ABSTRACT

CROUTER, S. E. Physiological comparison of incremental treadmill exercise and free range running. MS in Adult Fitness/Cardiac Rehabilitation, August 2000, 35pp. (C. Foster)

In view of previous studies demonstrating greater physiological responses during free range cycle exercise than incremental laboratory exercise, this study compared physiological responses during incremental treadmill exercise and free range running. Fifteen competitive cross country runners (19 ± 2 yr) from the University of Wisconsin-La Crosse performed an incremental treadmill test and an unpaced 1-mile run on an indoor 200 meter track. Physiological variables (VO_{2peak}, HR_{peak}, $VO_2 \bullet HR^{-1}{}_{peak}$, $V_{E\ peak}$) were measured using a portable metabolic gas analyzer. Blood lactate was measured post exercise. Outcome variables were analyzed with repeated measures ANOVA. Although directionally similar to previous studies with cycle ergometry, the observed peak values (track vs treadmill) for VO_2 (63.0 ± 7.4 vs 61.9 ± 7.2 ml • kg^{-1} • min^{-1}), V_E (147 ± 37 vs 144 ± 30 L • min^{-1}), HR (188 ± 5 vs 189 ± 7 beats • min^{-1}), and $VO_2 \bullet HR^{-1}$ (22.1 ± 4.4 vs 21.5 ± 4.5) were not significantly different. The observed peak values for BLa (14.4 ± 3.3 vs 11.7 ± 3.0 mmol • L^{-1}) were significantly different. The results are not in full agreement with previous findings from cycling studies with the exception of BLa. Whether this represents a fundamental lack of effect of free range exercise or is related to mode specificity remains to be determined.

PHYSIOLOGICAL COMPARISON OF INCREMENTAL TREADMILL EXERCISE AND FREE RANGE RUNNING

A MANUSCRIPT STYLE THESIS PRESENTED

TO

THE GRADUATE FACULTY

UNIVERSITY OF WISCONSIN–LA CROSSE

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MASTERS OF SCIENCE DEGREE

BY

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THESIS FINAL ORAL DEFENSE FORM

Candidate: Scott E. Crouter

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

Master of Science in Adult Fitness/Cardiac Rehabilitation

The candidate has successfully completed the thesis final oral defense.

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

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Garry Tymeson — Director of University Graduate Studies	3-20-00

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INTRODUCTION

Incremental ergometry is the normal laboratory technique for evaluating physiological responses to exercise and for determining reference values such as peak oxygen uptake (VO_{2peak}), ventilatory threshold (V_T), and peak heart rate (HR_{peak}). These physiological markers are, in turn, known to be well correlated to endurance performance (4,5,6,10,11,14,16,18,19,23,28,29). The concept of using incremental ergometry for measuring exercise capacity is based on early work suggesting a plateau in oxygen uptake (VO_2) despite increasing workloads (14,27) and on studies demonstrating that continuous incremental exercise protocols produce VO_{2peak} values comparable to those observed in the classical discontinuous protocols (15).

However, incremental exercise is not how humans, particularly athletes, perform exercise. Most typically athletes are trying to minimize the time to achieve a fixed amount of work (e.g., get to the finish line as quickly as possible). Recent studies in which this pattern of exercise was adopted (e.g., free range exercise) have demonstrated a greater magnitude of physiological responses than observed during incremental exercise. These studies call into question, at a fundamental level, the reasoning behind the concept of maximal oxygen uptake (VO_{2max}) and similar concepts based on incremental ergometry (7,8,12,22,24,25,26). Studies of free range exercise have until now been limited to cycle ergometry simply because ergometric technology has facilitated competitive simulation with specialized cycle ergometers. Treadmills have generally been too slow to respond to intended variations in velocity to allow for meaningful competitive simulations. However, with the advent of lightweight, portable respiratory gas analysis systems, it is now feasible to perform competitive simulations in the field rather than in the laboratory. Thus, the purpose of this study was to compare physiological responses (VO_{2peak}, HR_{peak}, peak oxygen pulse [$VO_{2peak} \bullet HR^{-1}_{peak}$], peak blood lactate [$Bla_{peak}$], and peak ventilation [V_{Epeak}]) between incremental exercise (a horizontal treadmill VO_{2max} test) and free range exercise (a one-mile run).

METHODS

Subjects. Fifteen healthy competitive runners (10 male, 5 female) from the University of Wisconsin-La Crosse (UWL) volunteered to participate. The subjects were cross country runners and had consistently trained on a regular basis (five days per week). Descriptive data of the subjects are presented in Table 1. All subjects were informed of the testing procedures and requirements and provided informed consent prior to testing (Appendix A). The protocol was approved by the University IRB before any data collection.

Protocol. Each subject's height and weight were measured prior to their first test. Respiratory metabolism was measured using open circuit spirometry with a lightweight portable metabolic system (K4b^2, Cosmed). Heart rate (HR) was monitored using radiotelemetry (Polar Vantage XL, Polar Instruments, Port

Table 1. Characteristics of Subjects (± SD)

	Male	Female
Age (yr)	19.4 ± 1.6	19.6 ± 1.5
Height (cm)	184 ± 5	167 ± 4
Weight (kg)	68.4 ± 5.4	57.4 ± 2.4
VO_{2peak} ($L \bullet min^{-1}$)*	4.51 ± 0.50	3.10 ± 0.26
VO_{2peak} ($ml \bullet min^{-1} \bullet kg^{-1}$)*	65.9 ± 4.3	54.0 ± 3.7
HR_{peak}*	188 ± 8	191 ± 6
% VO_2 at VT*	76.3 ± 9.1	75.2 ± 8.9
% VO_2 at RCT*	91.4 ± 5.1	92.4 ± 7.1
Peak Treadmill Velocity ($m \bullet sec^{-1}$)	5.88 ± 0.34	5.25 ± 0.44
Mile PR (sec)	271.40 ± 10.30	340.4 ± 17.76

* Treadmill max test

Washington, NY). Oxygen consumption (VO_2), ventilation, HR, and RER were recorded continuously and expressed as minute values based on a rolling one-minute integration of the data.

Treadmill test. The incremental test was performed on a motor driven treadmill. To ensure proper calibration of the $K4b^2$, a pneumotach flow calibration was performed using a three-liter calibration syringe. The $K4b^2$ was attached to the subject with the harness provided by Cosmed. This allowed for easy access and allowed for free movement by the subject.

Prior to testing, the subjects warmed up by walking for five minutes at 1.6 m • s^{-1} and 5% grade. The subjects performed a treadmill protocol at a constant 1% grade which started at 3.3 m • s^{-1} and 2.8 m • s^{-1} for the males and females, respectively. Every two minutes the speed was increased by 0.6 m • s^{-1} and 0.4 m • s^{-1} for the males and females, respectively until volitional fatigue. The VO_2, RER, and VCO_2 were measured every minute. After the test a blood sample was taken from a fingertip at one, three, five, and seven minutes of recovery (walking) and analyzed for lactate concentration using an enzyme electrode system (YSI Sport, Yellow Springs, OH).

One-mile run procedure. One one-mile run was performed on a 200m indoor track. The mile was run solo and was conducted with the metabolic system and HR monitor in place as described for the treadmill protocol. The subjects were instructed to run as hard as they could with the intent of completing the mile in minimal time. To facilitate pacing, splits were called to the subjects and recorded after each 200m segment. At the conclusion of the exercise bout, blood samples were taken at one, three, five, and seven minutes of recovery for blood lactate analysis.

Blood lactate analysis. Twenty-five microliters of capillary blood were taken from the fingertip at one, three, five, and seven minutes of recovery. The blood was placed in a buffer medium, which lysed the red blood cells. The concentration of lactate in the blood-buffer solution was analyzed using an enzyme electrode system (YSI Sport). The peak BLa was determined from a smoothed curve of blood lactate concentration versus time.

Statistical treatment. Group means and standard deviations were calculated for all physical characteristics (age, height, and body weight). Data on physiological outcome variables (VO_{2peak}, HR_{peak}, $VO_2 \bullet HR^{-1}{}_{peak}$, BLa_{peak}, and $V_{E\ peak}$) are reported as means and standard deviation (±SD). Means were compared with repeated measures analysis of variance to test the hypothesis that physiological outcome measures would be greater during free range exercise than during incremental exercise.

RESULTS

During the mile run, running velocity decreased through the third 400m and then increased to near the starting velocity over the last 400m. Mean (±SD) velocities at distances of 200, 400, 600, 800, 1000, 1200, 1400, and 1600m were 5.50 ± 0.65, 5.26 ± 0.64, 5.13 ± 0.59, 5.01 ± 0.56, 5.03 ± 0.54, 4.96 ± 0.50, 5.00 ± 0.58, and 5.21 ± 0.58 $m \bullet s^{-1}$, respectively (Fig. 1). This pacing pattern was consistent for most of the runners. With the exception of four subjects, everyone had their peak velocity during the first 200m. The other subjects had their peak velocity in the last 200m (two subjects) or during the fourth 200m or second 200m interval.

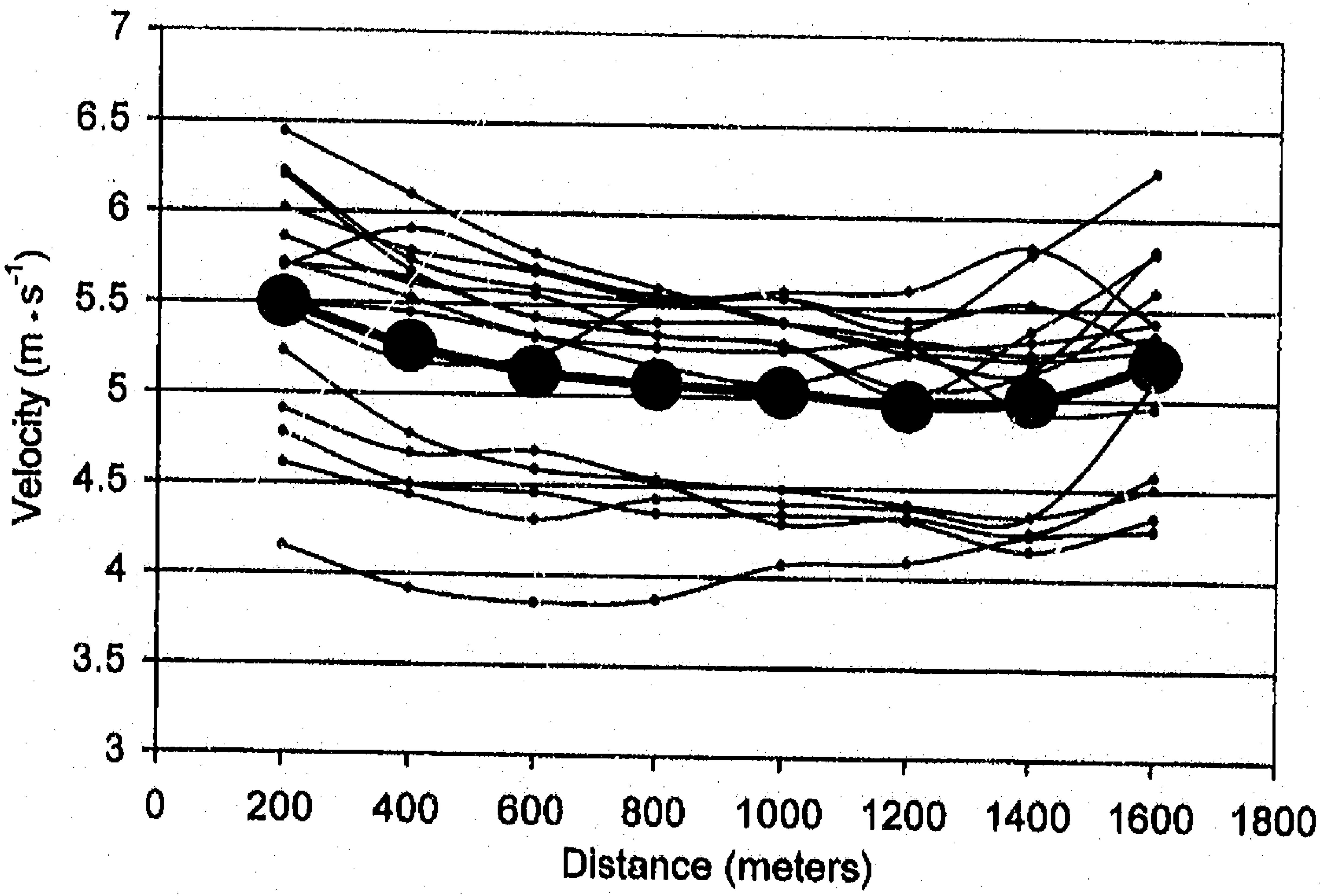

Figure 1--Serial responses of velocity for the one-mile run measured every 200m. The thick line with circles represents the mean, thin lines represent individual responses.

