ABSTRACT

HROVATIN, L. A. The effect of different interval durations on measures of exercise intensity. MS in Exercise and Sport Science-Human Performance, August 1999, 28pp. (C. Foster)

Monitoring training loads during continuous exercise has been validated, however given the importance of interval training, this method (RPE * duration) has not been validated during interval training of different durations. Twelve well trained individuals (m = 6, f = 6) performed an incremental cycle ergometer test to failure and four randomly ordered 30 min tests on a lode cycle. The four tests were steady state, 30-sec, 1-min, and 2-min, with a work relief ratio of 1:1. Workloads were calculated according to the individual anaerobic threshold (IAT) and physiological variables (HR, RPE, BLa, and VO_2) were measured every 10-min. RPE was also acquired 30-min after the exercise bout and multiplied by the duration to obtain a session RPE score. Heart rate data were collected from a Polar Heart Rate Monitor and a summated HR score was calculated. All of the physiological variables behaved similarly during interval training and steady state training by rising from rest to 10-min and then leveling off. The session RPE score and summated HR score were compared and found to be closely related suggesting that the summated HR score and session RPE are essentially the same. In conclusion, the session RPE * duration provides a reliable method to rate the intensity of interval training.

THE EFFECT OF DIFFERENT INTERVAL DURATIONS ON MEASURES OF EXERCISE INTENSITY

A MANUSCRIPT STYLE THESIS PRESENTED

TO

THE GRADUATE FACULTY

UNIVERSITY OF WISCONSIN-LA CROSSE

IN PARTIAL FULFILLMENT

OF THE REQUIREMENTS FOR THE

MASTER OF SCIENCE DEGREE

BY

LAURI A. HROVATIN

AUGUST 1999

COLLEGE OF HEALTH, PHYSICAL EDUCATION, AND RECREATION

UNIVERSTIY OF WISCONSIN-LA CROSSE

THESIS FINAL ORAL DEFENSE FORM

Candidate: Lauri A. Hrovatin

We recommend acceptance of this thesis in partial fulfillment of this candidate's requirements for the degree:

Master of Science in Human Performance

The candidate has successfully completed the thesis final oral defense.

[signature]	16 June 1999
Thesis Committee Chairperson Signature	Date
Phillip L. Esten	16 June 1999
Thesis Committee Member Signature	Date
Glenn Brice	16 June 1999
Thesis Committee Member Signature	Date
[signature]	16 June 1999
Thesis Committee Member Signature	Date

This thesis is approved by the College of Health, Physical Education, and Recreation.

Garry Tymeson	7-2-99
Associate Dean, College of Health, Physical Education, and Recreation	Date
Garry Tymeson	7-2-99
Dean of Graduate Studies	Date

ACKNOWLEDGMENTS

I would like to express my gratitude to Dr. Foster for making this project possible. Because of your patience, guidance, and knowledge I was able to complete this project that I thought was never ending. I am very proud of this achievement and will be forever thankful.

A very special thanks to Jessica Florhaug for your encouragement, motivation, and most of all, for our friendship. Thank you to our subjects for participating and completing the testing sessions.

I would like to express my appreciation to my committee, Dr. Phil Esten, Dr. Richard Mikat, and Dr. Glenn Brice for your time and effort. Dr Travis McBride, thank you for having faith in me, and the 126 Air Refueling Squadron for your support and flexibility. Lt. Col. Bruce Sweezy, thank you for convincing me to do a thesis.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APENDICES

INTRODUCTION

Background

Knowledge of applied training loads is important for understanding the underlying responses to training. Frequency, intensity, and duration are all important factors in monitoring training loads. A systematic concept to monitor training loads during steady state (SS) exercise has been validated (5,6,10,11,17,18). However, given the importance of interval training, a systematic concept has not been validated for this type of training.

The 1998 ACSM position stand indicates that frequency, intensity, and duration are all important factors to determine the magnitude of the training effect (1). Various studies have demonstrated the importance of each of these variables; however, the most important variable to the training effect is intensity (5).

Other studies have used similar methods to monitor the intensity of training for steady state exercise (5,6,10,11,17,18). The original methods to quantify exercise were the "aerobics" points system, (6) and the "training impulse" (TRIMPS) concept (10,17). TRIMPS is systematically quantified as the product of training duration and intensity. The TRIMPS concept was further developed by Busso, Candan, and Lacour (5) and Mujika et al. (18) using variables such as fitness and fatigue. These variables were used to describe the relationship between training and performance using percentages of maximal exercise. The most recent development of the TRIMPS concept was developed by Foster (11) using a modified Borg scale (4) to replace heart rate (HR) data. This concept has shown a good relationship between the calculated training load (Rating of perceived exertion (RPE * duration) and exercise intensity scores based on percent heart rate reserve, HR-blood relationship, and a summated HR score (11). All of the various attempts to quantify exercise have used SS exercise.

Interval training produces a greater training effect than steady state exercise in that it allows for rest in between high intensity work bouts and greater efficiency of glycogen utilization (2,8,9,12,13,14,16). Given the importance of training intensity and the frequent use of interval training, a need exists to know if the TRIMPS concept is applicable during interval training.

To date, all of the approaches based on the TRIMPS concept by various authors (5,6,10,11,17,18) have related to primarily SS exercise. However, given the importance of training intensity and the frequent use of interval training by competitive athletes, there is a need to know how and if the TRIMPS concept is applicable during interval training. Therefore, the purpose of this study was to evaluate different interval durations on measures of training intensity, including the global RPE and the summated HR score.

In order to extend the TRIMPS concept to intermittent exercise, the purpose of this study was to compare responses during SS exercise and interval exercise of varying durations. A companion study performed simultaneously involved varying interval magnitudes to evaluate the comparison of interval training and continuous exercise.

