm 0.34
Peak VO ₂ (ml/min/kg)	55 \pm 2	46 \pm 3
% Predicted VO ₂	143 \pm 14	141 \pm 10
Peak HR (bpm)	199 \pm 10	186 \pm 7
Peak VE (L/min)	140.4 \pm 14.0	108.5 \pm 15.7
IAT (Watts)	228 \pm 25	188 \pm 48
IAT (Watts/kg)	3.3 \pm 0.7	2.9 \pm 0.6
IAT HR (bpm)	174 \pm 19	160 \pm 16

IAT = Individual Anaerobic Threshold

Blood lactate samples were collected from the fingertip at rest, at the end of each 3 min stage, and at 1,3,5,7, and 10 min postexercise while the subject continued to pedal at a reduced workload. The individual anaerobic threshold (IAT) was calculated from the exercise and recovery blood lactate concentrations according to Stegmann, Kindermann, and Schnabel (20). The workloads for the subsequent interval sessions were determined using their IAT.

Experimental Protocol

Each subject performed four randomly ordered exercise bouts of 30 min in duration. A SS control ride was performed for 30 min at a power output approximating 90% of the subject's IAT. This level of training intensity has been found to be about as hard as reasonable for 30 continuous minutes (20). All subjects also underwent three 30 min interval sessions at 10, 25, and 50% above and below their SS power output (e.g. if 200W= 90% IAT, then 10%= 220W/180W, 25%= 250W/150W, 50%= 300W/100W). The power output of each interval session was alternated every min (1 min hard, 1min easy) and was performed at a 1:1 work-relief ratio. The total work done over each 30 min session was approximately the same for each protocol.

Outcome Measures

Session RPE was determined by having the subject rate the difficulty of the entire session 30 min after completion of the exercise bouts using a category ratio rating of perceived exertion scale (3). This was multiplied by the duration of the session (30 min). Following exercise, HR records were obtained from the heart rate monitor and a global summated HR score was calculated according to Edwards (5) and Foster (8). Lactate was

measured in capillary blood samples obtained from the fingertip at 0, 10, 20, and 30 min. These measures were then plotted against VO_2 response using the same time increments.

Statistical Analysis

Comparisons were made among the mean values of the session RPE and the summated HR score, VO_2 and blood lactate at 0, 10, 20, and 30 min. These physiological variables for the 10, 25, and 50% intervals were also compared to those found during the SS exercise session. A p value of < 0.0167 was accepted as statistically significant for paired t-tests with a Bonferoni correction. Specifically, it was hypothesized that the session RPE and all three physiological outcome measures would increase as the magnitude of the interval bout increases.

RESULTS

RPE, HR, VO_2 , and blood lactate values were compared to SS values throughout each 30 min exercise session (see Table 2-5 & Figures 1-4). RPE measures for all exercise sessions increased from 0-10 min then leveled off for the remainder of each 30 min session with the exception of the 30 min RPE during the 50% interval trial being significantly greater than SS exercise. VO_2 increased from 0-10 min and leveled off for all exercise sessions. HR increased from 0-10 min and drifted upward for the remainder of the 30 min session. There was a significant increase in HR from SS values at 10 min during the 25% interval session. Blood lactate values followed a similar pattern throughout the 30 min sessions with the values for the 25% intervals being significantly greater at 20 min and 50% interval values being significantly greater than SS at 10, 20 and 30 min. Blood lactate values for the 25 and 50% intervals appeared to be greater than the 10% values as well, but there was not a significant difference.

Table 2-5. Comparison of steady state values of HR, HLa, VO₂, and RPE during 10, 25, and 50% intervals (mean ± standard deviation)

Table 2. Heart Rate Response Comparison (bpm)

Session	Rest	10 min	20 min	30 min
SS	79 ± 13	155 ± 10	159 ± 11	160 ± 13
10%	79 ± 6	153 ± 10.1	158 ± 11	163 ± 9
25%	84 ± 9	159 ± 9.4*	166 ± 14	169 ± 11
50%	82 ± 10	155 ± 12.8	164 ± 11	170 ± 13

* indicates significant difference ($p < 0.0167$) for paired t-tests with a Bonferoni correction.

Table 3. Blood Lactate Comparison (mmol/L)

Session	Rest	10 min	20 min	30 min
SS	1.1 ± 0.5	2.8 ± 0.8	2.8 ± 0.8	2.5 ± 0.8
10%	1.0 ± 0.2	2.7 ± 0.9	2.7 ± 0.8	2.2 ± 0.9
25%	1.5 ± 0.6	4.4 ± 1.8	4.2 ± 1.4*	3.8 ± 1.6
50%	1.1 ± 0.5	4.8 ± 1.0*	4.9 ± 1.3*	5.6 ± 1.5*

* indicates significant difference ($p < 0.0167$) for paired t-tests with a Bonferoni correction.

Table 4. Oxygen Consumption Comparison (L/min)

Session	Rest	10 min	20 min	30 min
SS	.27 ± .03	2.32 ± .45	2.35 ± .43	2.34 ± .46
10%	.27 ± .03	2.11 ± .67	2.16 ± .61	2.16 ± .58
25%	.27 ± .03	2.45 ± .33	2.31 ± .45	2.25 ± .41
50%	.27 ± .03	2.22 ± .38	2.18 ± .37	2.28 ± .33

Table 5. Rating of Perceived Exertion Comparison

Session	Rest	10 min	20 min	30 min
SS	0.0 ± 0.0	2.8 ± 0.8	3.8 ± 1.2	3.8 ± 1.1
10%	0.0 ± 0.0	3.4 ± 1.1	3.6 ± 1.1	3.8 ± 1.2
25%	0.0 ± 0.0	3.5 ± 0.7	4.2 ± 0.9	4.2 ± 0.9
50%	0.0 ± 0.0	3.9 ± 1.0	4.4 ± 1.1	5.4 ± 1.2*

* indicates significant difference ($p < 0.0167$) for paired t-tests with a Bonferoni correction