During the mile run, VO_2 increased over the first 400m and then essentially leveled off with slight variation for the next 1200m. Figure 2 shows the mean (±SD) VO_2 for distances 200, 400, 600, 800, 1000, 1200, 1400, and 1600m were 42.3 ± 8.5, 57.2 ± 6.4, 59.9 ± 6.7, 61.5 ± 7.0, 61.9 ± 6.8, 61.9 ± 7.1, 62.1 ± 7.7, 60.6 ± 8.2 ml • kg^{-1} • min^{-1}, respectively. Figure 3 shows the serial response of VO_2 during the incremental laboratory test. During the mile run there was a consistent VO_2 pattern for the subjects that did not seem to be related to variations in velocity (Fig. 4). Serial responses of the one-mile run versus the incremental laboratory test for VO_2 are show in Figure 5.

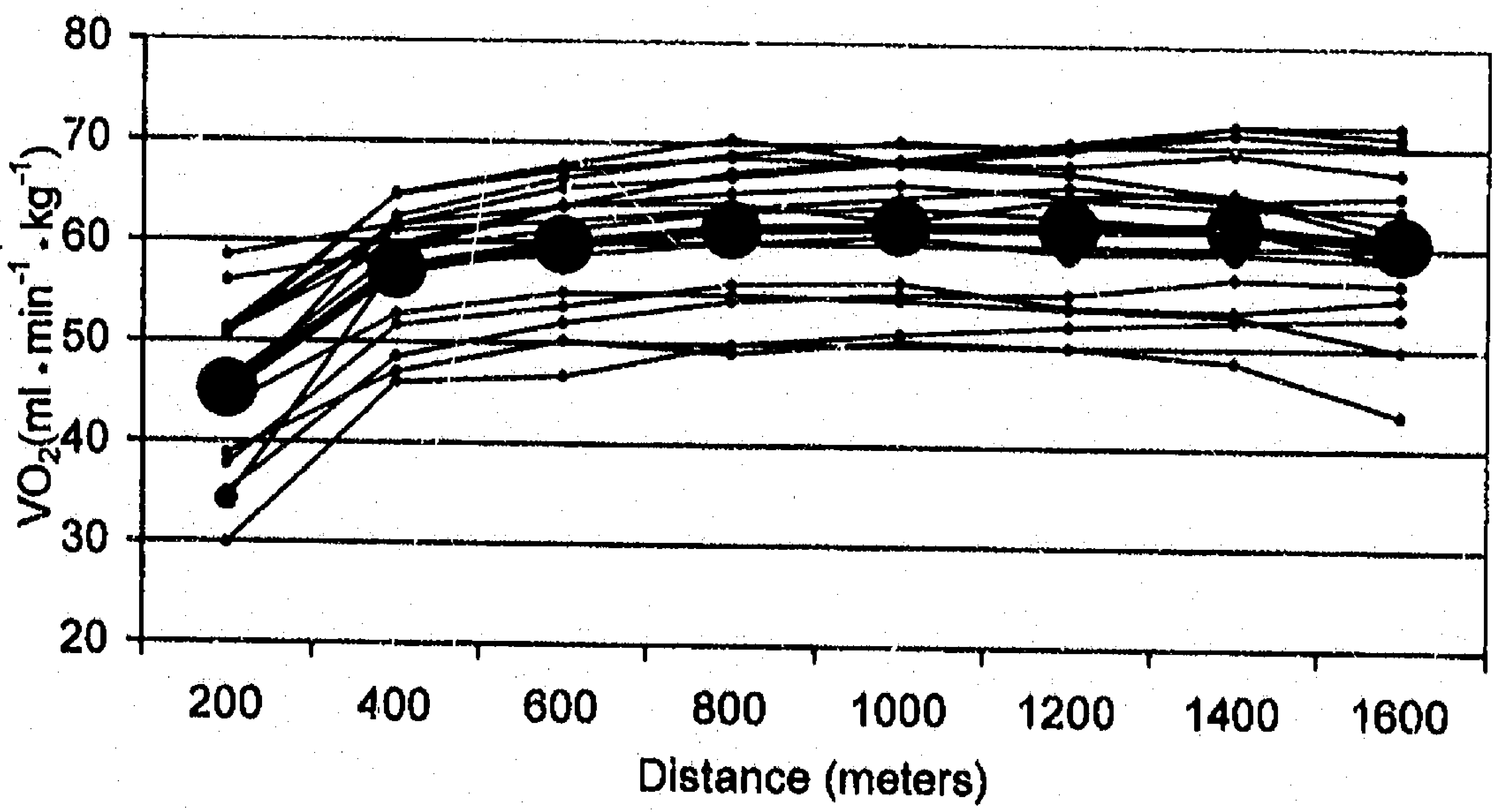

Figure 2-Serial response of VO_2 for the one-mile run, measured every 200m. Circles with thick line represents mean, thin lines represent individual responses.

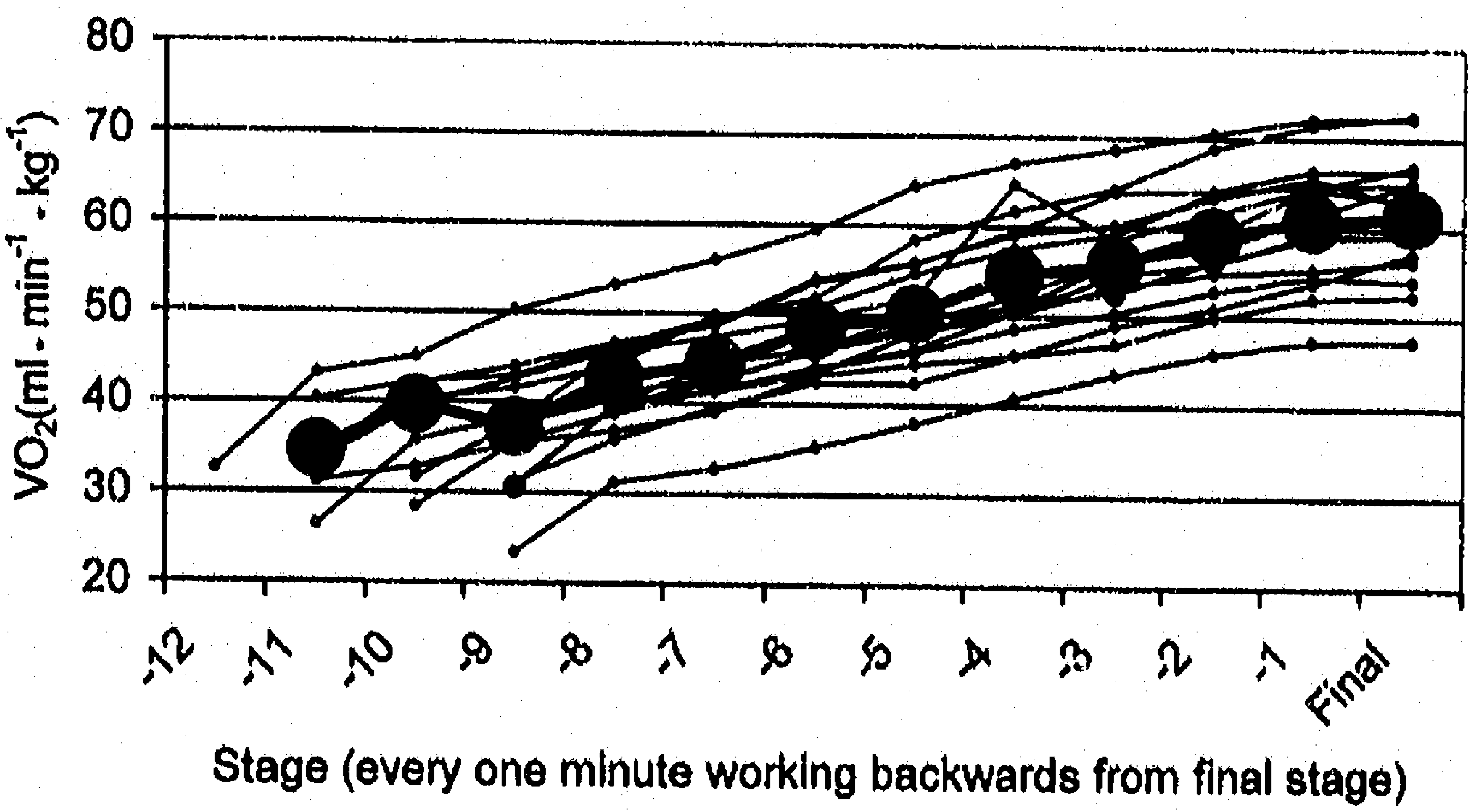

Figure 3-Serial response of VO_2 during the incremental max test. Measured every one-minute, starting with the final measurement and working backwards. The circles and thick line represents the mean, thin lines represent individual responses.

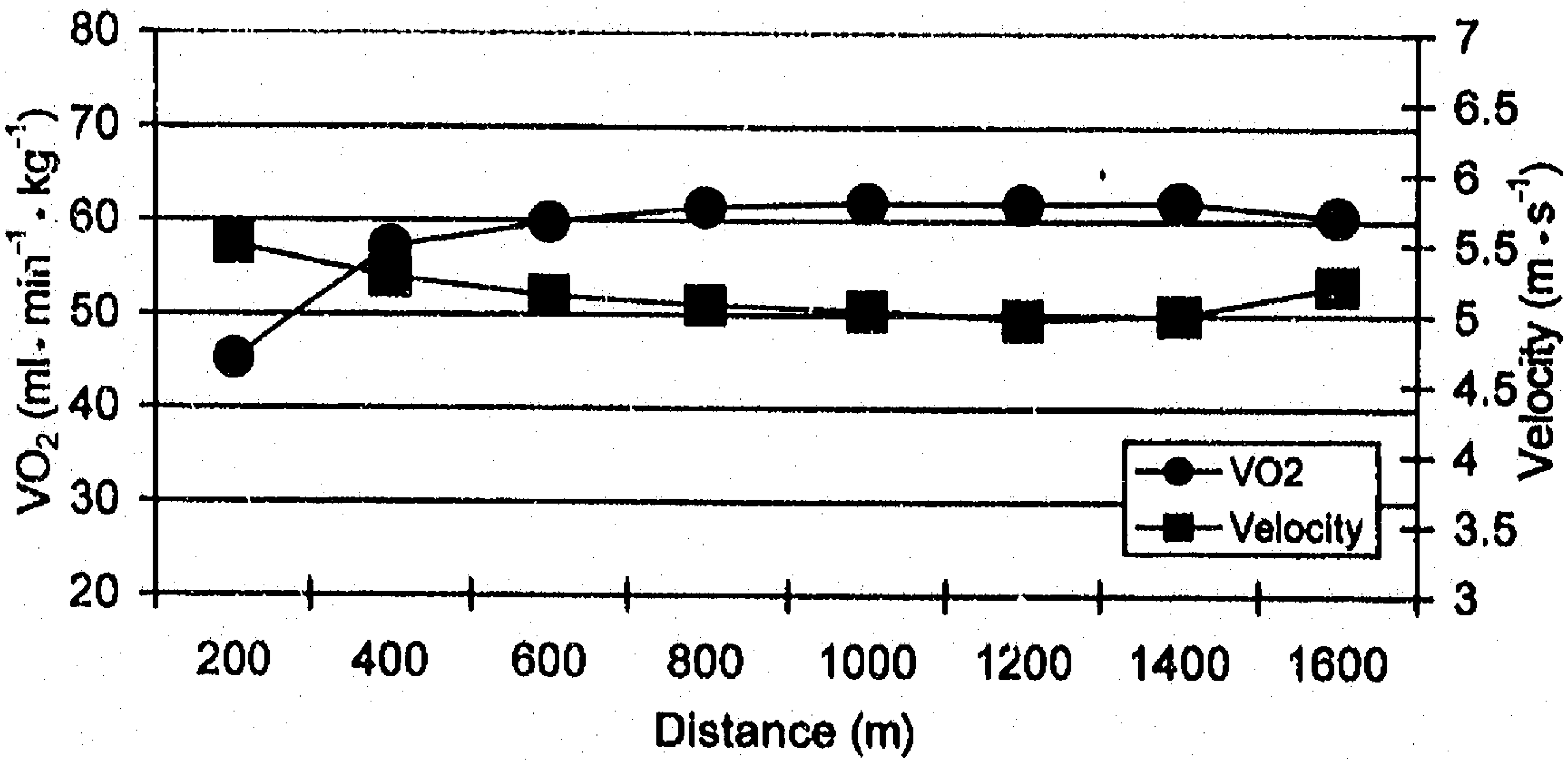

Figure 4-Average relationship of VO_2 and velocity, measured every 200m during the one-mile run.