METHODS AND PROCEDURES

Subjects

The subjects were 12 well-trained individuals (6 males and 6 females) accustomed to cycle exercise (primarily triathletes) with a mean age of 22 ± 3 years (see Table 1). All subjects were healthy and without major risk factors for cardiovascular disease (3). Subjects provided informed consent prior to participation, and the study was approved by the Institutional Review Board.

Methods

A preliminary test was performed on all subjects involving anthropometric measurements (height, weight, and skinfold thickness) and a VO_2 max test to determine maximal oxygen consumption. The maximal exercise test was performed on an electrically braked cycle ergometer (Lode, Groningen, The Netherlands) while measuring oxygen consumption using a open circuit spirometry (Q-Plex, Quinton Instruments, Seattle, WA). The power output was increased by 50 watts for all male subjects and by 40 watts for females weighing 60 kg or more and by 30 watts for females under 60 kg, workloads were increased every 3-min until fatigue. Throughout the duration of the test, VO2 , RPE, and HR were recorded during the last 30-sec of each stage.

Blood lactate concentrations were obtained from a finger tip during rest, at the end of each 3-min stage, and at 1, 3, 5, and 10-min postexercise. Using the exercise and recovery lactate data, the individual anaerobic threshold (IAT) was measured according to Stegmann and Kindermann (19).

Table 1. Mean (± sd) characteristics of the subjects.

Variable	Male	Female
Height (cm)	177.3 ± 3.7	164.6 ± 8.1
Weight (kg)	70.82 ± 7.2	63.8 ± 4.3
Age (yr)	23.0 ± 3.6	21.3 ± 1.5
% Fat	11.1 ± 4.8	20.9 ± 2.7
LBW (kg)	61.6 ± 6.80	50.4 ± 2.8
Peak Watts	315 ± 34	237 ± 33
Peak Watts/kg	4.52 ± 0.52	3.68 ± 0.38
Peak VO_2 (l/min)	3.84 ± 0.30	2.94 ± 0.34
Peak VO_2/kg (ml O_2/kg)	54.6 ± 2.4	46.2 ± 3.5
% Predicted VO_2	143 ± 14	141 ± 10
Peak HR (bpm)	198 ± 10	186 ± 7
Peak VE (l/min)	140.4 ± 13.97	108.5 ± 15.7
IAT (Watts)*	228 ± 25	188 ± 48
IAT (Watts/kg)	3.28 ± 0.65	2.94 ± 0.61
IAT HR (bpm)	174.3 ± 18.9	159.3 ± 15.6

*IAT = Individual Anaerobic Threshold

The experimental protocol involved participation in four randomly ordered 30-minute exercise bouts. Bout 1 was SS exercise at a power output equal to 90% of the IAT. Bouts 2-4 were intervals at a mean power output of 90% of the IAT, but with a 25% offset (e.g., 90% IAT = 200 Watts, intervals = 150 Watts/250 Watts); the work relief ratio was 1:1 with interval durations of 30-sec, 1-min, and 2-min, for bouts 2-4 respectively.

Outcome Measures

Using a modified Borg scale, the session RPE was acquired 30-min after the completion of each exercise bout to represent the overall intensity of exercise according to Foster (11). This rating was then multiplied by the duration of the exercise bout resulting in a session RPE score (e.g., RPE = 5, duration = 30 minutes, 5 x 30 = 150 session RPE).

Using a Polar HR monitor, the summated HR score was determined by evaluating the amount of time spent in the 5 HR zones (8). The amount of time spent in each zone was then calculated resulting in a single number to represent the summated HR score (7, 11). Blood lactate was measured at rest and 10, 20 and 30-min during exercise while the VO_2 was measured throughout the entire exercise bout.

Statistical Approach

Statistical comparisons were made among the mean session RPE scores and the mean summated HR scores, VO_2, and blood lactate (BLa) concentrations at 0, 10, 20, and 30-min during the four exercise bouts. It was hypothesized that both the session RPE and the summated HR score would increase with the duration of the interval pair. A two- tailed t-test with Bonferoni correction was used. A p value of < 0.0167 was accepted as statistically significant.

RESULTS AND DISCUSSION

Results

VO_2, HR, RPE, and blood lactate values were compared to SS values for each of the 30-min interval sessions (see Table 2-4 & Figures 1-4). Oxygen consumption increased from rest to10-min and then leveled off for the remainder of the exercise session during all four bouts. Heart rate increased from rest to 10-min for all sessions then increased slightly for the remainder of the exercise bout. There was a significant difference between the minute 10 SS value and the minute 10 value for the 1-min and 2- min interval bouts. The RPE values increased from rest to10-min and then leveled off except for the 2-min interval session. The 10-min and 30-min RPE scores during these sessions were significantly greater than the corresponding SS values. Blood lactate concentration also increased from rest to 10-min in all sessions. After 10-min, the 30-sec interval leveled off, whereas the 1-min and 2-min intervals had significant difference. During the 1-min interval bout, the 20-min value was significantly greater than steady state and during the 2-min interval bout, the 10-min and 30-min values were significantly greater than the SS values.

The session RPE score was compared to and plotted against the summated HR score for the four exercise sessions (see Figures 5-10). The summated HR score and the session RPE values during the 30-sec exercise bout showed no significant difference (see Figure 6 & Table 3). However, during the 1-min and 2-min exercise bouts there was a significant difference with the session RPE score being larger than the summated HR score (see Figures 7-8 & Table 3). The combined regression lines reveal a close relationship between the session RPE score and summated HR score (see Figure 10 & Table 3).

Table 2. Means and standard deviations of HR response (bpm) values for each session at rest, 10-min, 20-min, and 30-min.

Variable	Rest	10-min	20-min	30-min
SS	79 ± 13	155 ± 10	159 ± 11	160 ± 13
30-sec	77 ± 11	137 ± 56	140 ± 57	163 ± 16
1-min	84 ± 9.0	159 ± 9.0*	166 ± 14	169 ± 11
2-min	82 ± 12	166 ± 12*	169 ± 12	172 ± 14

* indicates a significant difference ($p < 0.0167$) vs steady state exercise for paired t-test with a Bonferoni correction.