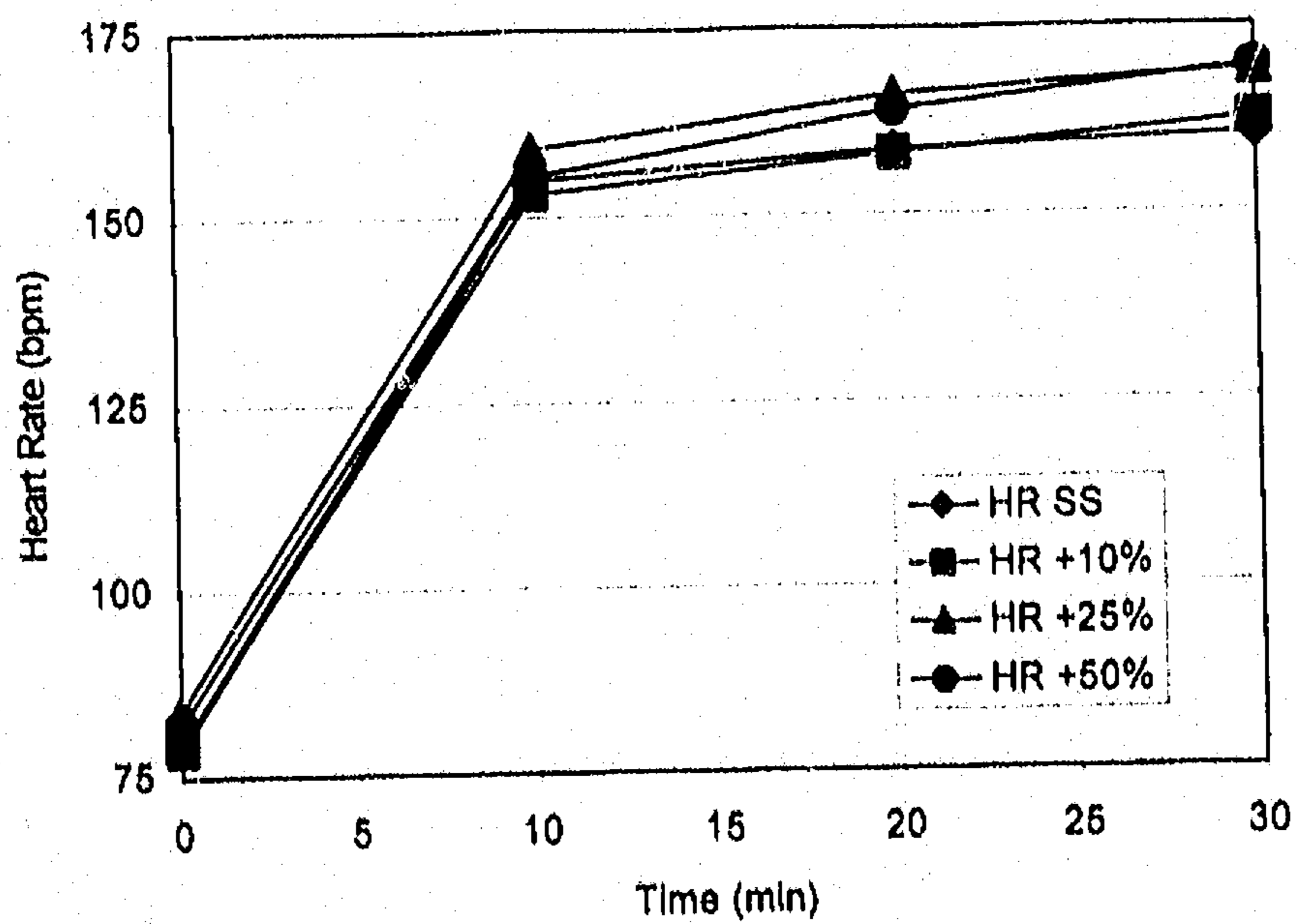


Figure 1. Comparison of SS HR values to 10, 25, and 50% intervals.

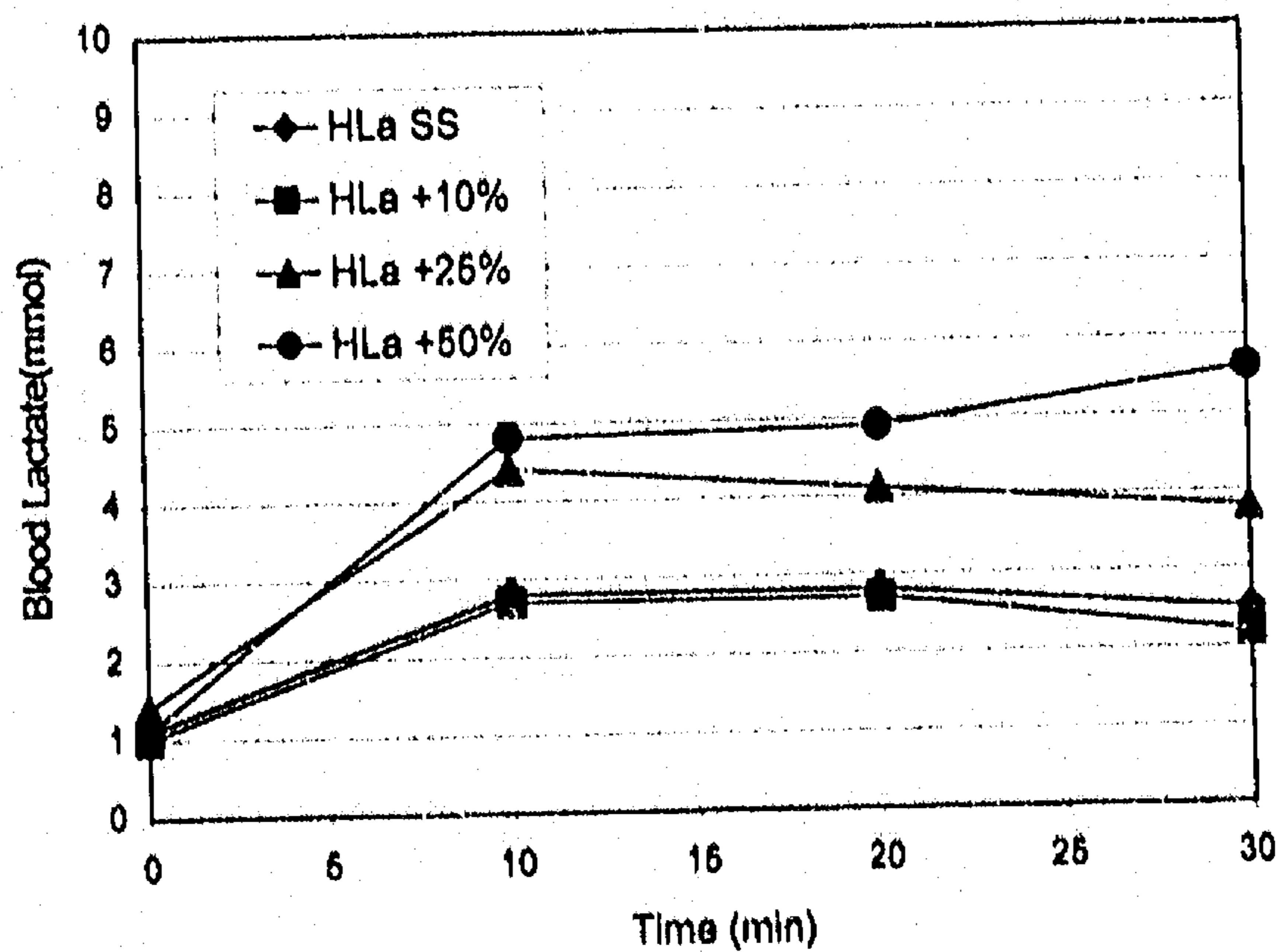


Figure 2. Comparison of SS HLa values to 10, 25, and 50% intervals.