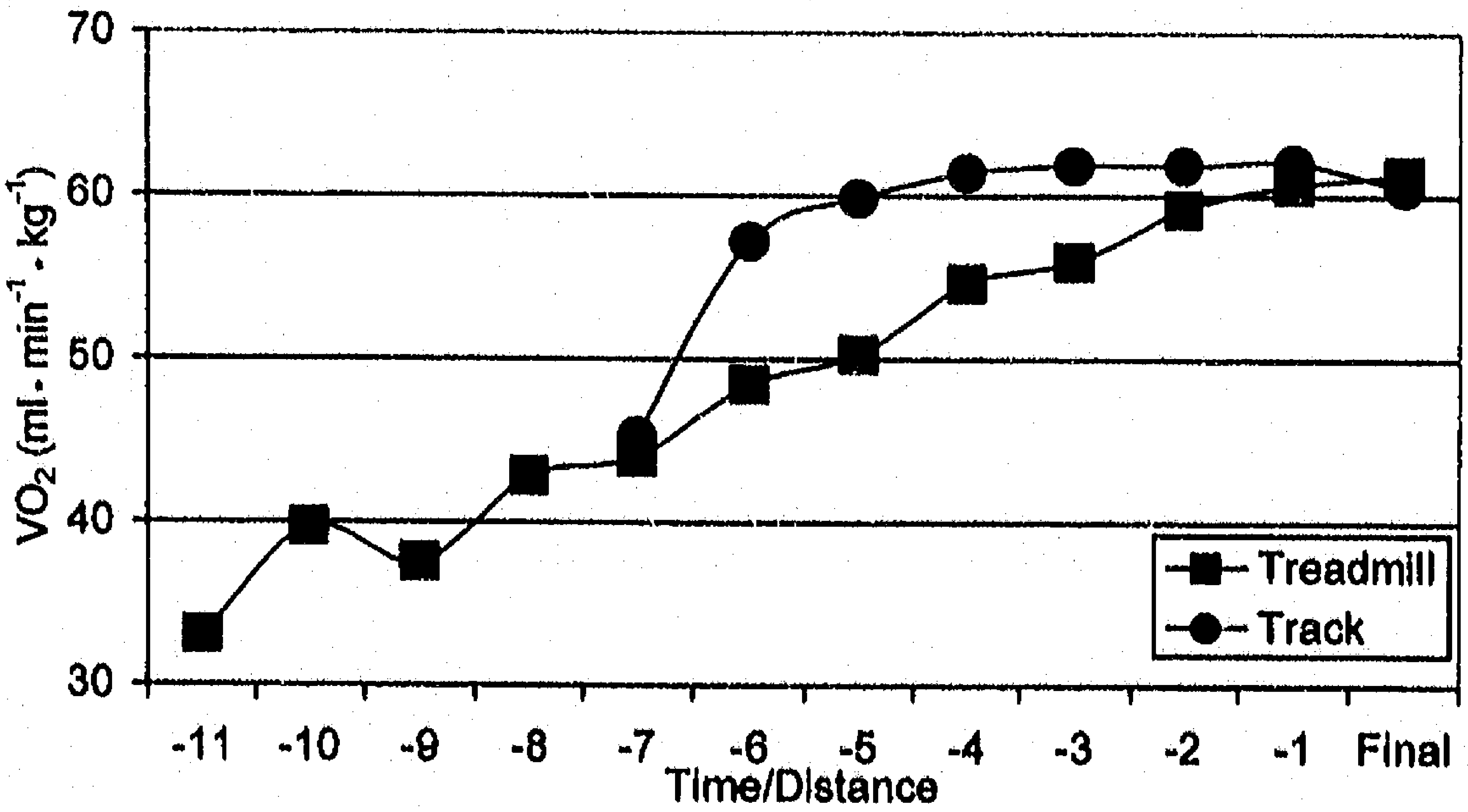

Figure 5-Average serial responses for VO_2 during the one-mile run and incremental test. Final represents the last 200m for the one-mile run and the last stage for the incremental test. The stages are every 200m for the one-mile run and every one min for the incremental test.

The observed peak values (track vs treadmill) for VO_2 (63.0 ± 7.4 vs 61.9 ± 7.2 ml • kg^{-1} • min^{-1}) (Fig. 6-7), V_E (147.37 ± 36.80 vs 143.85 ± 30.49 L • min^{-1}) (Fig. 8-9), HR (188 ± 5 vs 189 ± 7 beats • min^{-1}) (Fig. 10-11), and VO_2 • HR^{-1} (22.05 ± 4.41 vs 21.51 ± 4.54) (Fig. 12-13) were not significantly different. The observed peak values for BLa (14.4 ± 3.3 vs 11.7 ± 3.0 mmol • L^{-1}) were significant at the $p < .05$ level (Fig. 14-15). The peak BLa occurred for most individuals within the first minute (Fig. 16-17).

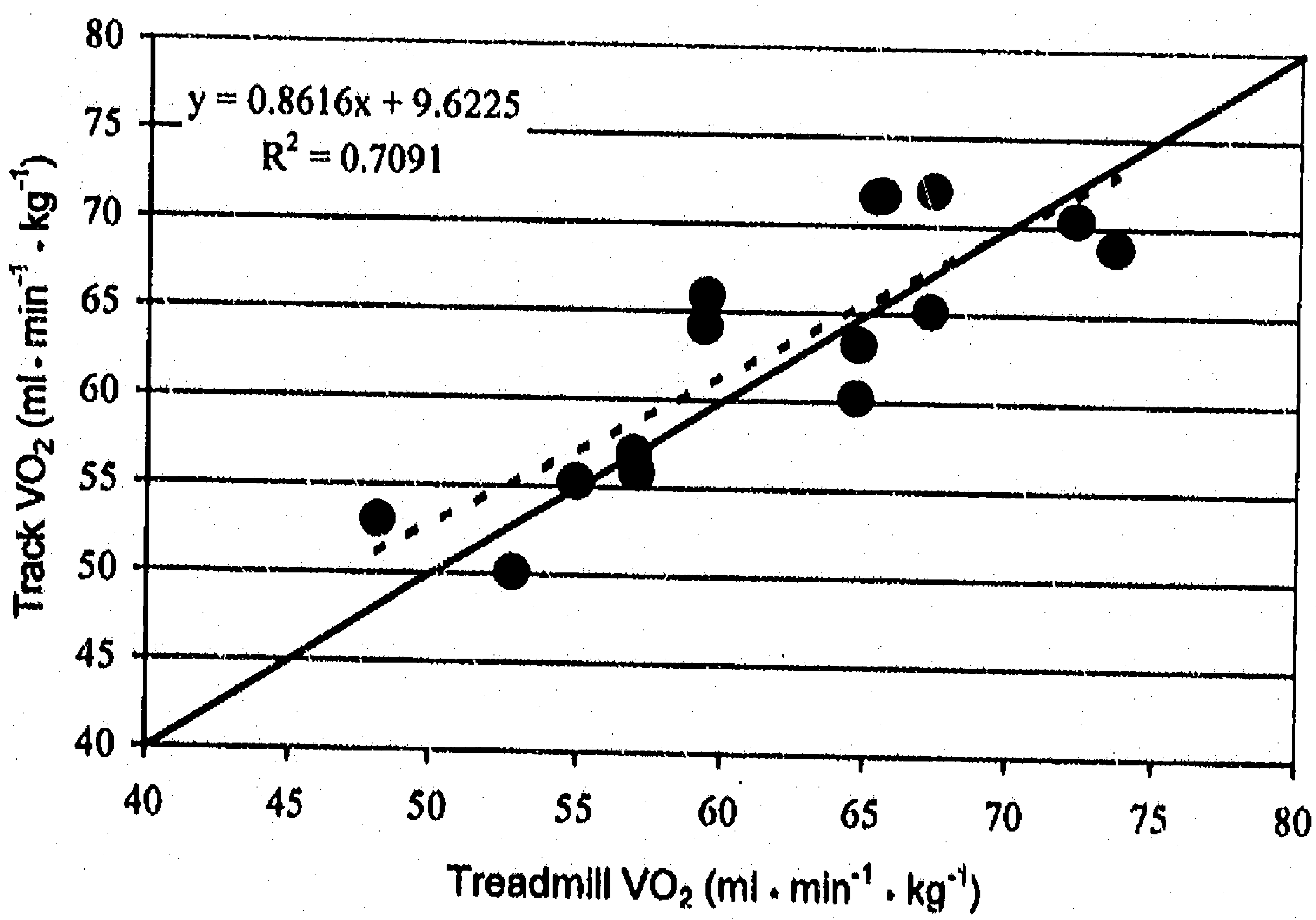

Figure 6-Relationship of VO_{2peak} between incremental test and one-mile run. Solid line represents line of identity and dashed line is regression line.

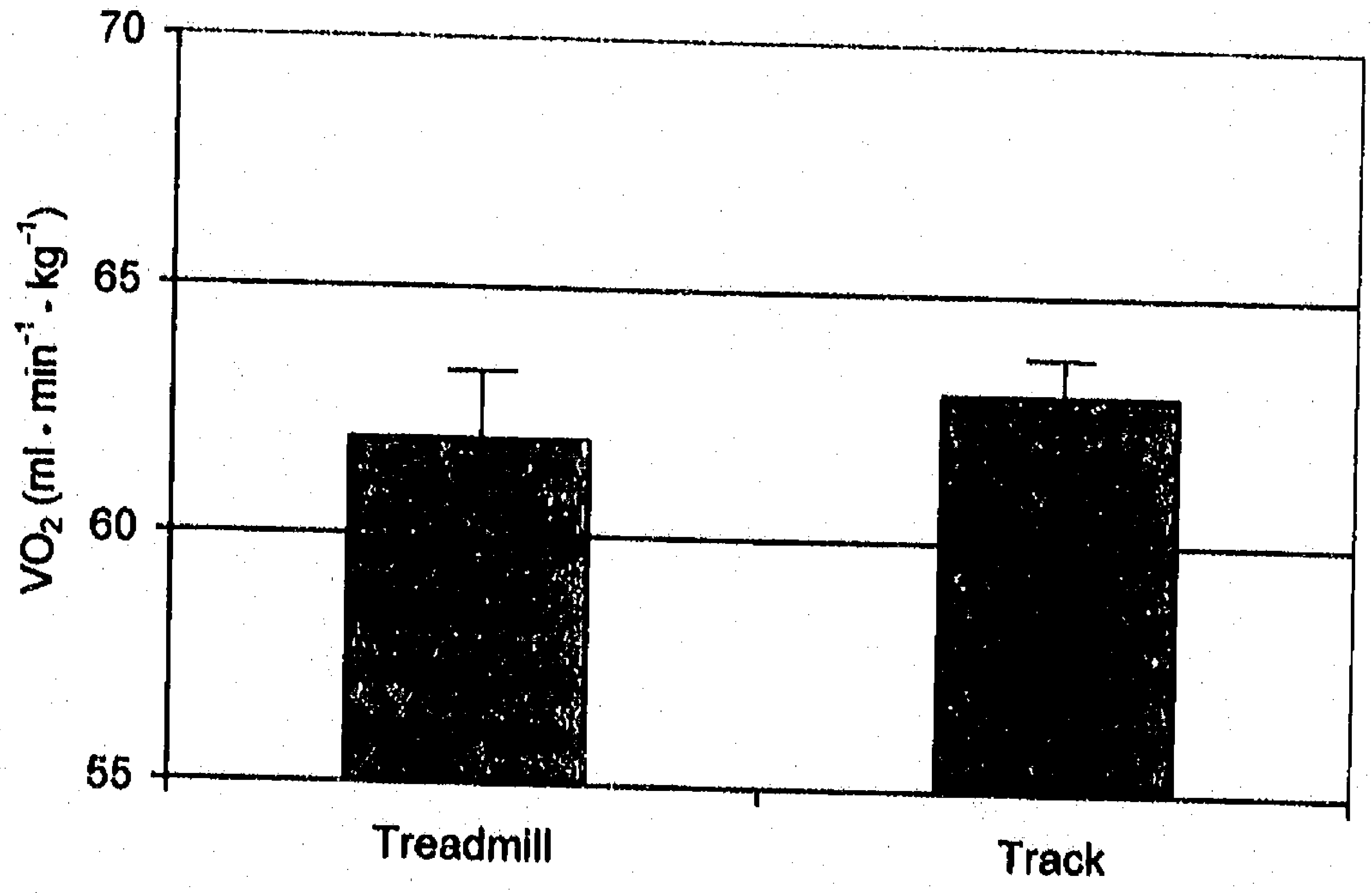

Figure 7-Mean VO_{2peak} of incremental test and one-mile run with standard error bars.