Table 3. Means and standard deviations for BLa (mmol/l) values for each session at rest, 10-min, 20-min, and 30-min.

Variable	Rest	10-min	20-min	30-min
SS	1.1 ± 0.5	2.8 ± 0.8	2.8 ± 0.8	2.5 ± 0.8
30-sec	0.9 ± 0.3	2.9 ± 0.6	3.0 ± 0.8	2.8 ± 0.7
1-min	1.5 ± 0.6	4.4 ± 1.8	4.2 ± 1.4 *	3.8 ± 1.6
2-min	1.5 ± 0.8	3.7 ± 1.2*	3.4 ± 1.5	3.9 ± 1.4*

* indicates a significant difference ($p < 0.0167$) vs steady state exercise for paired t-test with a Bonferoni correction.

Table 4. Means and standard deviations for oxygen consumption (L/min) values for each session at rest, 10-min, 20-min, and 30-min.

Variable	Rest	10-min	20-min	30-min
SS	0.27 ± 0.03	2.23 ± 0.45	2.35 ± 0.43	2.34 ± 0.46
30-sec	0.27 ± 0.03	2.21 ± 0.46	2.53 ± 0.55	2.63 ± 1.09
1-min	0.27 ± 0.03	2.45 ± 0.33	2.31 ± 0.45	2.25 ± 0.41
2-min	0.27 ± 0.03	2.53 ± 0.45	2.44 ± 0.43	2.61 ± 0.47

* indicates a significant difference ($p < 0.0167$) vs steady state exercise for paired t-test with a Bonferoni correction.

Table 5. Means and standard deviations of RPE values for each session at rest, 10-min, 20-min, and 30-min.

Variable	Rest	10-min	20-min	30-min
SS	0 ± 0	2.8 ± 0.8	3.8 ± 1.2	3.8 ± 1.1
30-sec	0 ± 0	3.2 ± 1.0	4.0 ± 1.2	4.2 ± 1.5
1-min	0 ± 0	3.5 ± 0.7	4.2 ± 0.9	4.2 ± 0.9
2-min	0 ± 0	4.1 ± 0.9*	4.3 ± 0.8	4.4 ± 1.1*

*indicates a significant difference ($p < 0.0167$) vs steady state exercise for paired t-test with a Bonferoni correction.

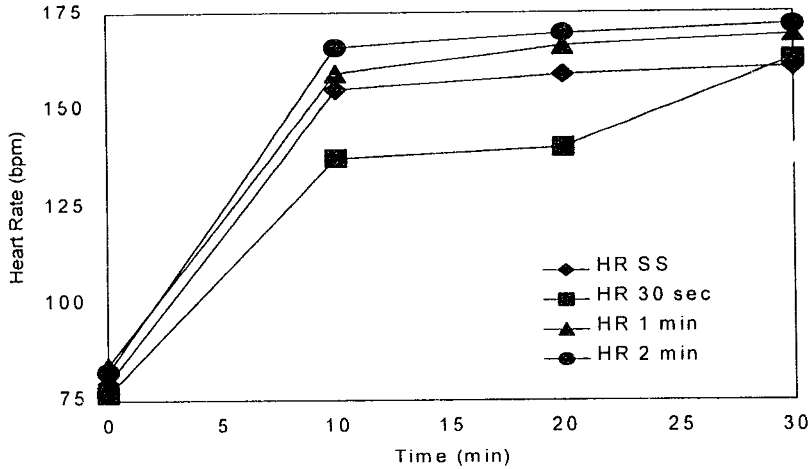

Figure 1. Comparisons of SS HR values to 30-min, 1-min, and 2-min intervals.

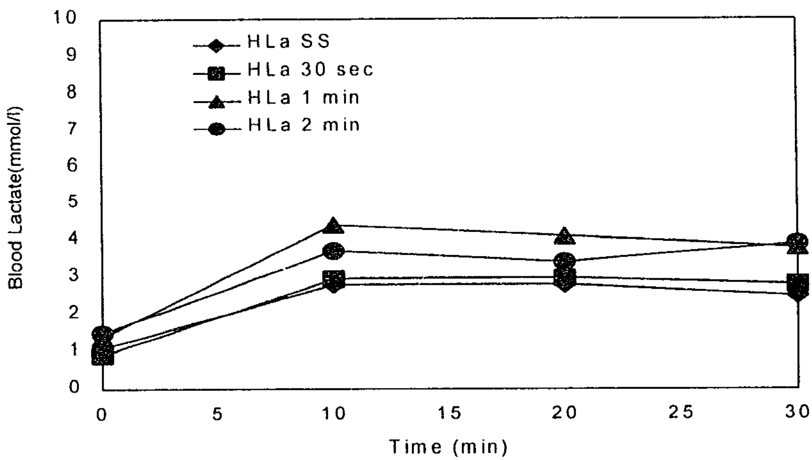

Figure 2. Comparisons of SS blood lactate values to 30-sec, 1-min, and 2-min intervals.