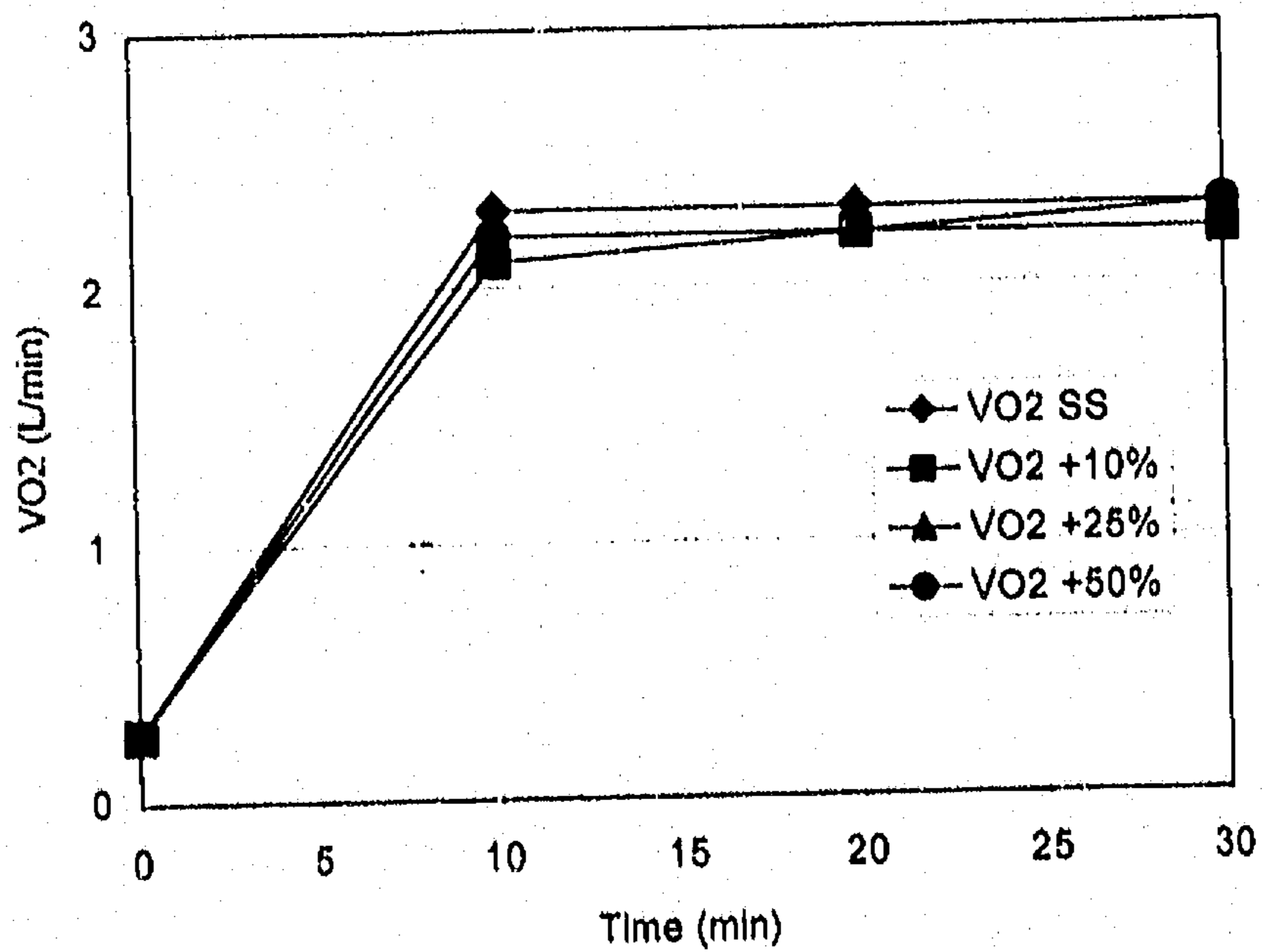


Figure 3. Comparison of SS VO₂ values to 10, 25, and 50% intervals.

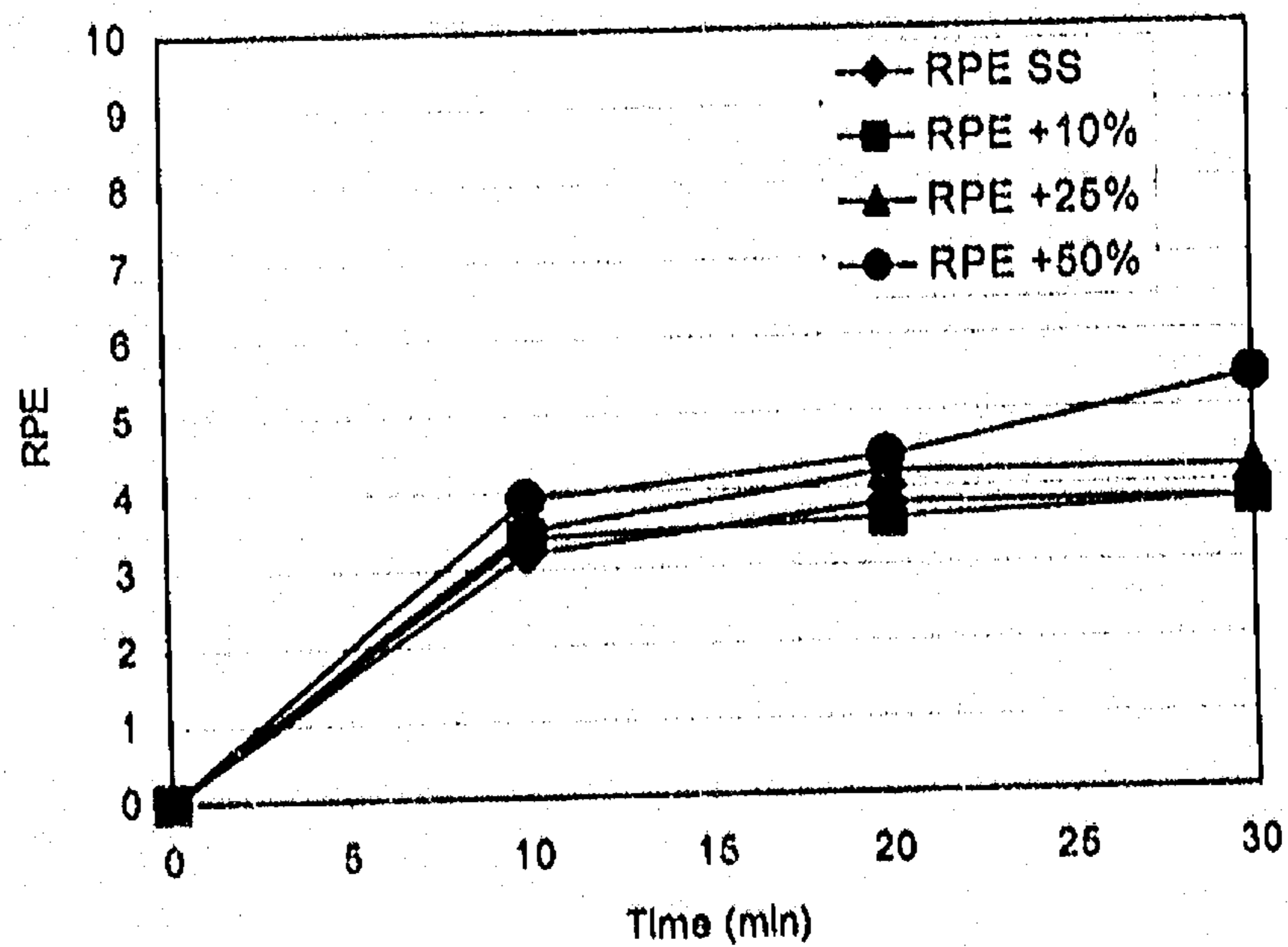


Figure 4. Comparison of SS RPE values to 10, 25, and 50% intervals.

During the transition from rest to 10 min all physiological variables (HR, VO₂, RPE, and HLa) increased significantly during each experimental condition (SS, 10%, 25%, and 50% trials). Steady state conditions were observed in all individual parallel comparisons for the entire 30 min duration. Heart rate rose from rest in all trials with a significant rise from 10-20 min for the 10 and 50% trials while the rest remained stable. VO₂ rose from rest in all trials as well, with a subsequent rise from 20-30 min in the 50% trial. RPE rose from rest in all trials with subsequent increases from 10-20 min in the SS, 25%, and 50% trials as well as from 20-30 min in the 50% trial. Blood lactate values rose significantly from rest to 10 min during SS, 10 and 25% trials and from 20-30 min during SS exercise. There were no large differences among experimental conditions in any major variable with the exception of blood lactate being significantly higher in the 50% trial. However, the increase in blood lactate across time increments of 10 to 30 min for each trial was less than 1 mmol/L, which satisfies the criteria for maximum lactate SS (21).

Session RPE ratings were compared to and plotted against the summated HR score for each exercise session (see Figures 5-8). Summated HR and session RPE values were not significantly different between SS, 10, and 25% exercise sessions. There was a significant difference between summated HR score and the session RPE for the 50% intervals (see Table 6). A plot of the regression lines shows that the relationship between session RPE and summated HR were very similar (see Figure 9). The exercise score represented by the session RPE was larger overall than summated HR but not significantly so. Individual regression lines showed approximately the same trend for

each trial (see Figure 10). We interpret this to indicate that the summated HR and exercise score are fundamentally the same regardless of the type of exercise performed.