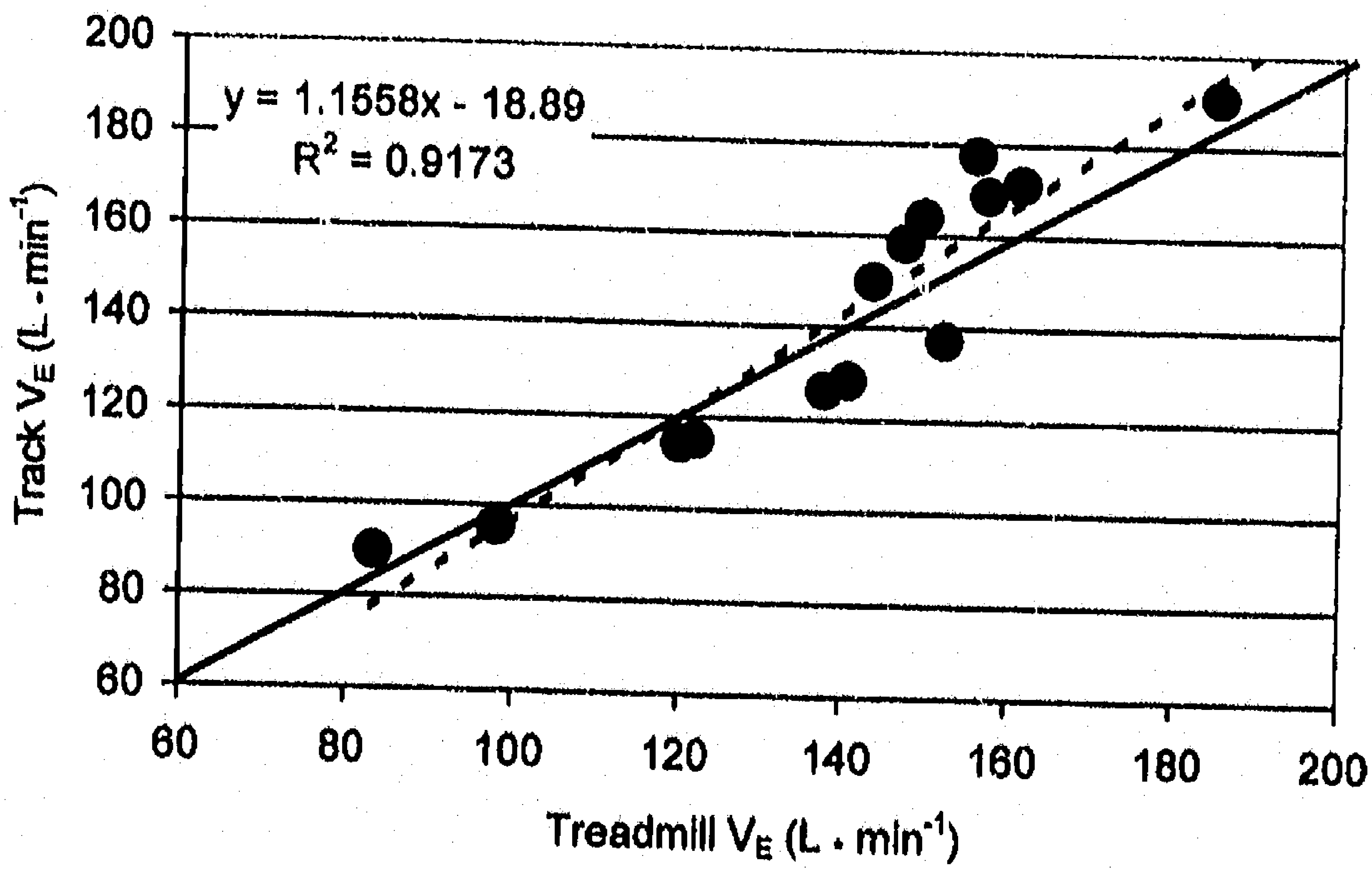

Figure 8-Relationship of V_{Epeak} between incremental test and one-mile run. Solid line represents line of identity and dashed line is the regression line.

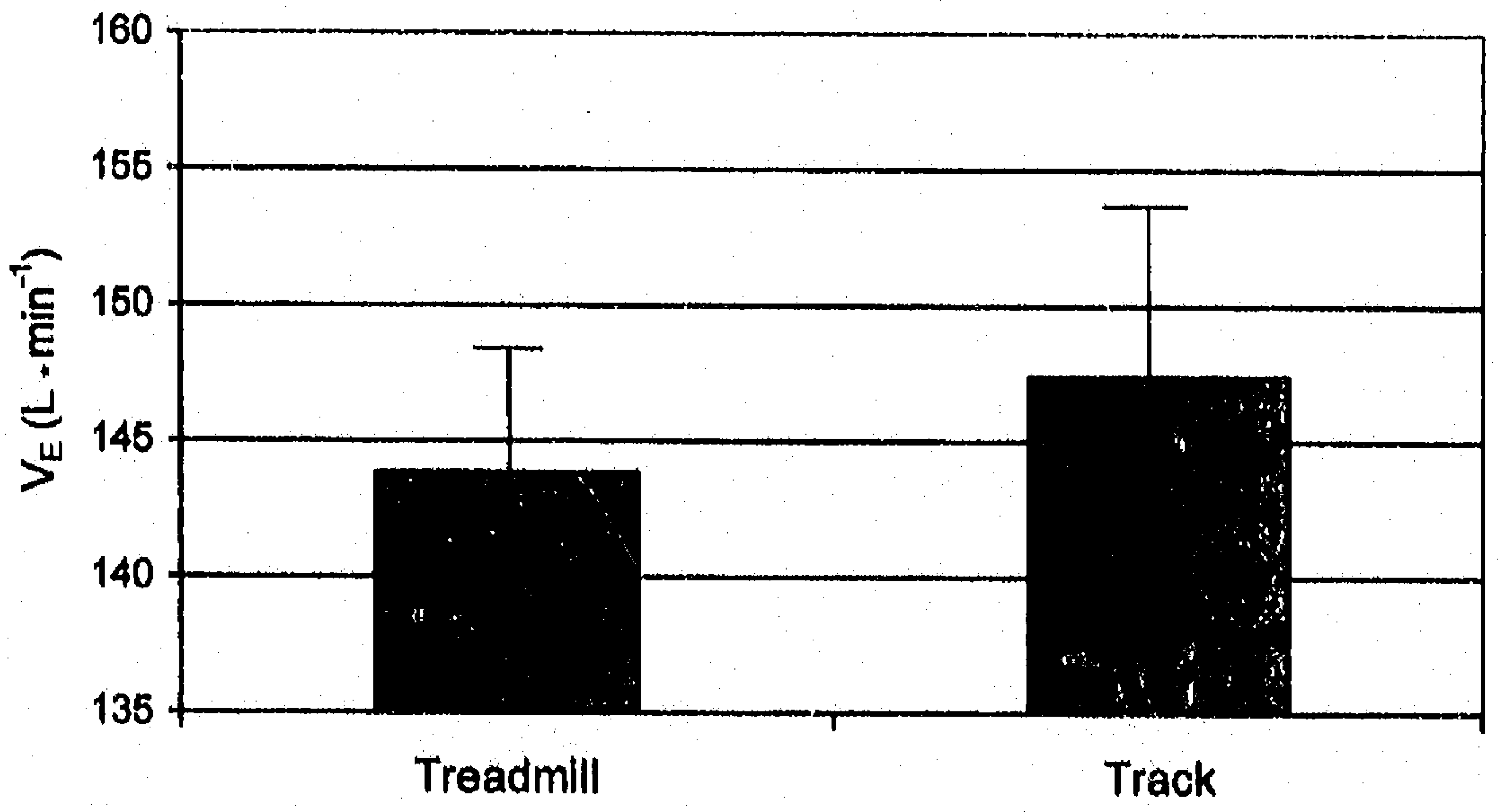

Figure 9-Mean V_{Epeak} of incremental test and one-mile run with standard error bars.

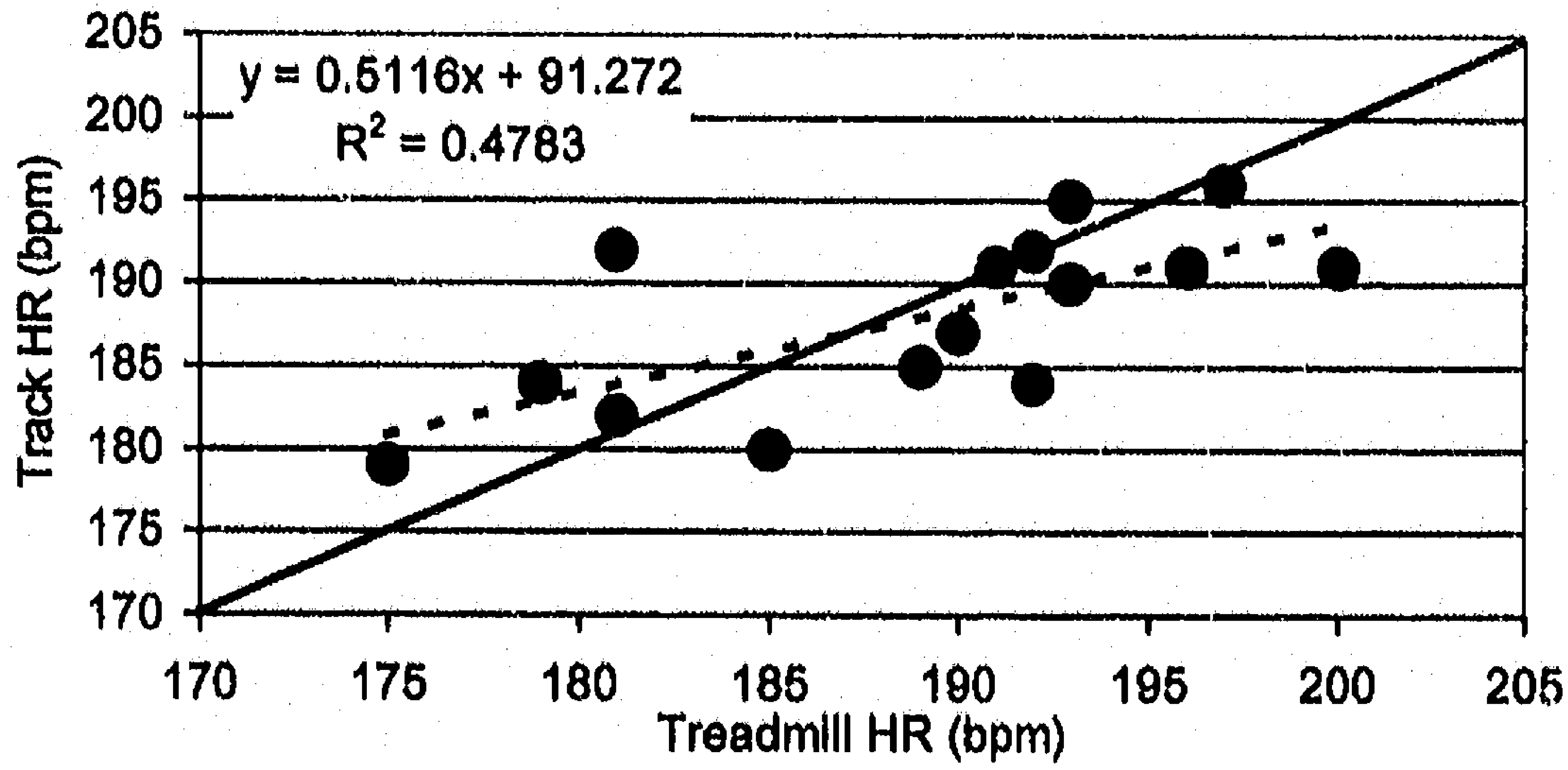

Figure 10-Relationship of HR_{peak} between incremental test and one-mile run. Solid line represents line of identity and dashed line is the regression line.

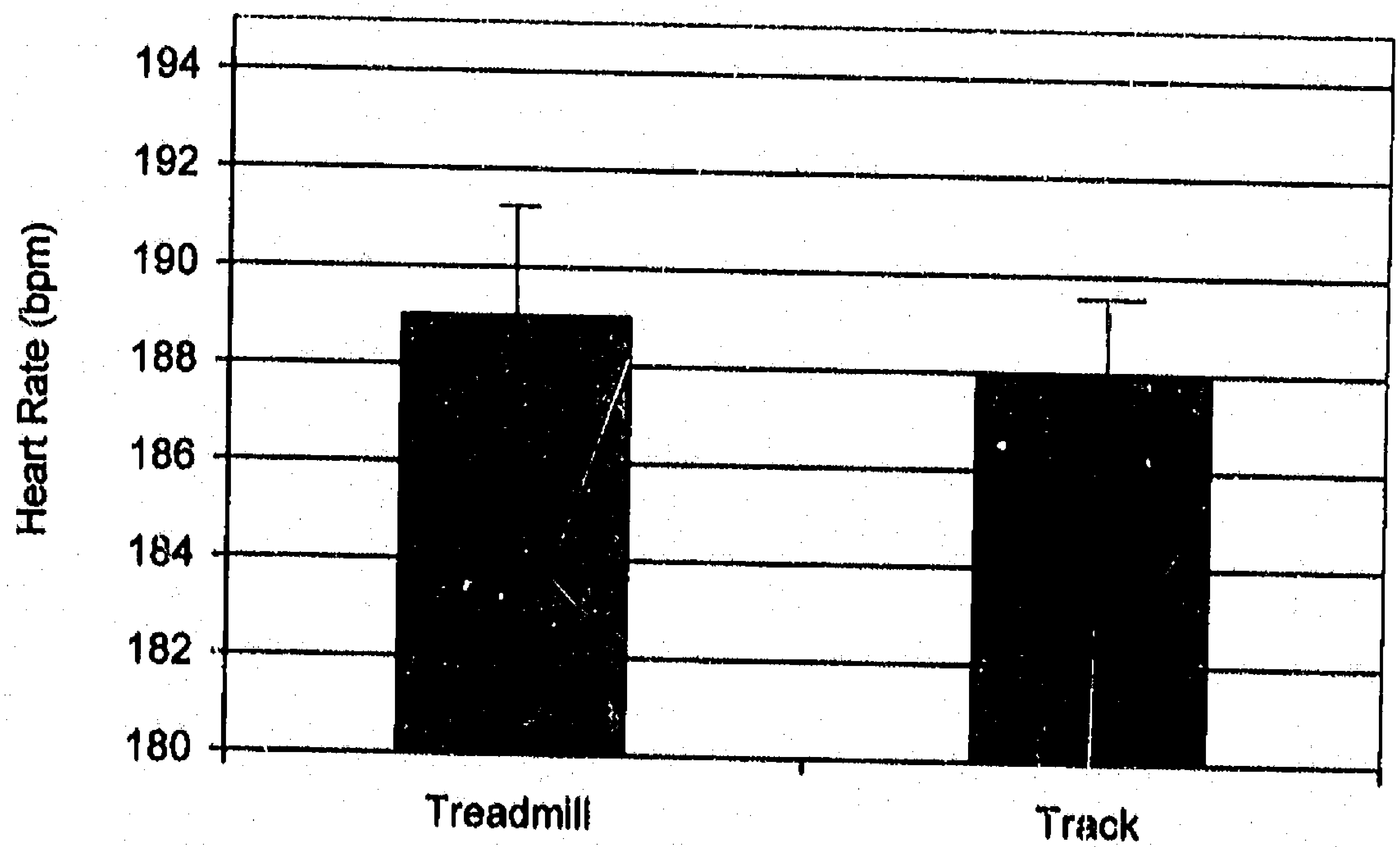

Figure 11-Mean HR_{peak} of incremental test and one-mile run with standard error bars.