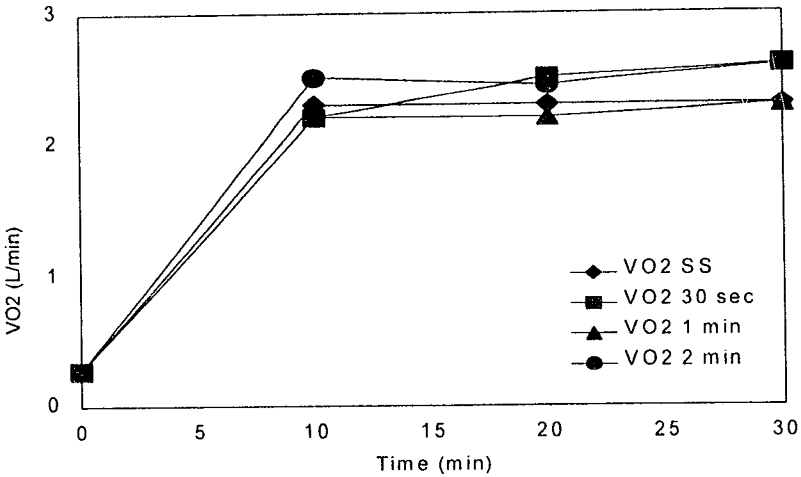

Figure 3. Comparisons of SS oxygen consumption values to 30-sec, 1-min, and 2-min intervals.

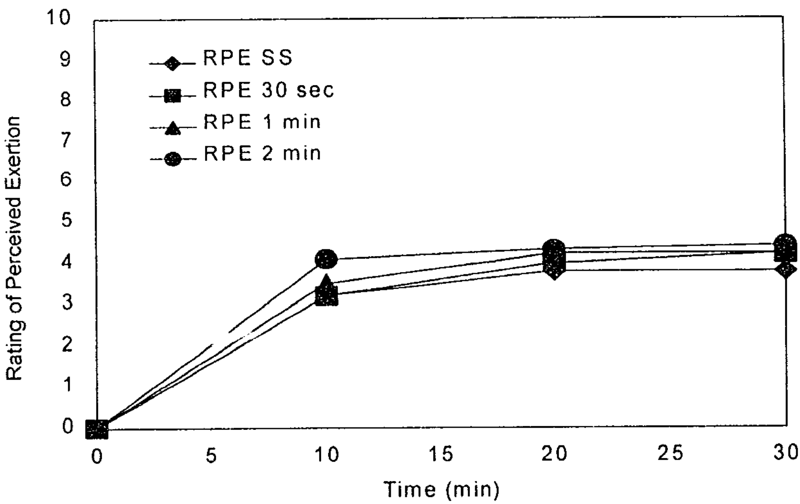

Figure 4. Comparisons of SS RPE values to 30-sec, 1-min, and 2-min intervals.

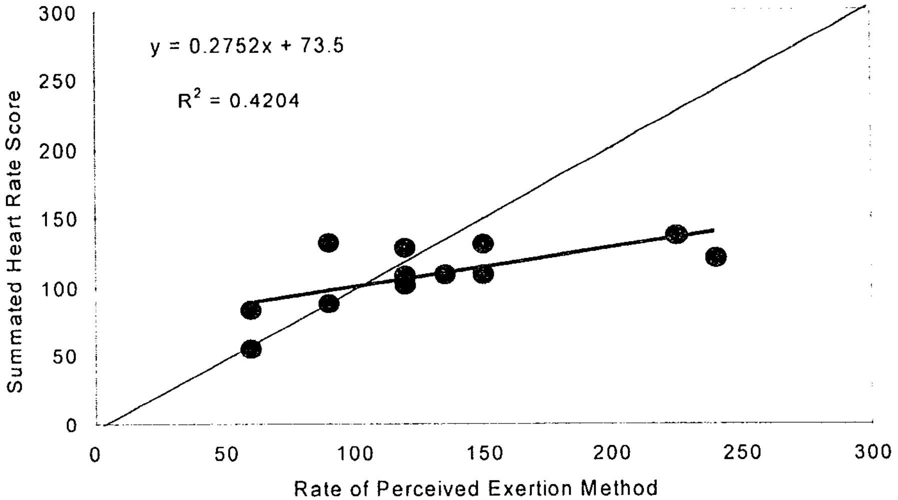

Figure 5. Summated HR score vs RPE during SS.

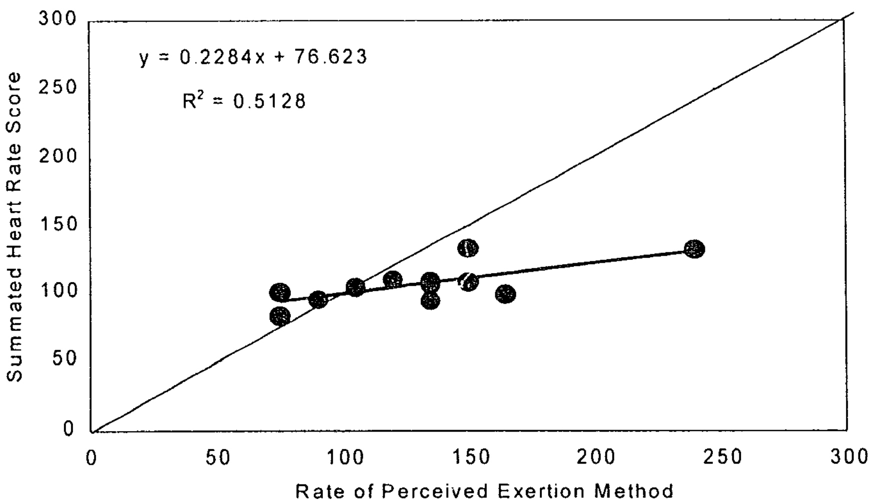

Figure 6. Summated HR score vs RPE during 30-sec interval durations.