Table 6. Summated HR scores compared to session RPE scores (mean \pm standard deviation)

Session	Summated HR	Session RPE	r
SS	110 \pm 24	130 \pm 57	.6484
10%	114 \pm 16	136 \pm 60	.7339
25%	117 \pm 18	148 \pm 54	.3046
50%	114 \pm 11	116 \pm 46*	.1741

* indicates significant difference ($p < 0.0167$) for paired t-tests with a Bonferoni correction

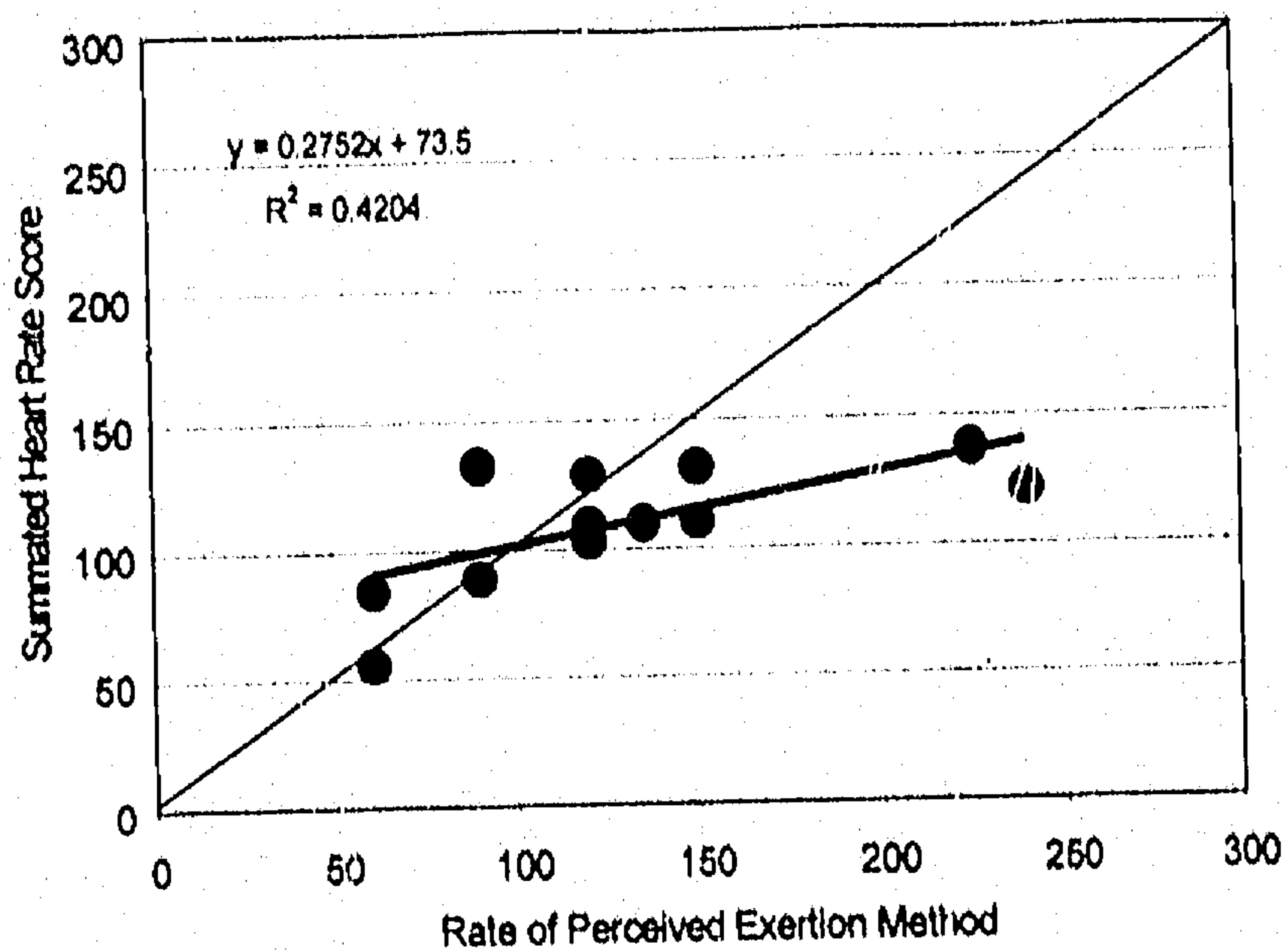


Figure 5. Summated HR score vs. RPE during SS exercise.

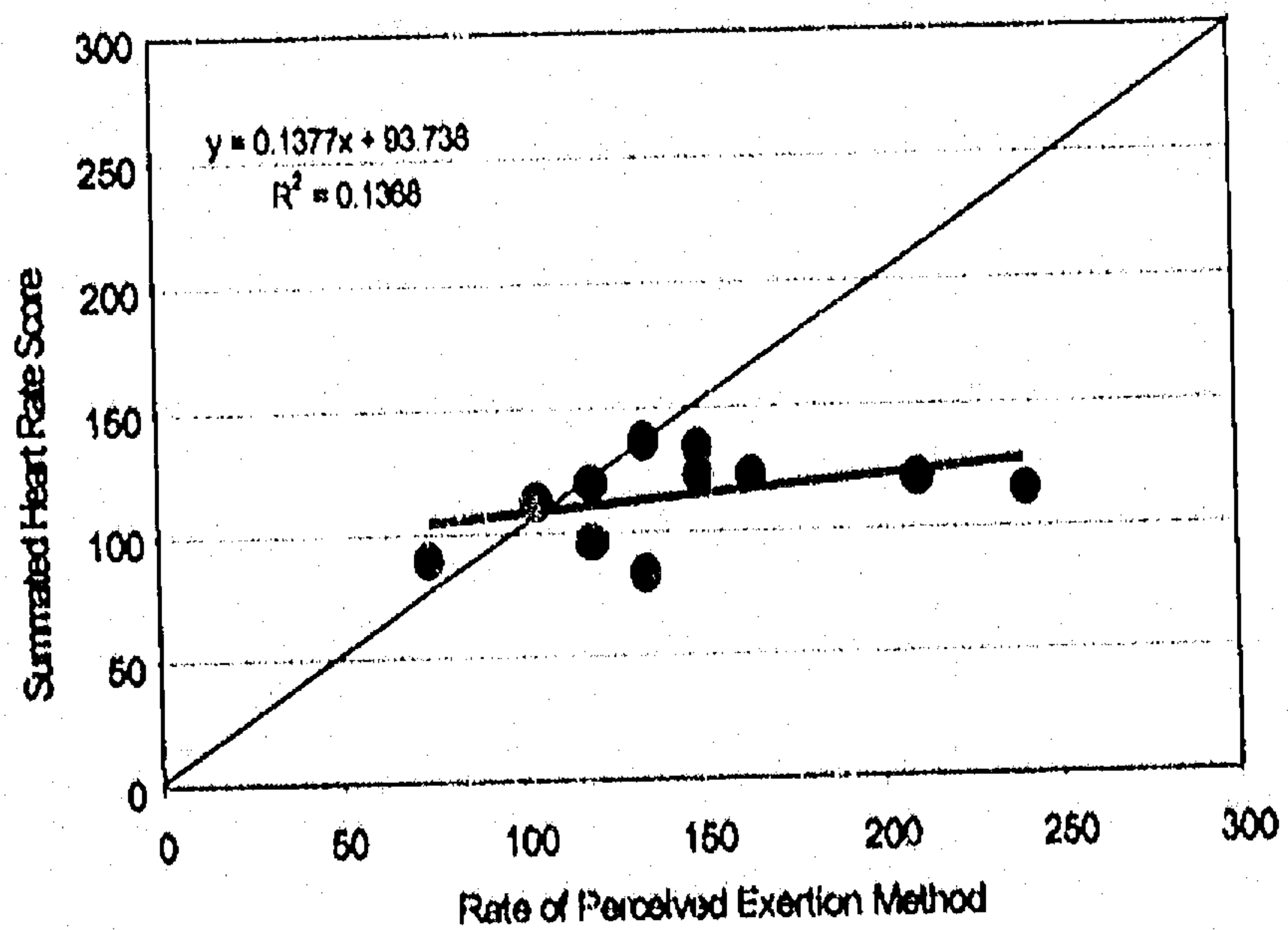


Figure 6. Summated HR score vs. RPE during 10% Interval exercise.