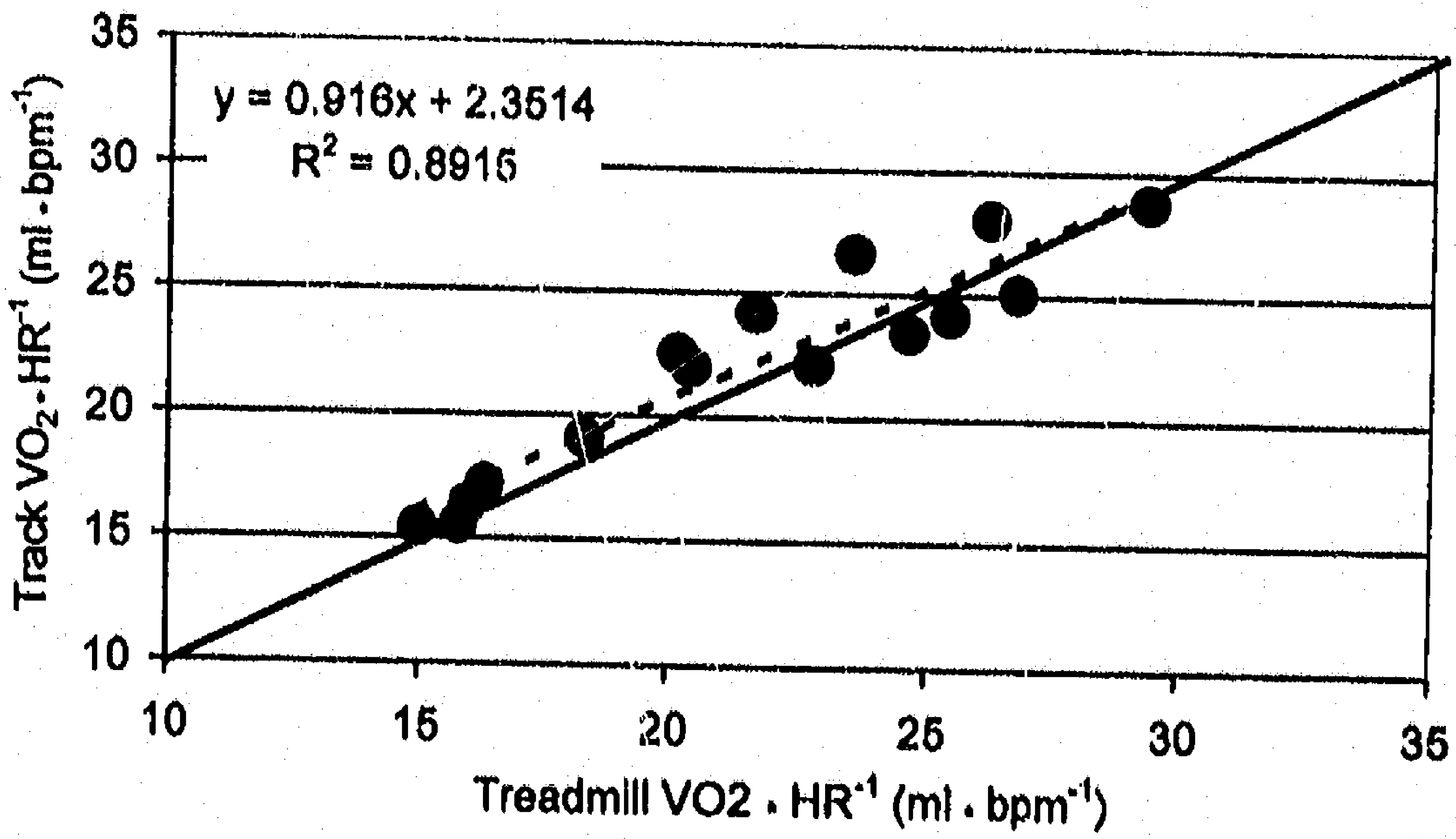

Figure 12-Relationship of $VO_2 \bullet HR^{-1}_{peak}$ between incremental test and one-mile run. Solid line represents the line of identity and dashed line is the regression line.

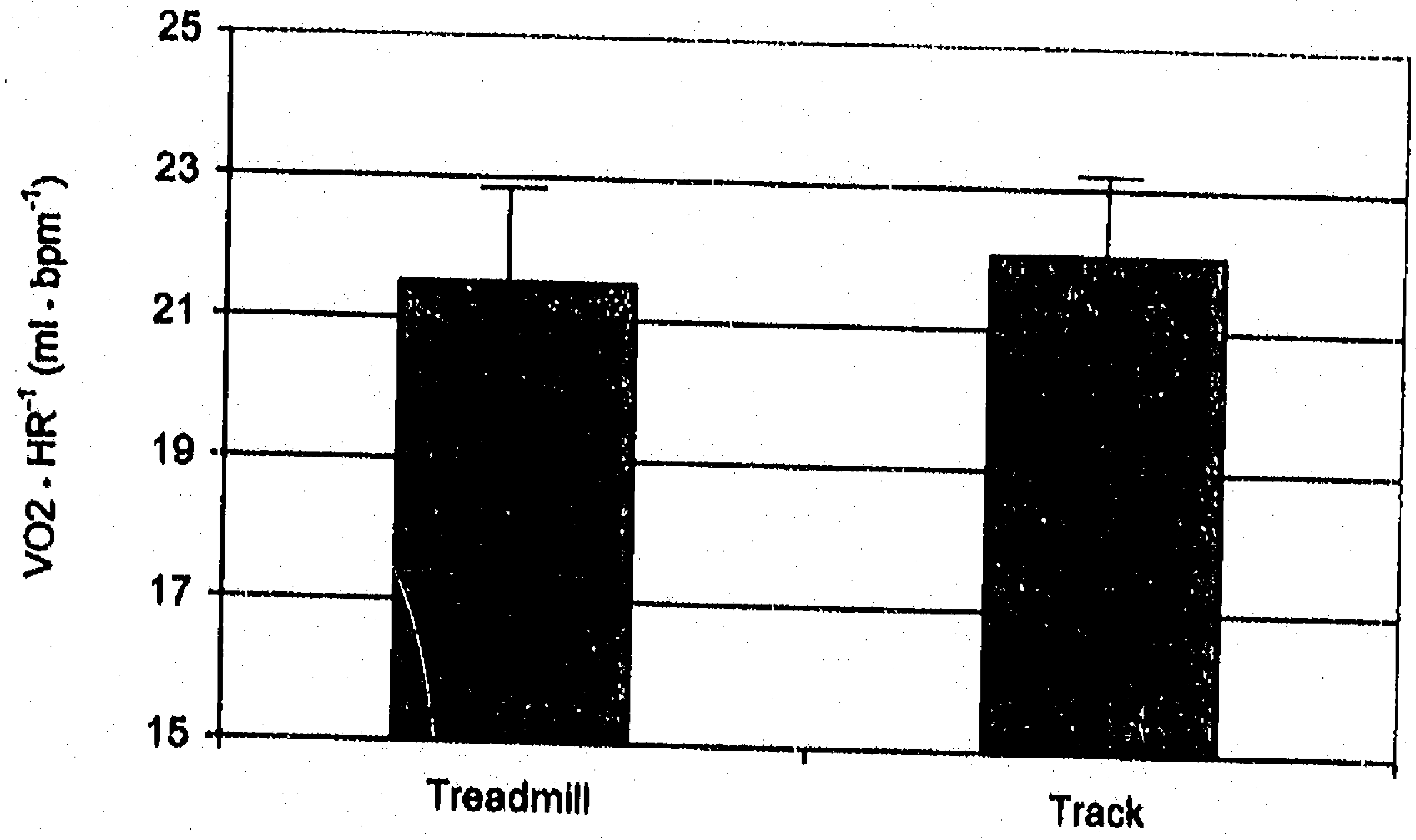

Figure 13-Mean $VO_2 \bullet HR^{-1}_{peak}$ of incremental test and one-mile run, with standard error bars.

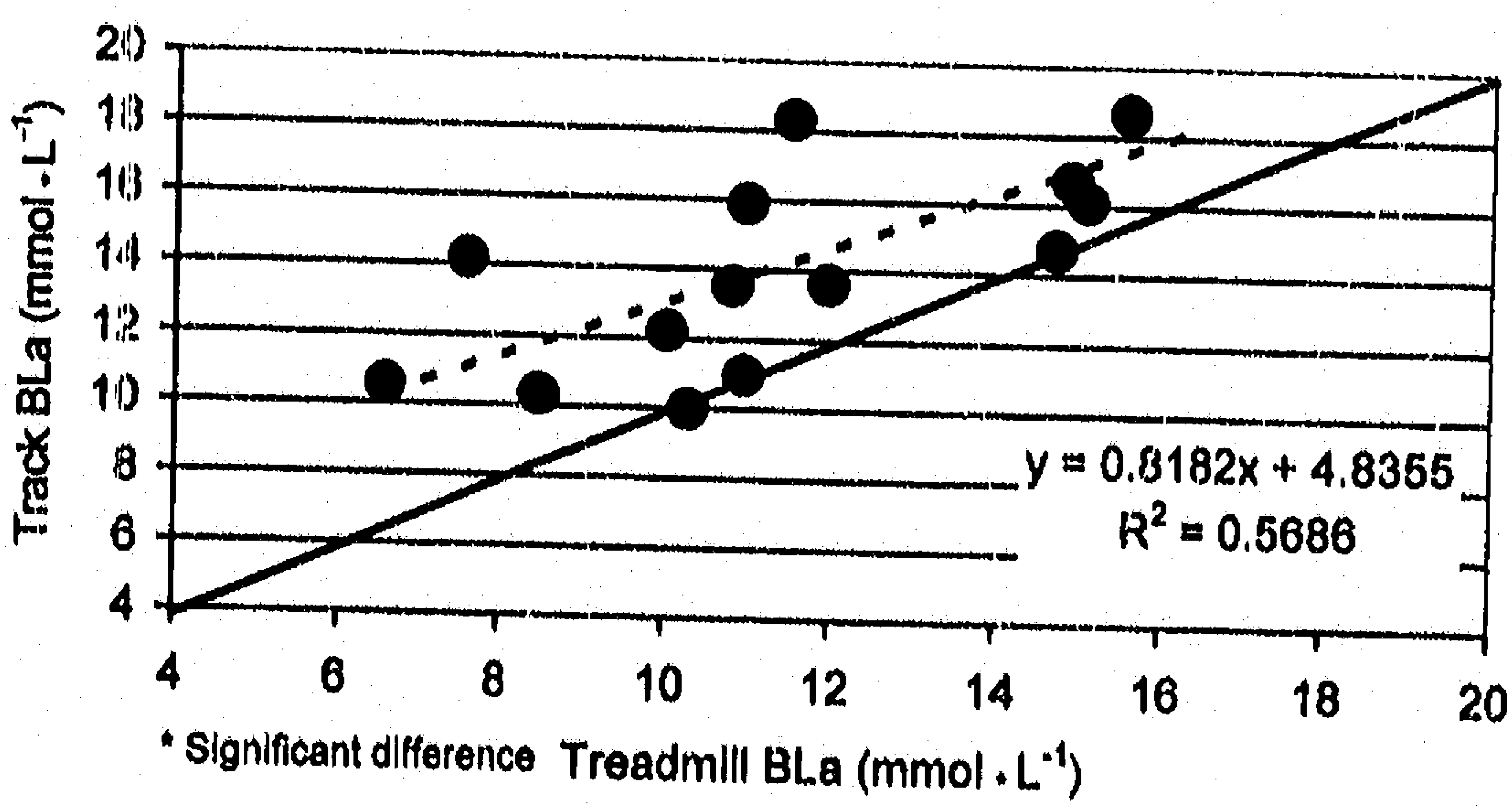

Figure 14-Relationship of BLa_{peak} between incremental test and one-mile run. Solid line represents the line of identity and dashed line the regression line.