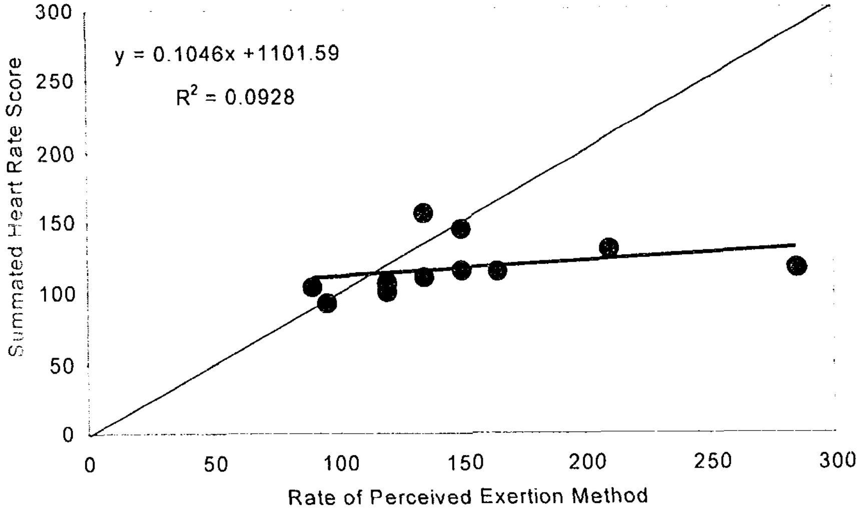

Figure 7. Summated HR score vs RPE during 1-min intervals.

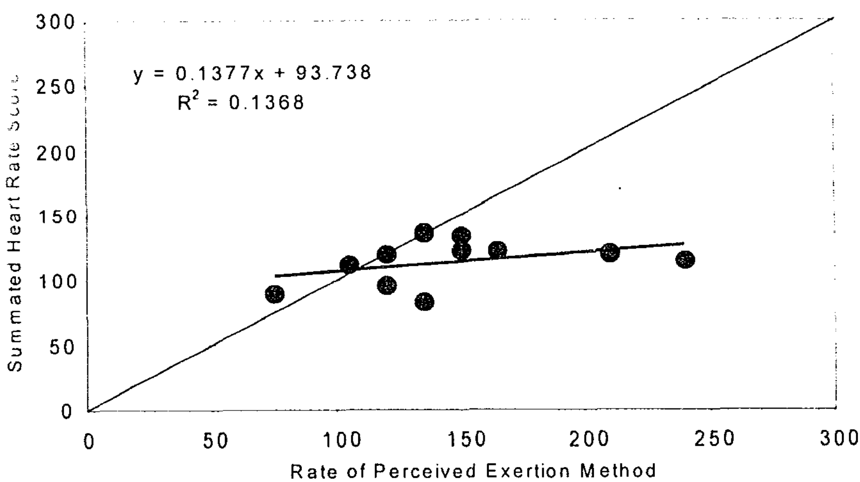

Figure 8. Summated HR score vs RPE during 2-min intervals

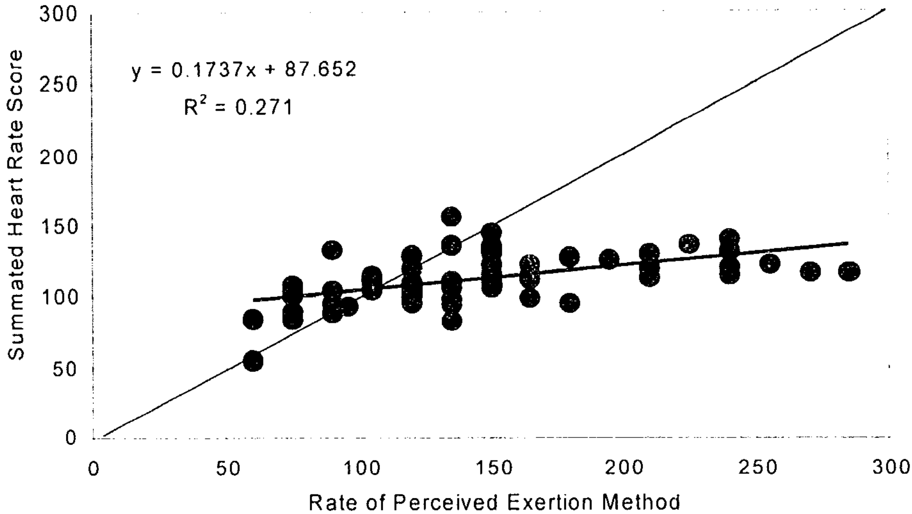

Figure 9. The average summated HR score vs the average session RPE score for SS, 30-sec, 1-min, and 2-min intervals.

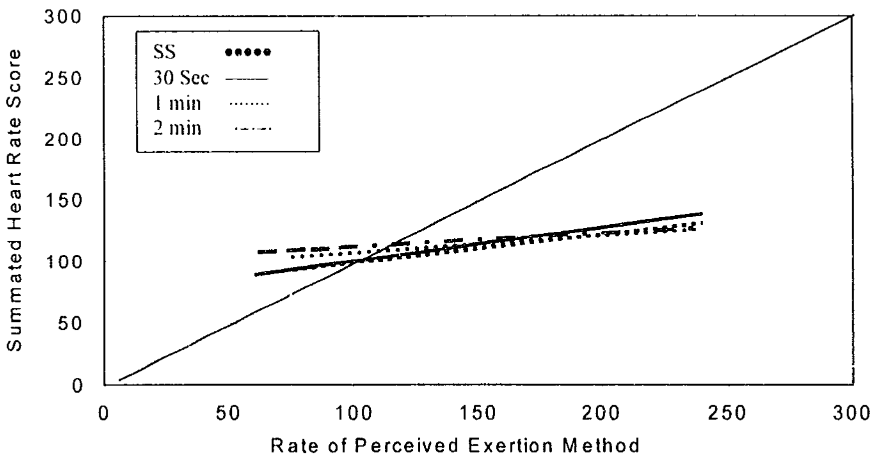

Figure 10. Individual regression lines representing summated HR score vs session RPE score for SS, 30-sec, 1-min, and 2-min intervals.

Table 6. Means and standard deviations of summated HR (bpm) and session load during each exercise session.