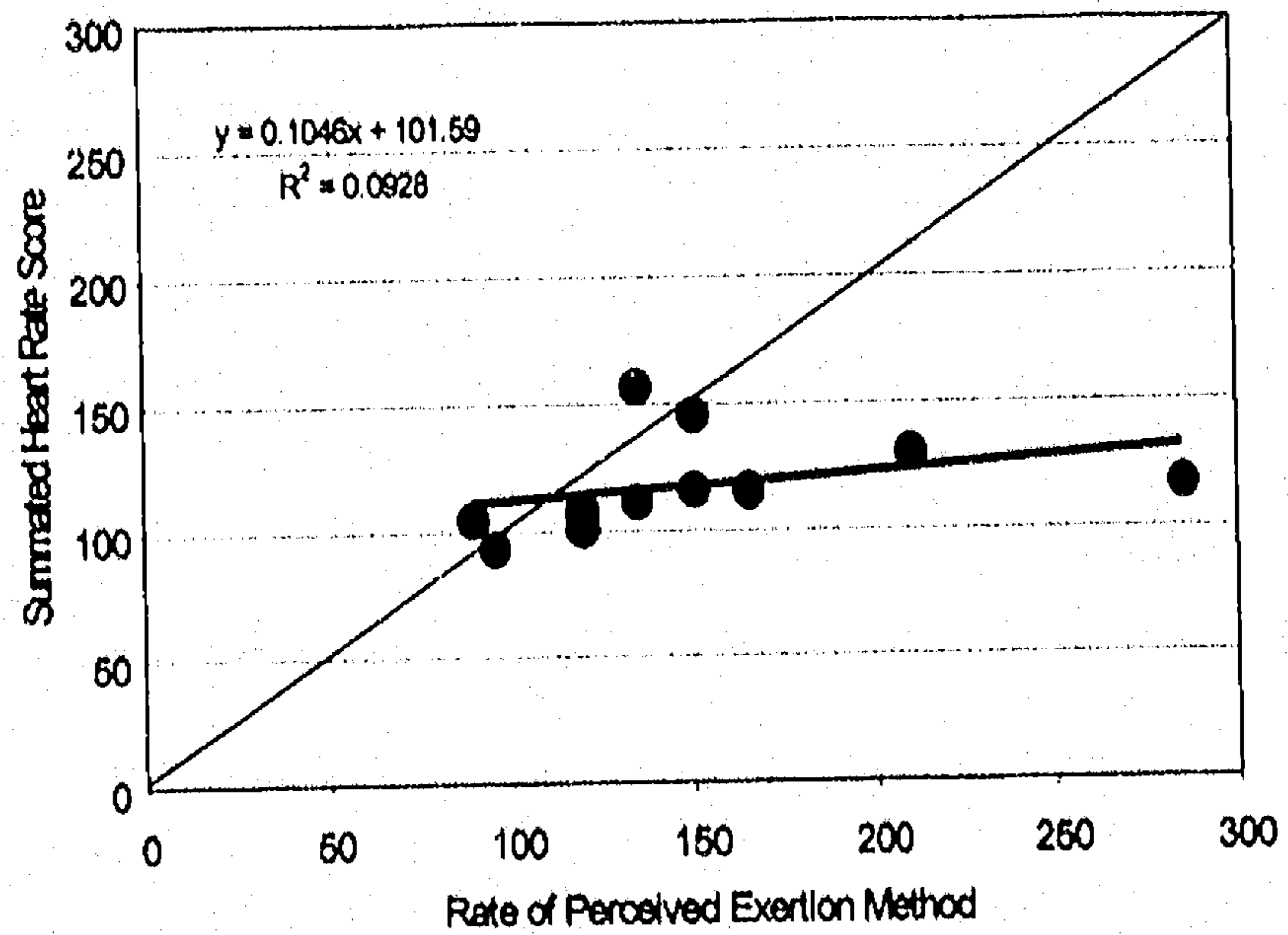


Figure 7. Summated HR score vs. RPE during 25% interval exercise.

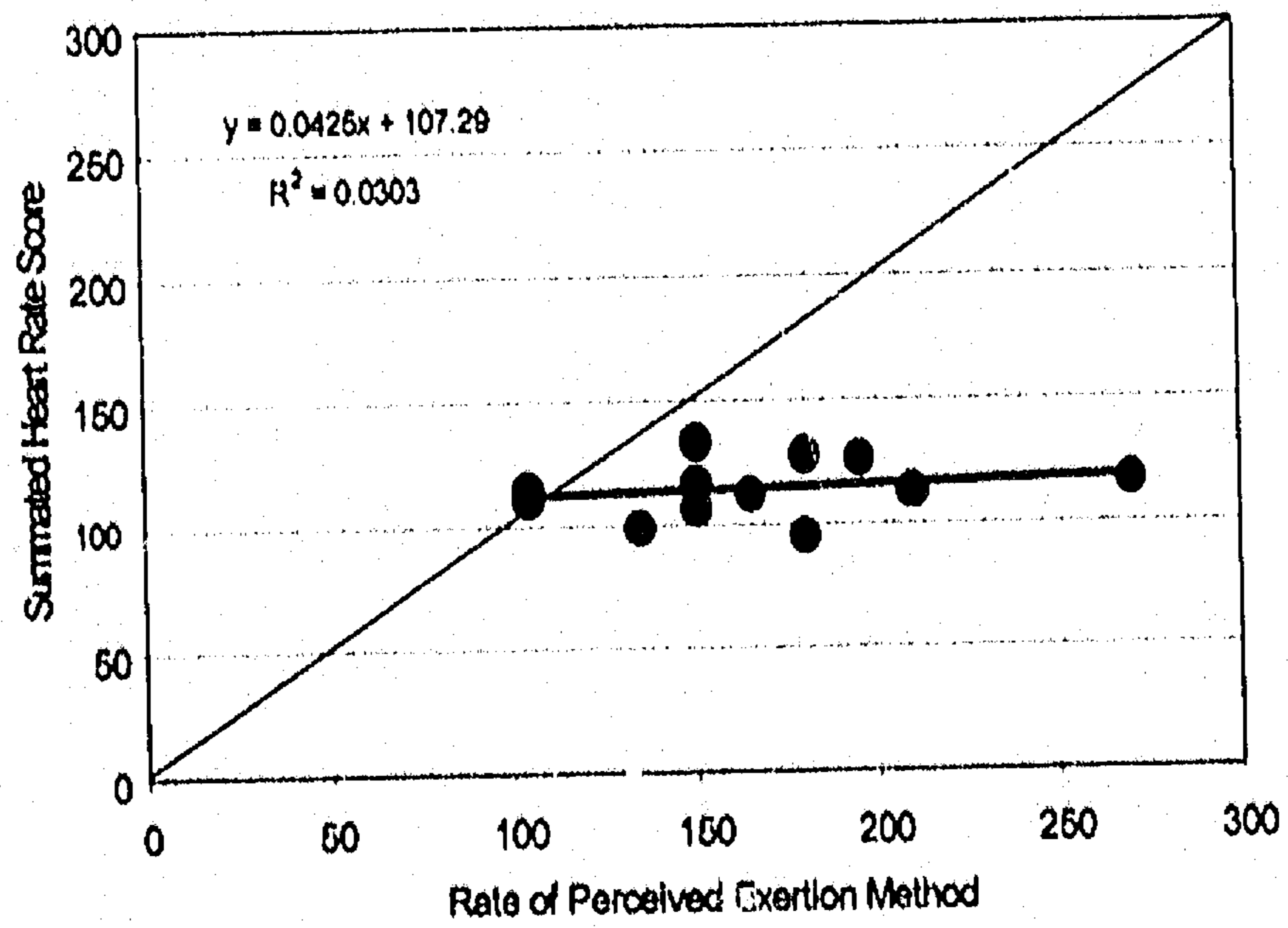


Figure 8. Summated HR score vs. RPE during 50% interval exercise.