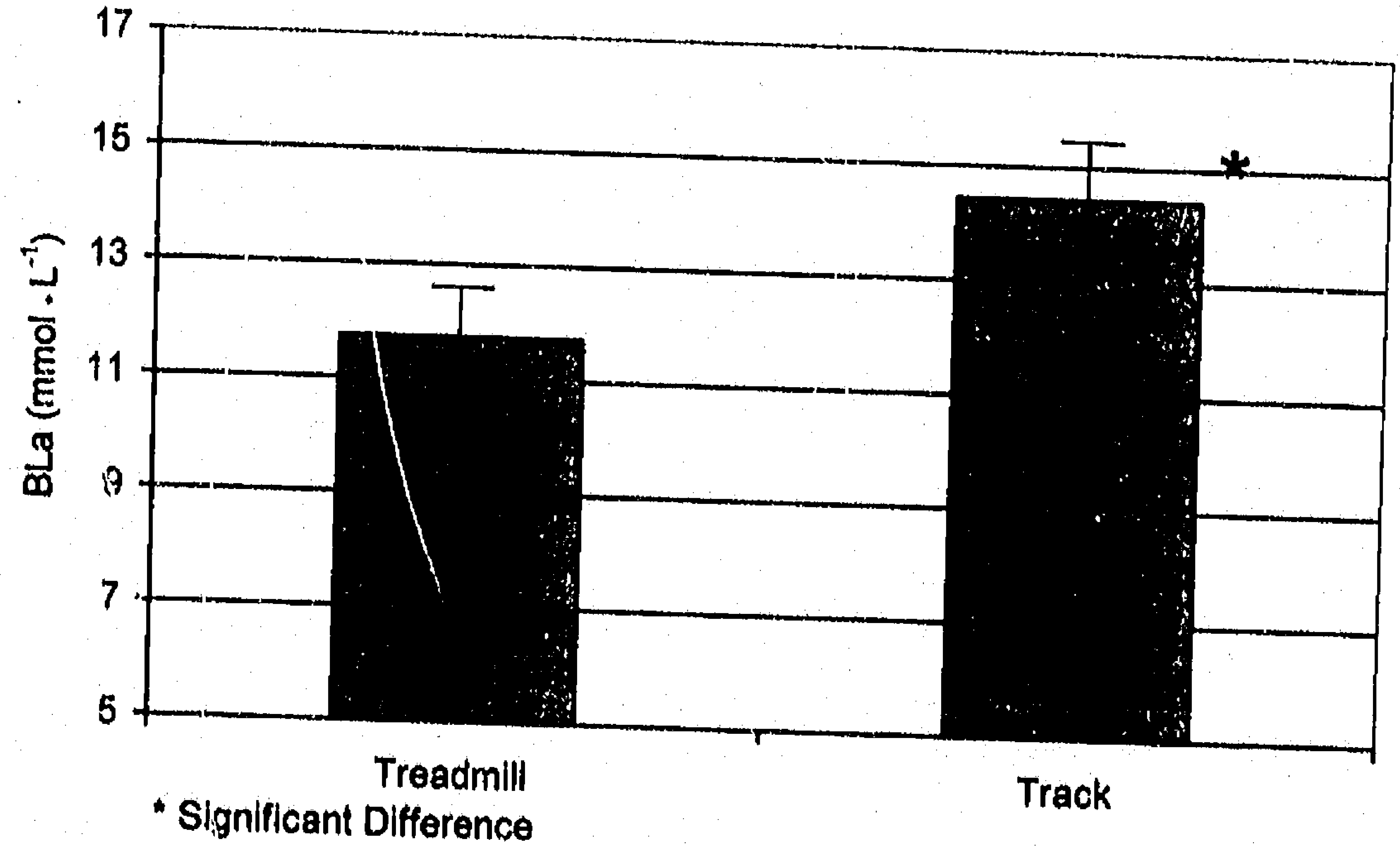

Figure 15-Mean BLa_{peak} of incremental test and one-mile run with standard error bars.

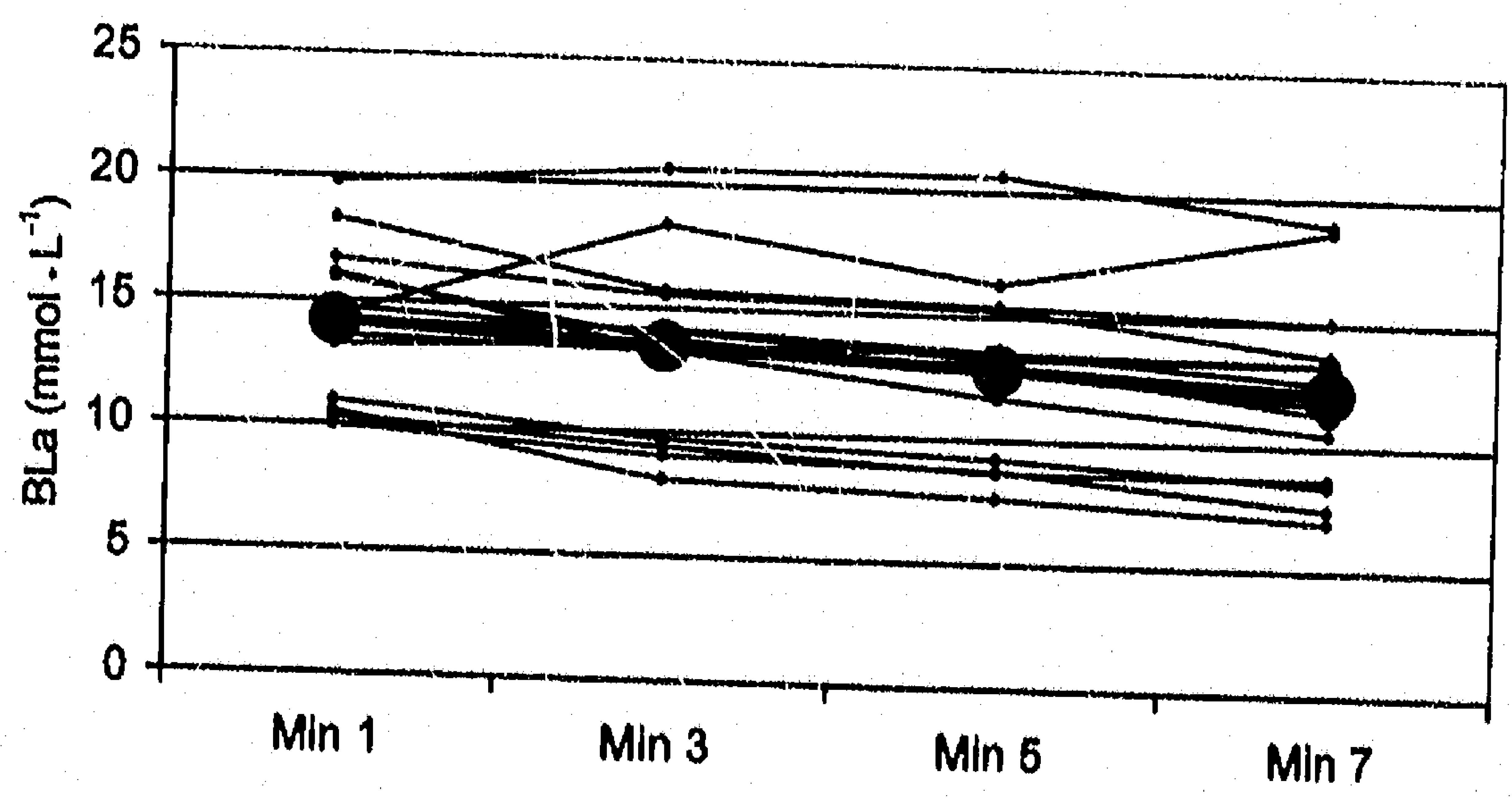

Figure 16-Serial response for BLa at 1, 3, 5, and 7 min post one-mile run. Circles and thick line represent mean, thin lines represent individual responses.

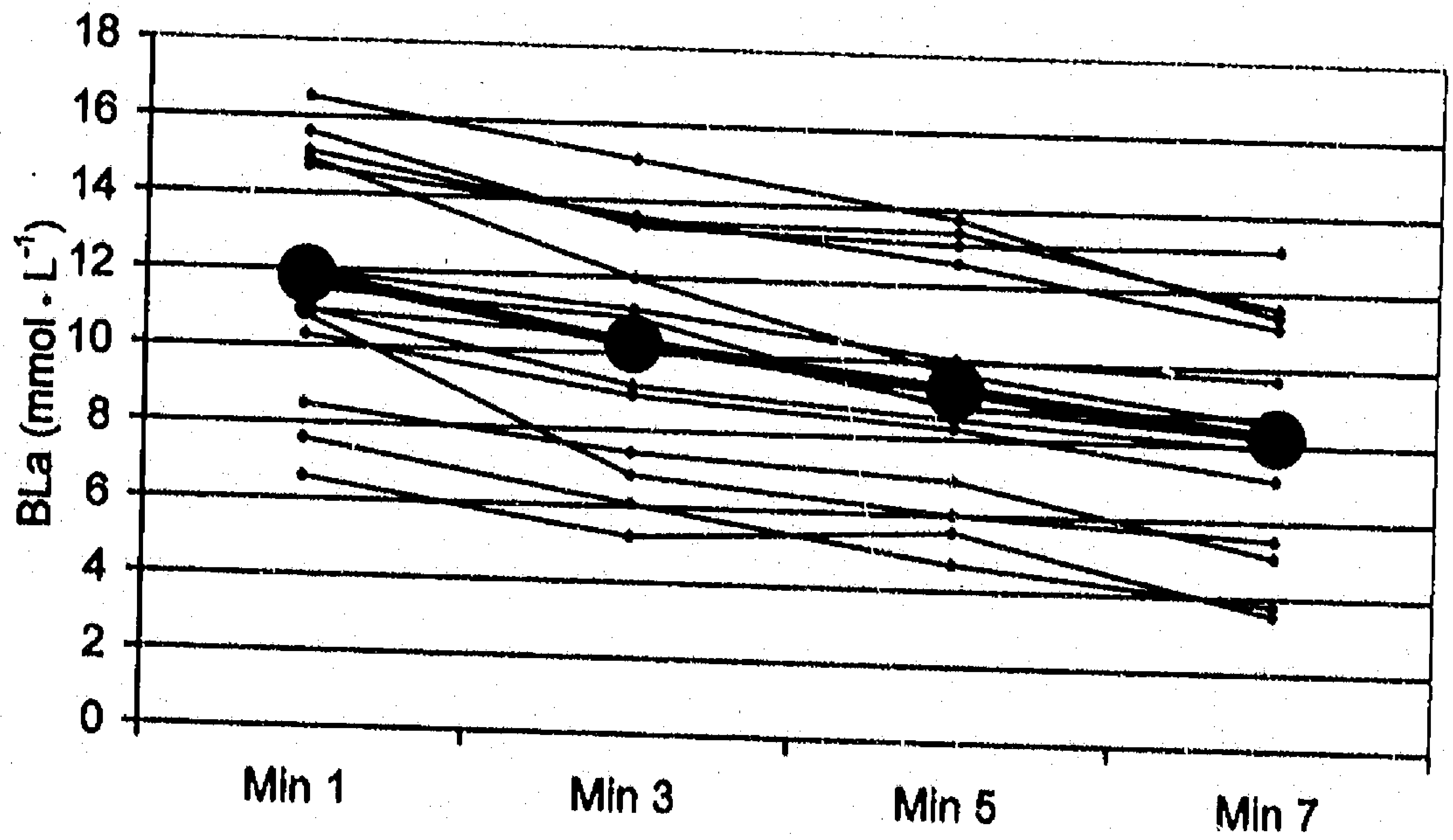

Figure 17-Serial response for BLa at 1, 3, 5, and 7 min post incremental test. Circles and thick line represent mean, thin lines are individual responses.

DISCUSSION

The present data are similar to previous studies in that physiological responses were numerically larger during free range exercise (7,8). However, unlike in the previous studies, the differences were not statistically significant. Whether this is related to differences between cycling and running or to other factors remains to be determined. In agreement with previous studies, post exercise blood lactate concentration was significantly greater during free range exercise. This is likely attributable to the longer period at heavy exertion during free range exercise (Fig. 5).