Variable	Summated HR	Session Load
Steady State	110 ± 24	130 ± 57
30-sec	107 ± 14	131 ± 45
1-min	117 ± 18	148 ± 54
2-min	114 ± 17	146 ± 47*

*indicates a significant difference ($p < 0.0167$) vs steady state exercise for paired t-test with a Bonferoni correction.

Discussion

The primary purpose of this study was to extend the TRIMPS concept from SS exercise to intermittent exercise. The primary outcome was the observation of the relationship between the session RPE and the summated HR score. The results provided that the session RPE and summated HR score were not systematically affected during interval training compared to SS training.

Various physiological responses were compared during interval sessions of varying durations and during SS. The sessions each lasted 30-min and each of the measured physiological variables (HR, VO_2, RPE, and BLa) rose from rest to 10-min and leveled off to near the SS values for the duration.

All previous research using similar means of monitoring the intensity of an exercise session dealt primarily with SS exercise sessions (5,6,10,11,18). The current study confirms a means monitoring the intensity of interval training, which is understood to produce a greater training effect than steady state exercise in many athletes (2,8,12,13,16). The results of the present study suggest that the summated HR score and RPE score * session duration correlate well and follow a similar trend. From this we can conclude that this system of rating the intensity of an interval training session is reliable. The RPE method (session RPE * session duration) is a simplistic and convenient method for coaches to monitor the difficulty of a workout and to plan future methodical training sessions.

Despite the simplicity of this method to determine the intensity of an exercise session, there are still limitations. The limitations when using a heart rate monitor are: having access to a heart rate monitor, a poor connection, cross talk, problems with the battery, and using high heart rates. There are also limitations when using the RPE scale. These limitations include: the limits of the RPE scale; only 90% of the population can accurately use it; group biasing; and idea that the number range may be too general and not specific enough.

The results demonstrated a somewhat more strenuous nature of interval exercise with longer stage durations. During the 1-min and 2-min interval bouts BLa and RPE compared to the SS and 30-sec interval bouts. These observations are consistent with previous studies demonstrating that the duration of the "work" part of an interval bout is the primary definer of the response during interval training (2,8). In summary, the interval duration does not change the value of the session RPE. This validates that this method of monitoring training can be used during interval training sessions.

REFERENCES

1. AMERICAN COLLEGE OF SPORTS MEDICINE. Position stand on the recommended quantity and quality of exercise for developing and maintaining cardiorespiratory and muscular fitness and flexibility in healthy adults The recommended quantity and quality of exercise for developing and maintaining cardiorespiratory and muscular fitness and flexibility in healthy adults. *Med.& Sci. Sports Exerc.* 30: 975-991, 1998.

2. Astrand, P. O., T.E. Eddy, B. Salton, and J. Stenberg. Cardiovascular output during submaximal and maximal work. *J. Appl. Physiol.* 19: 268-274, 1964.

3. Balady, G. J., B. Chaitman, D. Driscoll, C. Foster, E. Froelich, N. Gordon, R.Pate, J. Rippe, and T. Bazzarre. Recommendations for cardiovascular screening, staffing, and emergency policies at health/fitness facilities. *Med.& Sci. Sports Exerc.* 30:1009-1018, 1998.

4. Borg, G., P. Hassman, and M. Lagerstrom. Perceived exertion related to heart rate and blood lactate during arm and leg exercise. *Eur. J. Appl. Physiol.* 65: 679-685. 1987.

5. Busso,T., R. Candan, and J. Lacour. Fatigue and fitness modeled from the effects of training on performance. *Eur. J. Appl. Physiol.* 69:50-55, 1994.

6. Cooper, K. H. *Aerobics*. New York: Bantam Books. 1968.

7. Edwards, S. *The Heart Rate Monitor Book*. Sacramento, CA: Fleet Feet Press. 1990.

8. Essen, B. Studies on the regulation of metabolism in human skeletal muscle using intermittent exercise as an experimental model. *Acta Physiol Scand.* 454: 1-32, 1978.

9. Faria, I. E. Cardiovascular response to exercise as influenced by training of various intensities. *Res. Quart.* 41: 44-50, 1970.

10. Fitz-Clarke, J.R., R. H. Morton, and E.W. Banister. Optimizing athletic performance by influence curves. *J. Appl. Physiol.* 71:1151-1158, 1991.

11. Foster, C. Monitoring training in athletes with reference to overtraining syndrome. *Med.& Sci. Sports Exerc.* 30:1164-1168, 1997.

12. Foster C., L. Hector, A. Snyder, and R. Welsh. Athletic performance in relation to training load. *Wisc. Med. J.* 6:370-374, 1996.

13. Gaiga, M.C. and D. Docherty. The effect of an aerobic interval training program on intermittent anaerobic performance. *Can. J. Appl. Physiol.* 20:452-464, 1995.

14. Gorostiaga, E.M., C.B.Walter, C. Foster, and R.C. Hickson. Uniqueness of interval and continuous training at the same maintained exercise intensity. *Eur. J. Appl. Physiol.* 63:101-107, 1991.

15. Hickson, R. C., Foster, M.L. Pollack, T.M. Galassil, and S. Rich. Reduced training intensities and loss of aerobic power, endurance and cardiac growth. *J. Appl. Physiol.* 58: 492-499, 1985.

16. Lindsay, F.H., J.A. Hawley, K.H. Myburgh, H.H. Schomer, T.D. Noakes, and S.C. Debbus. Improved athletic performance in highly trained cyclists after interval training. *Med. Sci. Sport Exerc.* 28:1427-1434, 1996.

17. Morton, H.R., J.R. Fitz-Clarke, and E.W. Banister. Modeling human performance in running. *J. Appl. Physiol.* 69:1171-1177, 1990.

18. Mujika, I., T. Busso, L. Lacoste, F. Barale, A. Geyssant, and J. Chatard. Modeled responses to training and taper in competitive swimmers. *Med. Sci. Sport Exerc.* 28: 251-258, 1996.