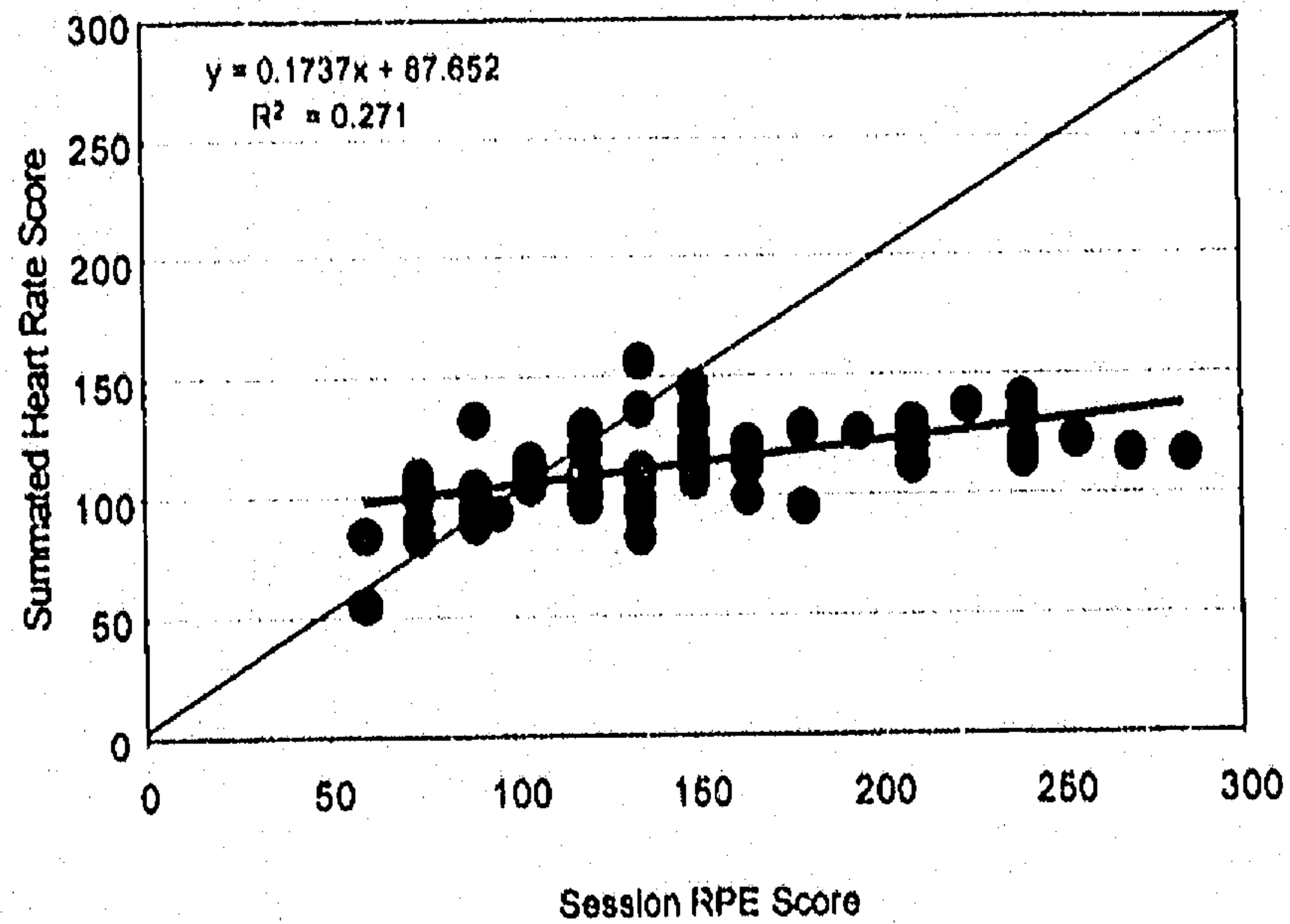


Figure 9. The average summated HR score vs. the average session RPE score for SS, 10, 25, and 50% exercise.

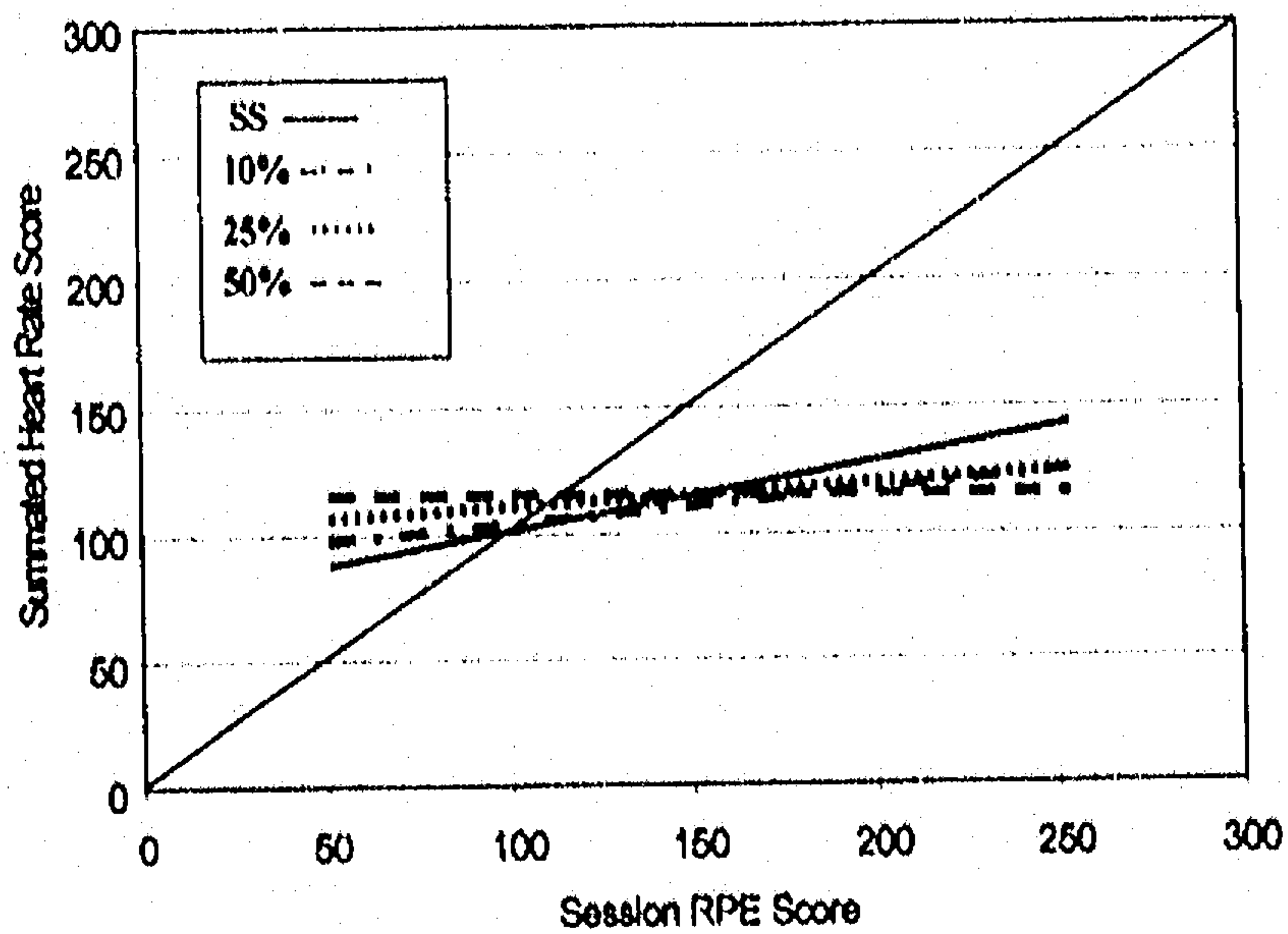


Figure 10. Individual regression lines representing summated HR score vs. session RPE score for SS, 10, 25, and 50% intervals.