Thirty years ago, Karlsson and Saltin (13) demonstrated relatively constant muscle lactate values during exhaustive cycling exercise with durations ranging from two to six minutes, with only slightly lower muscle lactate concentrations during exhaustive work of 15 minutes duration. Previous free range exercise results have been interpreted with reference to Karlsson and Saltin's data, suggesting that very brief reductions in power output during free range exercise could be used to manage the rate of muscle lactate accumulation without being so large as to limit exercise by increasing local muscular fatigue. Alternatively, during incremental exercise when muscle lactate concentration reaches critical levels, exercise must stop even if maximal cardiorespiratory stress has not been achieved. On the basis of the reduced duty cycle during running, compared to cycling, and the generally smaller degree of muscular loading during running, it may be that there is less of a tendency to reach critical muscle lactate concentrations during incremental exercise. Although, post exercise blood lactate values should be used with caution as markers of muscle lactate concentration (9), the generally lower post exercise blood lactate concentrations in the present study, compared to earlier observations with cycling and rowing athletes, supports the concept that critical lactate concentrations during cycling may be greater. This would provide a rationale for understanding the apparent advantage of free range exercise during cycling and rowing but not during running.

Recently there has been renewed interest in the concept of VO_{2max} with Noakes (20,21) suggesting that the traditional concept of a VO_{2max} plateau is not supported by adequate experimental data. Others (1,2,3) have argued for the traditional concept. The present data set, along with previous data (7,8,12,22,24,25,26), suggest that the highest VO_2 observed during incremental laboratory exercise is not always the greatest VO_2 that an individual is capable of demonstrating. In that sense the present data support the argument put forth by Noakes.

In the present study, 8 of the 15 subjects demonstrated a plateau of VO_2 during incremental exercise. Of the subjects that reached a plateau, during the incremental laboratory test, six reached higher values during free range exercise. Mean (±SD) VO_2 (track vs treadmill) for these subjects was 63.6 ± 7.7 vs 61.1 ± 7.8 $ml \bullet kg^{-1} \bullet min^{-1}$. In the seven subjects that did not reach a plateau during the incremental laboratory test, only two achieved a higher value during free range exercise (62.3 ± 7.5 vs 62.8 ± 7.0 $ml \bullet kg^{-1} \bullet min^{-1}$). These data suggest that the achievement of a plateau during incremental exercise may be an artifact of the incremental protocol and supports previous suggestions that the nature of free range exercise may allow an individual to escape the exercise limitation related to local muscular fatigue, with potentially greater cardiorespiratory responses.

This present study has only examined a small possibility of what is occurring during free range exercise. Future research needs to focus on differences among athletic events (e.g., running vs cycling/rowing) to determine differences that may be occurring. It would also be beneficial to evaluate responses during competition compared to free range exercise. During competition athletes have to constantly change their workload in order to adjust for the race and environmental factors. A better understanding of how these factors affect the athlete physiologically may help improve training techniques.

REFERENCES

1. Bassett, D. R. JR., and E. T. Howley. Maximal oxygen uptake: "classical" versus "contemporary" viewpoints. *Med. Sci. Sports Exerc.* 29:591-603, 1997.
2. Bassett, D. R. JR., and E. T. Howley. Limiting factors for maximum oxygen uptake and determinants of endurance performance. *Med. Sci. Sports Exerc.* 32:70-84, 2000.
3. Bergh, U., B. Ekblom, and P. O. Astand. Maximal oxygen uptake "classical" versus "contemporary" viewpoints. *Med. Sci. Sports Exerc.* 32:85-88, 2000.
4. Billat, V., J. C. Renoux, J. Pinoteau, B. Petit, and J. P. Koralsztein. Reproducibility of running time to exhaustion at VO_2max in subelite runners. *Med. Sci. Sports Exerc.* 26:254-257, 1994.
5. Billat, V., J. C. Renoux, J. Pinoteau, B. Petit, and J. P. Koralsztein. Times to exhaustion at 100% of velocity at VO_2max and modeling of the time-limit velocity relationship in elite long-distance runners. *Eur. J. Appl. Physiol.* 26: 271-273, 1994.
6. Dorociak, J. J., and J. K. Nelson. The 1 mile and 2 mile runs as measures of cardiovascular fitness in college women. *J. Sports Med.* 23:322-325, 1983.
7. Foster, C., R. B. Coye, A. Crowe, M. Dumit, and S. Lettau. Comparison of free range and graded exercise testing. *Med. Sci. Sports Exerc.* 29:1521-1526, 1997.
8. Foster, C., M. A. Green, A. C. Snyder, and N. T. Thompson. Physiological responses during simulated competition. *Med. Sci. Sports Exerc.* 25:877-882, 1993.
9. Foster, C., and A. C. Snyder. Blood lactate and respiratory measurement of the capacity for sustained exercise. In: *Physiological Assessment of Human Fitness.* Maud, P. J., and C. Foster (Eds.) Champaign, IL: Human Kinetics, 1995, pp. 245-256.
10. Gleser, M. A., and J. A. Vogel. Endurance capacity for prolonged exercise on the bicycle ergometer. *J. Appl. Physiol.* 34:438-442, 1973.
11. Grant, S., I. Craig, J. Wilson, and T. Aitchison. The relationship between 3 km running performance and selected physiological variables. *J. Sports Sci.* 15: 403-410, 1997.
12. Hagerman, F. C. Physiology of competitive rowing. In: *Exercise and Sport Science.* W. E. Garrett, JR., and D. T. Kirkendall (Eds.) Philadelphia: Lippencott Williams & Wilkins, 2000, pp. 843-873.
13. Karlsson, J., and B. Saltin. Lactate, ATP, and CP in working muscles during exhaustive exercise in man. *J. Appl. Physiol.* 29:598-602, 1970.

14. Leger, L., D. Mercier, and L. Gauvin. The relationship between %VO_2max and running performance time, In: *The 1984 Olympic Scientific Congress Proceedings Vol. 3: Sport and Elite Performers.* D. M. Landers (Ed) Champaign, IL: Human Kinetics, 1986, pp. 113-120.
15. Maksud, M. G., and K. D. Coutts. Comparison of a continuous and discontinuous graded treadmill test for maximal oxygen uptake. *Med. Sci. Sports Exerc.* 3:63-65, 1971.
16. Maron, M. B., S. M. Horvath, J. E. Wilkerson, and J. A. Gliner. Oxygen uptake measurements during competitive marathon running. *J. Appl. Physiol.* 40: 836-838, 1976.
17. Mitchell, T. E., B. J. Sproule, and C. B. Chapman. The physiological meaning of the maximal oxygen intake test. *J. Clin. Invest.* 37:538-547, 1958.
18. Morgan, D. W., F. D. Baldini, P. E. Martin, and W. M. Kohrt. Ten kilometer performance and predicted velocity at VO_2max among well-trained male runners. *Med. Sci. Sports Exerc.* 21:78-83, 1989.
19. Morton, R. H., and V. Billat. Maximal endurance time at VO_2max. *Med. Sci. Sports Exerc.* (In Press)
20. Noakes, T. D. Challenging beliefs: ex Africa semper aliquid novi. *Med. Sci. Sports Exerc.* 29:571-590, 1997.
21. Noakes, T. D. Maximal oxygen uptake: "classical" versus "contemporary" viewpoints: a rebuttal. *Med. Sci. Sports Exerc.* 30:1381-1398, 1998.
22. Palmer, G. S., Dennis, S. C., Noakes, T. D., and Hawley, J. S. Effects of steady-state and stochastic exercise on subsequent cycling performance. *Med. Sci. Sports Exerc.* 25:684-687, 1997.
23. Peronnet, F., G. Thibault, E. C. Rhodes, and D. C. McKenzie. Correlation between ventilatory threshold and endurance capability in marathon runners. *Med. Sci. Sports Exerc.* 19:610-615, 1987.
24. Schabort, E. J., J. A. Hawley, W. G. Hopkins, I. Mujika, and T. D. Noakes. A new reliable laboratory test of endurance performance for road cyclists. *Med. Sci. Sports Exerc.* 30:1744-1750, 1998.
25. Schabort, E. J., W. G. Hopkins, and J. A. Hawley. Reproducibility of self-paced treadmill performance of trained endurance runners. *Int. J. Sports Med.* 18:1-4, 1997.
26. Schabort, E. J., W. J. Hopkins, J. A. Hawley, and H. Blum. High reliability of performance of well-trained rowers on a rowing ergometer. *J. Sports Sci.* 17:627-632, 1999.
27. Taylor, H. L., E. Buskirk, and A. Henshel. Maximal oxygen intake as an objective measure of cardio-respiratory performance. *J. Appl. Physiol.* 8:73-80, 1955.
28. Tokmakidis, S. P., L. Leger, D. Mercier, F. Peronnet, and G. Thibault. New approaches to predict VO_2max and endurance from running performances. *J. Sports Med.* 27:401-409, 1987.

29. Yoshida, T., M. Udo, K. Iwai, and T. Yamaguchi. Physiological characteristics related to endurance running performance in female distance runners. *J. Sports Sci.* 11:57-62, 1993.

APPENDIX A

INFORMED CONSENT FORM

Informed Consent

PHYSIOLOGICAL COMPARISON OF INCREMENTAL TREADMILL EXERCISE AND FREE RANGE RUNNING

I,____________________________, volunteer to participate in a research study designed to compare physiological responses during maximal incremental treadmill exercise and a one-mile run. I have been informed that I will be required to complete a maximal treadmill test with respiratory gas analysis, blood lactate analysis, and two one-mile runs, performed as fast as possible. The treadmill test will be performed at the University of Wisconsin-La Crosse Human Performance Lab and the one-mile runs will be performed on the 200 meter indoor track located in Mitchell Hall on the campus at University of Wisconsin-La Crosse. For the treadmill test and the second one-mile run I will be required to wear and breathe through a portable gas analyzer so that my expired air can be collected and analyzed. I will also be required to wear a heart rate monitor that will be strapped to my chest. Blood lactate analysis will be performed which requires 25 microliters of blood to be taken from a finger tip puncture at 1, 3, 5, and 7 minutes of recovery.

As with any exercise, there exists the possibility of adverse changes occurring during the testing period. These include dizziness, difficulty in breathing, abnormal blood pressure, and in rare instances, cardiac arrest, stroke, or even death. In patients being evaluated for heart disease the risk of non-serious complications is approximately 6/10,000 tests and for serious (e.g., life threatening) complications is approximately 1/10,000 tests. In young, prospectively healthy and/or athletic individuals the risk of serious complications approaches, but does not reach, zero. I declare that I am not aware of any pre-existing conditions (i.e., heart disease, lung/respiratory conditions, prone to fainting or seizures, and blood-borne contagious diseases) which may put me at risk, or prevent my participation in this study. I understand that personnel involved in the testing procedures are CPR certified and that there is a well established emergency protocol in place in both the Human Performance Lab and at the track in Mitchell Hall. I should expect to become quite fatigued during both the treadmill and one mile field tests. I may also have a sore finger due to the finger tip puncture(s) to take the blood sample.

I have been informed that the overall results of this study may be presented at scientific meetings and published, however I understand that all individual information will be kept confidential. The expected benefit to myself is a better understanding of my athletic capabilities which may help me better understand my sport performance. I understand that I am free to withdraw at any time without penalty.

The tests will be conducted by Scott Crouter, a graduate student in the Adult Fitness/Cardiac Rehab program at UWL, who may be reached at 785-3185. The thesis chairperson will be Carl Foster, PhD (785-8687). Questions regarding the protection of human subjects may be addressed to Dr. Garth Tymeson, Chair, UWL-IRB protection of human subjects, (608) 785-8155.

I have read and understand the procedures as described above and explained to me. I have been fully advised of the nature of the tests and possible risks involved, of which I assume voluntarily. I hereby acknowledge that no representations, warranties, guarantees, reassurances of any kind pertaining to the procedure have been made to me by the UWL, the officers, and administration, the employees, or by anyone acting on behalf of any of them. I understand that I am free to ask any question pertaining to the study an I am free to withdrawal at any time.

Signed:_______________________________ Date:__________

Witness:______________________________ Date:__________

APPENDIX B

REVIEW OF RELATED LITERATURE

REVIEW OF RELATED LITERATURE

Concept of VO_{2max}

Hill and Lupton (18) were the first to develop the notion of maximal oxygen uptake (VO_{2max}) by finding a linear relationship between oxygen intake and workload until VO_{2max} is reached. Hill and Lupton believed that a plateau in oxygen consumption occurred at maximal effort, concluding that maximal exertion is limited by the cardiovascular-respiratory system. The plateau theory developed by Hill and Lupton has been the standard that most exercise physiologists would use as a basis for testing.

Taylor, Buskirk, and Henshel (33) felt that motivation and skill in performing the given task were factors in a maximal exertion test. Taylor et al., like Hill and Lupton, concluded that there is a linear relationship between oxygen intake and workload until the VO_{2max} is reached, thus supporting the plateau theory as a criterion for reaching one's maximal oxygen intake. They found that involving larger muscle groups (e.g., arms and legs) produced a larger VO_{2max} and concluded that VO_{2max} is only maximal for the given working conditions.