19. Stegmann, H. and W. Kindermann. Comparison of prolonged exercise tests at the individual anaerobic threshold and the fixed anaerobic threshold of 4 mmol/l lactate. *Int. J. Sports Med.* 3:105-110, 1982.

APPENDIX A

INFORMED CONSENT FORM

INFORMED CONSENT FORM

The Effect of Different Interval Durations and Magnitudes on Measures of Exercise Intensity

1. I ___________________, give my informed consent to participate in this study designed to evaluate the effect of different interval magnitudes and durations on measures of exercise intensity. I have been informed 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-La Crosse. 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.

2. I have been informed that my participation in this study will involve my participation in eight cycling tests performed on a cycle ergometer, each lasting approximately 30 minutes with at least 48 hours in between each session (see graph). During these studies my maximal aerobic power (VO_{2max}) will be measured by collecting the air I breathe through a scuba type mouthpiece. My heart rate will be measured by radio telemetry (Polar Heart Rate Monitor). The concentration of lactic acid in by blood will be measured in samples obtained from my fingertips. My perceived exertion will be measured using a rating scale. These studies will also involve a preliminary test on a cycle ergometer to determine VO_2, blood lactate, and individual anaerobic threshold. The studies will take place in the Human Performance Laboratory of the University of Wisconsin-La Crosse.

3. I have been informed that I may experience a high level of fatigue as a result of the studies, similar to a training session or cycle competition. I am aware that I will perform a warm up and cool down in conjunction with each session. A sterile lancet will be used to draw blood samples from the fingertips, taken to measure blood lactate. I should also expect to have sore fingers from the multiple puncture sites. Theoretically, there exists the possibility of serious complications (e.g. heart attack), however, in the population selected for this study the risk approximates zero. I have been informed that the testing will be supervised by individuals trained in CPR. There is an established emergency protocol in place in the laboratory.

4. I have been informed that the primary benefits that I might expect from participating in this study are the high intensity workouts, increases in VO_2 max, and experience using the rating of perceived exertion monitoring system. Additionally, my own data will be shared with me with the intent to help me optimize my own athletic career.

5. I have been informed that there are no "disguised" procedures in this study. All procedures can be taken at face value.

6. I have been informed that I am free to withdraw from this study at any time with out penalty.

7. 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

Importance of Frequency, Intensity, and Duration

Mujika (11) reviewed the importance of exercise intensity on cardiorespiratory fitness. Studies revealed that in an athletic population, VO_2 max increases were noticed after training at 80-100% of VO_2 max. However, subjects that exercised at or below 50% VO_2 max demonstrated little or no improvements in work capacity or VO_2 max. Faria (4) observed no improvements in work capacity after training at a relatively low heart rate of 120-130 bpm. These studies concluded that intensity of exercise is the key factor to elicit a change in work capacity and in VO_2 max.

Hickson, Foster, Pollack, Galassi, and Rich (7) evaluated the effects of reduced training intensity. After a 10 week high intensity training program, the intensity was reduced by either 1/3 or 2/3, while the duration and frequency remained constant. As a result of the decreases in training intensity, aerobic power, VO_2 max, and cardiac enlargement were decreased.

Training frequency and duration are also of clear importance to the magnitude of the training effect, but their importance appears to be secondary to training intensity. The effect of training frequency was studied by Mujika et al. (12) during a 6 week swimming program involving two groups. One group practiced two times a day for 1.5 hours each session and the other group practiced once a day for 1.5 hours. The group with the greater training frequency did not demonstrate enhanced performance.

Hickson and Rosenkoetter (9) studied the effect of reduced training frequencies on the maintenance of increased aerobic power. The test protocol involved 10 weeks of high intensity endurance training involving 40-min of running or cycling, 6 days a week. For the next 15 weeks training frequency was reduced to 4 days a week, or 2 days a week, with no change in duration or intensity. During the first 10 weeks, the average increase of VO_2 max was 25% on the bicycle and 20% on the treadmill. During the 15 week reduced training period, the two-day a week and the four day a week VO_2 max values remained about the same. They concluded that to increase VO_2 max, more exercise is required than the amount of exercise required to maintain VO_2 max.

Hickson et al. (8) evaluated the effects of reduced training duration. The protocol involved high intensity training 40-min, 6 days per week for 10 weeks. During the following 15 weeks, the training duration was reduced to 26-min a day or 13-min a day with no changes in frequency or intensity. The VO_2 max was maintained at baseline levels; however, performance was not improved during the decrease in training duration.

Quantifying Exercise

From the standpoint of a global understanding of the training response, it would be ideal if there was an effective way to integrate the combined effects of intensity, frequency, and duration into a single number representing the "input" to the system that might result in a particular "output" or improved performance related to training. The first systematic attempt to accomplish this goal was the "aerobics" point system developed by Cooper in 1968 (2). This approach used an estimate of the absolute exercise intensity multiplied by duration to yield a single number, "points," that represented the training input from the activity. This system is conceptually attractive because of its simplicity and the ability to combine the effects of multiple modes of exercise. However, given that relative, rather than absolute, exercise intensity is the more powerful training stimulus, the utility of this method was fundamentally limited.