DISCUSSION

The primary purpose of this study was to determine how the intensity of an exercise session represented by the session RPE corresponded to the summated HR score for that same exercise session. We compared responses during interval sessions of varying intensities as well as during SS exercise. All sessions were 30 min in duration and all measured physiological variables (HR, VO_2 , RPE, and HLa) rose from rest to 10 min and leveled off to SS for the duration. There was no major difference among experimental conditions (SS, 10, 25, and 50% trials) in any of the measured physiological variables. The summated HR and exercise score (session RPE) were found to be essentially the same regardless of exercise pattern.

Previous work using similar means of monitoring the intensity of an exercise session have dealt mainly with SS exercise (2,4,7,8,11,17,18). The current study validates a means of monitoring the intensity of interval exercise which is understood to produce a greater training effect in many athletes (6,10,12,13,15). Since our results suggest that summated HR score and session RPE are related and follow the same trend, we can conclude that this system of rating the intensity of interval exercise is valid.

Previous studies have examined the effects of training intensity in enhancing the effects of training performance (9,14,16,19). Interval training allows a program to stress intensity and has been shown to be more effective than continuous SS training (6,12,13,15). The method of quantifying interval training used in this study extends previous works that have used similar methods to quantify SS exercise (2,7,17). We have

expanded the concept of using a modified RPE scale to replace heart rate data and provide a single number representation of the difficulty of a training session. This number corresponds with physiological aspects of fatigue and can now be applied to interval exercise.

In summary, the relationship between summated HR score and session RPE are essentially the same regardless of the type of exercise intervention. Based on this information, we have provided a means of quantifying the intensity of interval exercise. This method is a simple way for athletes and coaches to monitor the difficulty of a workout and to evaluate the effect of training programs.

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APPENDIX A
INFORMED CONSENT

1. INFORMED CONSENT FOR "The effect of different interval magnitudes and duration on measures of exercise intensity."
2. I _____, give my informed consent to participate in this study designed to evaluate the effect of different interval magnitudes and durations on measures of training intensity. I understand that the study is under the direction of Jessica Florhaug and Lauri Hrovatin who are graduate students in the department of Exercise and Sports Science at the University of Wisconsin-LaCrosse. Dr. Carl Foster who is an associate professor in the same department is the faculty supervisor. I consent to the presentation, publication, and other release of the summary data from the study which is not identifiable with myself.
3. I have been informed that my participation in this study will involve my participation in seven cycling tests performed on a cycle ergometer, each lasting approximately 30 minutes with 48 hours in between each session. These studies will also involve a preliminary test on a cycle ergometer to determine VO₂, blood lactate, and individual anaerobic threshold. The studies will take place in the Human Performance Laboratory of the University of Wisconsin-LaCrosse.
4. I been informed that I may experience a high level of fatigue as a result of the vigorous activity. I am aware that I will perform a warm up and cool down in conjunction with each session. I may also have sore fingers from the puncture sites for small blood samples, taken to measure blood lactate.
5. I have been informed that the primary benefits that I might expect from participating in this study are the high intensity workouts, increases in VO₂ max, and experience using the rating of perceived exertion monitoring system.
6. I have been informed that there are no "disguised" procedures in this study. All procedures can be taken at face value.
7. I have been informed that testing will be supervised by individuals trained in CPR.
8. I have been informed that I am free to withdraw from this study at any time with out penalty.
9. Concerns about any aspects of this study may be referred to Jessica Florhaug at (608) 796-9694, Lauri Hrovatin at (608) 785-4686, and Dr. Carl Foster at (608) 785-8687. Questions regarding the protection of human subjects may be addressed to Dr. Garth Tymeson, chair University of Wisconsin-LaCrosse Institutional Review Board at (608) 785-8155.

Investigator _____ Participant _____ Signature _____
 Date _____ Date _____

APPENDIX B
REVIEW OF RELATED LITERATURE

REVIEW OF RELATED LITERATURE

Introduction

The purpose of this study was to evaluate the effect of different interval magnitudes on measures of training intensity represented by the session rating of perceived exertion (RPE) and how it compares to the summated heart rate (HR) score of the same exercise session. By assessing the session RPE at increasing, varying power outputs above and below a steady state (SS) level, an athlete should be able to identify the intensity of the interval session that will maximize their training goals, leading to optimal performance while decreasing the possibility of developing overtraining syndrome (OTS).

In a study dealing with OTS, Foster (8) used the session RPE method of deriving training load to calculate the training monotony as well as training strain (negative influences of training in the context of Mujika et al.) (20). Daily training loads were summated to calculate a weekly training load. Training monotony (an index of the day to day variability of training) was calculated by dividing the daily mean training load by the standard deviation over a week. Training strain was defined as the weekly training load multiplied by the monotony. Training strain was shown to be highly related to negative responses to training and is thought to be related to early manifestations of OTS (banal infections).

The following provides a review of literature pertaining to: 1) the components of F.I.T (Frequency, Intensity, and Time/Duration) and the role they play in the

development of training programs; 2) the development and expansion of different approaches to monitoring training; and 3) the effect and importance of interval training. The lack of literature dealing with interval training and its effects on measures of training intensity is the primary impetus for this investigation.

Training Loads

Relationship to Training Response

In the quest to optimize performance, coaches and athletes have tried many types of training methods. During the course of progressive training most athletes find the method and training load that works best for them and their particular event. The training load consists of components attributable to training frequency, intensity, and duration/time (F.I.T.). The appropriate F.I.T. combination varies depending on the athlete, their sport, and their specific training goals.

The most recent position stand by the American College of Sports Medicine (ACSM) (21) discusses the importance and necessity of these three factors (F.I.T.) in improving health and fitness among the general population. Moderate levels of physical activity are sufficient for sedentary individuals to achieve the health benefits of exercise training. Programs involving higher intensities and/or frequency and duration provide greater fitness benefits.

Intensity

The 1998 ACSM Position Stand (21) is in agreement with the general understanding that greater training loads result in greater training effects. Many studies have attempted to determine which component of F.I.T. plays the most active role in

producing the greatest training effect. It is widely agreed that higher training intensities are required for the major central circulatory adaptations to training. In a review by Foster (7) the importance of increases in VO_2 max in adaptations to increasing levels of physical activity were discussed. Increases in VO_2 max occur in the untrained healthy, in cardiac patients, as well as in elite athletes. It was noted that increases in VO_2 max in athletes are less related to increases in overall training load, but more to training intensity.

Pollock, Ward, and Ayres (22) showed that high-intensity efforts might not be necessary to maintain cardiorespiratory fitness in the average middle-aged man. Sedentary men trained at high intensity for 30 min/day for 20 weeks. The subjects showed an increase in VO_2 max and V_{E} max as well as decreased HR max, resting heart rate (RHR), body weight, and percent fat. Subsequently, the intensity of exercise was decreased and a portion of the subjects stopped training, another portion of the subjects were a control group, and the rest exercised continuously for a 26 week period. The group that trained continuously at a decreased intensity maintained their cardiorespiratory fitness while the group that stopped training showed a significant decrease. This implies that high intensity efforts are not necessary to maintain cardiorespiratory fitness in the average middle-aged man. While this may be true for enhancing fitness of the general population, the athlete looking to improve performance depends on different combinations of F.I.T. than persons looking to primarily benefit their health.

Hickson and colleagues evaluated the effect of reductions in training on the retention of training induced increases in aerobic power, and short and long-term endurance (14,15,16). After a standard program of cycling or running for 40 min per day

for 6 days a week at a high intensity for a period of 10 weeks, induced F.I.T. components were reduced by either 1/3 or 2/3 for an additional 10 weeks. Reductions in intensity, but not duration or frequency, resulted in reductions in performance and VO₂ max. This led to the conclusion that intensity of exercise is more critical to the maintenance of aerobic power than frequency or duration.