Companion studies by Morton, Fitz-Clarke, and Banister (10), and Fitz-Clarke, Morton and Bannister (9) developed the concept of TRIMPS or the "training impulse." This was a method of describing changes in both fitness and fatigue resulting from training and how they contribute to changes in performance. TRIMPS was systematically quantified as the product of training durat on and intensity (5,10). Intensity was calculated as the average heart rate multiplied by a nonlinear metabolic adjustment, multiplied by the duration of effort (10). The TRIMPS concept demonstrated that the training input dose affected performance both positively and negatively, the positive effect being fitness and the negative effect, fatigue. The combined sum of these effects resulted in a single number, which is considered to represent performance ability. Morton et al. (10) tested this model by performing an experimental validation, although with only two subjects. A 28 day training study was performed which resulted in the predicted performances being consistent with the observed criterion performance. Using the mathematical model of the TRIMPS concept, Fitz-Clarke et al. (5) used an influence curve technique to optimize athletic performance through training and tapering. The curve was a conceptualization of the effect of each consecutive day's training on subsequent performance. When the training impulse was multiplied by the influence curve, a product function was produced. This function represented the theoretical performance at a given time. Fitz-Clarke et al. (5) found this model to be useful to plan for a single event or group of events. The model predicted that a best performance could only be accomplished once a season. This performance requires a period of tapering which compromises training for future events. The use of influence curves provides a tool to study the effect of training on performance at any given time. The TRIMPS model is very attractive conceptually and deserves future study. It is limited, however, by the need to have an accurate record of HR during training to serve as the basis for the intensity component of the training impulse. While this is not overwhelmingly difficult given the widespread use of electronic HR monitors, if the athlete forgets to use their HR monitor or the monitor malfunctions, the estimate of the training impulse for that day is limited. Similarly, for very high intensity exercise where the HR fails to reflect the magnitude of the exercise load, the method is limited.

The TRIMPS concept has been further developed by Busso, Candan, and Lacour (1) and Mujika et al. (12) using a rating system based on percentages of maximal possible performances to represent the exercise intensity. Busso et al. studied the effects of training on performance using time-varying parameters (1). This confirmed that a systems model composed of both fitness and fatigue variables results in a good representation of the change in performance during training. Mujika et al. (12) expanded the TRIMPS concept during tapering, variations in training, and performance variables. The statistical significance of the performances confirmed that the TRIMPS concept was applicable to describe the relationship between training and performance. Enhanced performance could be attributed primarily to reduced negative influences of training during tapering (e.g., reduced fatigue). Positive influences of training (e.g., fitness) did not improve, nor were they compromised by reduced training sessions (12).

Foster (6) used a modification of the rating of perceived exertion (RPE) scale to replace heart rate (HR) as a marker of training intensity in the TRIMPS conceptual model. He demonstrated a good relationship between the calculated training load (session RPE * duration) and exercise intensity scores based on % HR reserve, the HR-blood lactate relationship, and a summated HR score (6). This approach has the advantage of not being dependent on the availability of HR data and of being able to account for very high intensity exercise such as resistance exercise, plyometrics, and sprint training.

To date, all of the approaches based on the TRIMPS concept by various authors (1,2,5,6,12) have related primarily to SS exercise. However, given the importance of training intensity and the frequent use of interval training by competitive athletes, we need to know how and if the TRIMPS concept applies during interval training.

Interval Training

Interval characteristics can be compared to that of SS exercise. In a landmark study in 1978 by Essen (3), heart rate and oxygen uptake during intermittent exercise were similar to continuous exercise at a similar average workload, corresponding with 50-60% VO_2 max. Continuous exercise at a similar workload as the peak workload during intermittent training required 100% VO_2 max. Lactate increased in a similar fashion during intense intermittent exercise bouts and during moderate intensity continuous exercise. During intense continuous exercise bouts, a significant increase in lactate was observed. Essen (3) studied the characteristics of 60-min of continuous exercise at 50-60% VO_2 max and 60-min of intermittent exercise, 15-sec on, 15-sec off, at 100% VO_2 max. Intermittent exercise at equivalent average power output as continuous exercise produced a smaller accumulation of lactate and smaller glycogen utilization than continuous exercise. The smaller glycogen utilization during intermittent exercise could be due to a greater oxidative metabolism, and in part to an increased contribution from lipids during recovery periods (3).

REFERENCES

1. Busso,T., R. Candan, and J. Lacour. Fatigue and fitness modeled from the effects of training on performance. *Eur. J. Appl. Physiol.* 69:50-55,1994.

2. Cooper, K. H. *Aerobics*. New York: Bantam Books. 1968.

3. Essen, B. Studies on the regulation of metabolism in human skeletal muscle using intermittent exercise as an experimental model. *Acta Physiol. Scand.* 454:1-32, 1978.

4. Faria, I. E. Cardiovascular response to exercise as influenced by training of various intensities. *Res. Quart.* 41:44-50, 1970.

5. Fitz-Clarke, J.R., R.H. Morton, and E.W. Banister. Optimizing athletic performance by influence curves. *J. Appl. Physiol.* 71:1151-1158, 1991.

6. Foster, C. Monitoring training in athletes with reference to overtraining syndrome. *Med.& Sci. Sports Exerc.* 30:1164-1168, 1997.

7. Hickson, R. C., C. Foster, M.L. Pollock, T.M. Galassi, and S. Rich. Reduced training intensities and loss of aerobic power, endurance and cardiac growth. *J. Appl. Physiol.* 58: 492-499, 1985.

8. Hickson, R.C., J.C. Kankis, J.R. Davis, A.M. Moore, and S. Rich. Reduced training duration effects on aerobic power, endurance, and cardiovascular growth. *J. Appl. Physiol.* 53: 255-259, 1982.

9. Hickson, R. C. and M.A. Rosenkoetter. Reduced training frequencies and maintenance if increased aerobic power. *Med. Sci. Sport Exerc.* 13:13-16, 1981.

10. Morton, H.R., J.R. Fitz-Clarke, and E.W. Banister. Modeling human performance in running. *J. Appl. Physiol.* 69:1171-1177, 1990.

11. Mujika, I. The influence of training characteristics and tapering on the adaptations in highly trained individuals: A review. *Int. J. Sports Med.* 19:439-436, 1998.

12. Mujika, I., T. Busso, L. Lacoste, F. Barale, A. Geyssant, and J. Chatard. Modeled responses to training and taper in competitive swimmers. *Med. Sci. Sport Exerc.* 28: 251-258, 1996.