Lehmann et al. (18) demonstrated that increases in training intensities produced improved performance and was well tolerated, whereas large increases in training volume resulted in a decline in performance. Both the Hickson et al. and Lehmann et al. studies support the concept that training at a higher intensity versus higher frequencies or durations may have the greatest effect on improving performance. This in turn supports the idea that intensity is the most important component of the F.I.T. paradigm for athletes.

Approaches to Monitoring Training

F.I.T.

The F.I.T. concept has become a universal approach to evaluating training programs for both the general public and the athlete. However, it is inconvenient in that it doesn't provide a single number that allows evaluation of the exercise session. F.I.T. provides us with a combination of percentages of each of its components that can be applied to a training regimen, but fails to provide a single representation that can be used to measure or describe training input and output. Therefore, it is not only inconvenient, but also conceptually difficult to use in input-output evaluations.

Aerobics Points System

In 1968, Cooper (4) developed the "aerobics" points system that was based on absolute training intensity. It was a very popular, standard approach to exercise monitoring. Based on published values for absolute exercise intensities, the aerobics point system effectively integrated the intensity and duration of exercise training activities. However, its limitation was that it used absolute training intensities. A wealth of exercise literature suggests that the relative training intensity (e.g., % VO_2 max) is the dominant factor relative to explaining adaptations to training (7).

TRIMPS System and its Expansion

A systems model developed and discussed by numerous authors (1,6,19) provides a way to estimate the level of performance by using two competing factors related to training. Performance is estimated by finding the difference between the fatigue (negative function) and fitness (positive function) associated with training. This model takes into account both the volume and intensity of training. These studies introduced the concept of the training impulse (TRIMP), which is the duration of training effort multiplied by the intensity (measured as the average heart rate times a conversion factor related to relative intensity). This system enables one to predict and optimize training methods for an individual based on development of fatigue (decreases in performance) and fitness (increases in performance).

The TRIMPS concept of describing training input has been extended by Mujika, Busso, Lactose, Barale, and Chatard (20). Here, the antagonistic factors or components of the model were the negative influences and positive influences of training on

performance. Negative influences included all physical variables contributing to fatigue having a negative impact on performance. Positive influences included physical variables leading to enhanced performance. The model parameters in this study were assumed to be constant over time, which didn't account for changes resulting from training intensity or duration over a prolonged period of training.

Busso, Denis, Bonnefoy, Geyssant, and Lacour (3) further expanded the TRIMPS systems model concept by taking into account time-varying parameters. Time-varying parameters allowed for day-to-day variations in model parameters (gain terms and time constants) which may consequently describe adaptations to training and long-term fatigue that are present in performance. The goal was to find out if using a time-varying systems model provides more information concerning the adaptation to training than the time-invariant parameter mode of Mujika et al. (20). They concluded that time-varying parameters allow for a better description of the effects of training over time in regards to previous and future training loads.

Rating of Perceived Exertion (RPE)

The TRIMPS system is a step beyond the F.I.T. concept and the "aerobics" points system in that it provides a single number to evaluate training input that takes frequency, relative training intensity, and training time into account. This makes the monitoring of training more convenient and conceptually easy to understand. The limitation to this system, however, is that it is dependent on knowing the heart rate of the athlete during training and performance. Although commercially available HR monitors simplify the evaluation of data, either failing to have a HR monitor or technical limitations in their use

limits the ability to monitor training during that training session. Another limitation is that this system is useful primarily in evaluating the responses to training during submaximal steady-state exercise. High intensity and/or intermittent exercise is not as easily evaluated using HR criteria.

To expand on the TRIMPS concept, Foster et al. (11) used a modification of the Borg RPE scale (2) to replace the heart rate data on which the TRIMPS systems model depends. A single number that globally represents the overall intensity of an entire training session is collected, known as the session RPE. This numeric representation of the difficulty of the training session has been shown to correspond to the percent heart rate reserve, to the portion of the session in which the heart rate is in common blood lactate defined training zones, and to the summated HR score. The training load calculated from this technique was defined as the product of the session RPE and the session duration. Additionally, it has been shown to be related to athletic performance (9).

In summary, the TRIMPS concept developed by Bannister et al.(1), Fitze-Clarke et al. (6), and Morton et al. (19), and extended by others (3,8,11,20) suggests a convenient strategy for monitoring exercise training loads. These concepts have been shown to be useful in terms of explaining training induced changes in performance and negative outcomes from training. However, most of the data with this technique has been developed using relatively continuous, SS exercise.

Interval Training

Importance of Interval Training

The previously mentioned studies dealing with the TRIMPS concept deal mostly with SS exercise. Competitive athletes however, often use interval training to enhance performance. It is widely understood that the more specific a training program, the greater the training effect (10). Training specificity involves stressing certain energy systems and muscle groups unique to a desired performance. However, high intensity training cannot be continued for long durations without exhausting the athlete. Interval training was developed as a technique to allow a fairly large volume of high intensity specific training without incurring unreasonable fatigue.

Impact of Interval Training

Interval training may provide a way to stress a specific energy system without exhausting the athlete. Gaiga and Docherty (12) studied the effect of an aerobic interval-training program on intermittent anaerobic performance. They found that completing 3 min work to rest intervals and progressing from 5-10 repetitions increased aerobic power and enhanced performance in anaerobic activities of high-intensity and short duration.

Interval training allows for periods of rest between high-intensity work bouts. This allows the aerobic energy system to facilitate in the removal of lactate that has accumulated, as well as in the replenishment of energy stores in preparation for the next high-intensity work-bout. Through removal of lactate and replenishment of energy stores, interval training provides the athlete with the ability to do more total work at a higher intensity. This is a critical factor in the success of an athlete's performance.

Gorostiaga et al. (13) compared interval training with a continuous training. They found that interval training was more effective than continuous training in improving exercise performance as well as VO_2 max.

Lindsay et al. (17) examined the effects of incorporating a 4 week high intensity interval program (HIT) as a portion of an aerobic base training on a 40 km time trial performance of cyclists. The results demonstrated that the HIT program increased the peak power output and fatigue resistance while improving their 40 km time trial.

In Essen's (5) thesis, the landmark study relative to interval training, oxygen uptake and HR were compared during intermittent intense exercise, continuous exercise at $\frac{1}{2}$ the work load, and continuous exercise at a similar high work load. Intense intermittent and continuous exercise both corresponded to 50-60% VO_2 max whereas, continuous exercise at a similar high workload demanded 100% VO_2 max. Similar leg oxygen uptake, leg respiratory exchange ratio, and lung respiratory exchange ratio were observed in intermittent intense and continuous moderate exercise. She also looked at lactate release and found a net release during the whole period of intense intermittent exercise in contrast to constant moderate exercise. Arterial lactate concentration increased similarly in the early phase of continuous and intermittent exercise, but decreased progressively thereafter in continuous exercise and remained at a constant level throughout the remainder of intermittent exercise. During continuous high intensity exercise there was a large decrease in muscle glycogen concentration (5). Intense intermittent exercise displayed a glycogen saving effect, leading to the suggestion that this type of exercise may obtain energy from another source (such as lipid substrates),

allowing for more efficient glycogen utilization. The more efficient use of glycogen was also attributed to greater oxidative metabolism. This in depth study by Essen relays many supporting factors for the efficiency and effectiveness of intermittent (interval) type exercise. These findings can lead one to assume that the training load can be decreased in duration by using higher intensity intervals, while still achieving the effect of a lower intensity but longer SS work bout.

Summary

In conclusion, interval training has been shown to be an effective mode of training. By providing the athlete with a high intensity work-bout interval training can produce effective results in the performance of an athlete without overworking the body and its energy systems. The need to examine the monitoring of interval training has been established through lack of research in this area. The effect of different interval magnitudes on measures of training intensity can provide a representation of session RPE and the summated HR score in relation to HR, HLa, and VO₂. By examining the effects of varying the magnitude of intervals on these physiological variables an athlete should be able to design a training program that effectively incorporates interval training.

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