Mitchell, Sproule, and Chapman (24) set out to clarify the physiological meaning of a VO_{2max} test by examining cardiac capacity, ventilatory factors, and the relationship between cardiac output and the a-v oxygen difference. Mitchell et al. agreed with Taylor et al. (33) that VO_{2max} is related to the task at hand.

Mitchell et al. concluded that both cardiac output and a-v oxygen difference play a role in VO_{2max}. They realized that their findings needed to be studied further, but felt that increasing cardiac output is more important than the a-v oxygen difference in normal individuals.

Noakes (27) has challenged the plateau theory set forth by Hill and Lupton (18) and tested by others (4,21,24,33) and set off a debate as to what actually limits VO_{2max}. Noakes believes that Hill and Lupton contradicted themselves in their original conclusions. Noakes proposed an alternate theory that "skeletal muscle contractile function is regulated by a hierarchy of controls specifically to prevent damage to any of a number of different organs" (27, p. 587). This opened the door to a controversial subject. Bassett and Howley (4) responded to Noakes' challenge and sided with Hill and Lupton by supporting the work that has set the standard for exercise testing. Noakes (28) responded and stood strong on his views but acknowledged that further research is needed to fully understand the limiting factors of VO_{2max}. The concept of skeletal muscle contraction as setting the end point of a VO_{2max} test and not the cardio-respiratory response raises many issues which will only help exercise physiologists better understand the human body during prolonged endurance exercise.

Relation of VO_{2max} to Running Performance

Traditionally, VO_{2max} and endurance running performance have been positively correlated with one another because of the high demand placed on the aerobic system during prolonged endurance activity. Most studies have found a high positive correlation between VO_{2max} and endurance running performance (14,16,25).

Running economy has also been a factor correlated with VO_{2max} and running performance. Running economy has been studied by evaluating running velocity at VO_{2max} (v-VO_{2max}) (5,6,16,25,26). This is an important concept when relating VO_{2max} to running performance because it helps evaluate the maximal time one can sustain a maximal speed before fatiguing which is important in predicting one's performance. Studies have shown that the optimal time at v-VO_{2max} ranges anywhere from 2.5 to 10 minutes (5, 6,15,20,22,23). Billat et al. (5) found a range of 2.5 to 11.5 minutes. The mean between the two trials performed were 6 minutes 44 seconds and 6 minutes 42 seconds, respectively, and were not found to be significantly different. Morton and Billat (26) found similar results with a horizontal treadmill protocol. They found that the maximal time at VO_{2max} was 603 seconds, which was slightly over 10 minutes. It is slightly higher than some studies, but supports what has previously been found. Katch, Petchar, McArdle, and Weltman (19) found that runs shorter than 4 minutes were not acceptable for predicting running performance and the test should be at least 5 minutes to predict cardiovascular fitness.

Daniels, Krahenbuhl, Foster, Gilbert, and Daniels (11) measured submaximal and maximal responses of female distance runners and compared the results to males. They found that males and females have similar aerobic demands at submaximal speeds. Lastly they found that the main difference between the running performance of males and females is their difference in VO_{2max}. Morgan et al. (25) found a high correlation between v-VO_{2max} and 10km run time (as time at v-VO_{2max} increases, 10km time gets faster). They concluded that v-VO_{2max} could be used as a predictor of running performance.

Prediction of VO_{2max} from Overground Performance

In order to asses physical fitness, researchers have needed to develop a test that could be used on large groups of people and is less fatiguing, but would still give an accurate measure of one's fitness level. Some of the first studies were conducted on military personnel and then expanded to the general population in order to better assess the fitness level of our country (1,2,3,9,10,34). Balke and Ware (3) were one of the first to examine the fitness level of a large population. They examined the cardiovascular and ventilatory responses in military personnel by using a treadmill test to assess their fitness level. Balke (2) felt that physical fitness needed to be defined and then speculated on a specific time and distance that would be appropriate for a fitness test of the general population. He felt that a 20 minute steady state run or two and one half miles would be a sufficient time to test the fitness level of individuals.

Balke (1) developed the 15 minute best effort run as a field test that could be substituted for standard lab testing. He found that runs longer than 20 minutes gave a performance that was inferior to that on a treadmill and runs around 5 minutes were performed for the most part in oxygen debt. Balke concluded that for a field test to be physiologically meaningful it should be at least 12 minutes. Results from his data gave higher oxygen intakes on the track versus the treadmill, 44.4 ml • kg^{-1} • min^{-1} and 43.6 ml • kg^{-1} • min^{-1}, respectively.

Cooper (9) set a standard with his 12 minute fitness test that is still widely used today because of its ease of administration. Cooper, like Balke and others (1,2,3), indicated that motivation plays a large role in these field tests. Without motivation the outcomes would fall short of what they actually should be. Since the work of Balke (1,2), Balke and Ware (3), and Cooper (9), others have tried to develop new tests (10,34). In one study VO_{2peak} was predicted from a one-mile run/walk performance (10). The equation developed to predict VO_{2peak} was accurate for the general population but in highly fit individuals it underestimates the VO_{2peak} and in unfit individuals it overestimates the VO_{2peak}.

Free Range Exercise

Most investigators have focused on predicting performance from laboratory data while others have used field tests to predict VO_{2max}. Few have looked at what happens during free range exercise or competition (7,8,12,13,17,21,29,30,31,32,35). The majority of free range testing has been done on cyclists due to the ease of administering the testing protocol (12,13,28,29). This does not represent true free range though, because the testing is done in the laboratory and uses simulators to help enhance the sensation of being in the field. Free range exercise performed on the treadmill is not true free range because the treadmill is too slow to adjust to the normal responses that a runner would make during normal competition (31). During free range cycling it has been found that when a subject is allowed to regulate their intensity they demonstrate higher physiological responses then during an incremental test (12,13,29,30).

This notion of free range can also be applied to the clinical setting. Foster et al. (12) remarked that free range activity may be a better diagnostic tool for cardiovascular and respiratory disease than a standard graded exercise test. Others (7,8,17,35) researching free range exercise in the clinical setting have found that submaximal exertion such as a 6-minute walk test, or a 9-minute self-powered treadmill test are beneficial in predicting disease and can be a useful tool with cardiorespiratory compromised patients that may be contraindicative to an incremental test.

REFERENCES

1. Balke, B. A simple field test for the assessment of physical fitness. *Civil Aeromedical Research Institute* 63-6:1-8, 1963.
2. Balke, B. The effect of physical exercise on the metabolic potential, a crucial measure of physical fitness. In: *Exercise and Fitness*. The Athletic Institute, Chicago, 1960, pp. 73-81.
3. Balke, B., and R. W. Ware. An experimental study of "physical fitness" of Air force personnel. *U. S. Armed Forces Medical J.* 10:675-688, 1959.
4. Bassett, D. R. JR., and E. T. Howley. Maximal oxygen uptake: "classical" versus "contemporary" viewpoints. *Med. Sci. Sports Exerc.* 29:591-603, 1997.
5. Billat, V., J. C. Renoux, J. Pinoteau, B. Petit, and J. Koralsztein. Reproducibility of running time to exhaustion at VO_2max in subelite runners. *Med. Sci. Sports Exerc.* 26:254-257, 1994.
6. Billat, V., J. C. Renoux, J. Pinoteau, B. Petit, and J. Koralsztein. Times to exhaustion at 100% of velocity at VO_2max and modeling of the time-limit velocity relationship in elite long-distance runners. *Eur. J. Appl. Physiol.* 69: 271-273, 1994.
7. Bittner, V., D. H. Weiner, S. Yusuf, W. J. Rogers, K. M. McIntyre, S. I. Bangdiwala, M. W. Kronenberg, J. B. Kostis, R. M. Kohn, M. Guillotte, B. Greenberg, P. A. Woods, and M. G. Bourassa. Prediction of mortality and morbidity with a 6-minute walk test in patients with left ventricular dysfunction. *JAMA* 270:1702-1707, 1993.
8. Cahalin, L. P., M. A. Mathier, M. J. Semigran, G. W. Dec, and T. G. DiSalvo. The six-minute walk test predicts peak oxygen uptake and survival in patients with advanced heart failure. *Chest* 110:325-332, 1996.
9. Cooper, K. H. A means of assessing maximal oxygen intake. *JAMA* 203:135-204, 1968.
10. Cureton, K. J., M. A. Sloniger, J. P. O'Bannon, D. M. Black, and W. P. McCormack. A generalized equation for prediction of VO_{2peak} from 1-mile run/walk performance. *Med. Sci. Sports Exerc.* 27:445-451, 1995.
11. Daniels, J., G. Krahenbuhl, C. Foster, J. Gilbert, and S. Daniels. Aerobic responses of female distance runners to submaximal and maximal exercise. *Ann. NY Acad. Sci.* 301:726-733, 1977.
12. Foster, C., R. B. Coye, A. Crowe, M. Dumit, and S. Lettau. Comparison of free range and graded exercise testing. *Med. Sci. Sports Exerc.* 29:1521-1526, 1997.
13. Foster, C., M. A. Green, A. C. Snyder, and N. T. Thompson. Physiological responses during simulated competition. *Med. Sci. Sports Exerc.* 25:877-882, 1993.

14. Foster, C., D. L. Costill, J. T. Daniels, and W. J. Fink. Skeletal muscle enzyme activity, fiber composition, and VO_2max in relation to distance running performance. *Eur. J. Appl. Physiol.* 39:73-80, 1978.
15. Gleser, M. A., and J. A. Vogel. Endurance capacity for prolonged exercise on the bicycle ergometer. *J. Appl. Physiol.* 34:438-442, 1973.
16. Grant, S., I. Craig, J. Wilson, and T. Aitchison. The relationship between 3 km running performance and selected physiological variables. *J. Sports Sci.* 15:403-410, 1997.
17. Guyatt, G. H., S. O. Pugsley, M. J. Sullivan, P. J. Thompson, L. B. Berman, N. L. Jones, E. L. Fallen, and D. W. Taylor. Effect of encouragement on walking test performance. *Thorax* 39:818-822, 1984.
18. Hill, A. V., and H. Lupton. Muscular exercise, lactic acid, and the supply and utilization of oxygen. *Q. J. Med.* 16:135-171, 1923.
19. Katch, F. I., G. S. Petchar, W. D. McArdle, and A. L. Weltman. Relationship between individual differences in a steady pace endurance running performance and maximal oxygen intake. *Res. Q.* 44:206-215, 1973.
20. Lavoi, N. F., and T. H. Mercier. Incremental and constant load determinations of VO_2max and maximal constant load performance time. *Can. J. Appl. Sports Sci.* 12:229-232, 1987.
21. Maron, M. B., S. M. Horvath, J. E. Wilkerson, and J. A. Gliner. Oxygen uptake measurements during competitive marathon running. *J. Appl. Physiol.* 40:836-838, 1976.
22. McLellan, T. M., and S. Y. Cheung. A comparative evaluation of the individual anaerobic threshold and the critical power. *Med. Sci. Sports Exerc.* 24:543-550, 1992.
23. McLellan, T. M., and J. S. Skinner. Submaximal endurance performance related to the ventilatory thresholds. *Can. J. Appl. Sports Med.* 10:81-87, 1985.
24. Mitchell, J. H., B. J. Sproule, and C. B. Chapman. The physiological meaning of the maximal oxygen intake test. *J. Clin. Invest.* 37:538-546, 1958.
25. Morgan, D. W., F. D. Baldini, P. E. Martin, and W. M. Kohrt. Ten kilometer performance and predicted velocity at VO_2max among well-trained male runners. *Med. Sci. Sports Exerc.* 21:78-83, 1989.
26. Morton, R. H., and V. Billat. Maximal endurance time at VO_2max. *Med. Sci. Sports Med.* (In press)
27. Noakes, T. D. Challenging beliefs: ex Africa semper aliquid novi. *Med. Sci. Sports Exerc.* 29:571-590, 1997.
28. Noakes, T. D. Maximal oxygen uptake: "classical" versus "contemporary" viewpoints: a rebuttal. *Med. Sci. Sports Exerc.* 30:1381-1398, 1998.
29. Palmer, G. S., S. C. Dennis, T. D. Noakes, and J. S. Hawley. Effects of steady-state and stochastic exercise on subsequent cycling performance. *Med. Sci. Sports Exerc.* 25:684-687, 1997.

30. Schabort, E. J., J. A. Hawley, W. G. Hopkins, I. Mujika, and T. D. Noakes. A new reliable laboratory test of endurance performance for road cyclists. *Med. Sci. Sports Exerc.* 30:1744-1750, 1998.
31. Schabort, E. J., W. G. Hopkins, and J. A. Hawley. Reproducibility of self-paced treadmill performance of trained endurance runners. *Int. J. Sports Med.* 18:1-4, 1997.
32. Schabort, E. J., W. J. Hopkins, J. A. Hawley, and H. Blum. High reliability of performance of well-trained rowers on a rowing ergometer. *J. Sports Sci.* 17:627-632, 1999.
33. Taylor, H. L., E. Buskirk, and A. Henshel. Maximal oxygen intake as an objective measure of cardio-respiratory performance. *J. Appl. Physiol.* 8:73-80, 1955.
34. Tokmakidis, S. P., L. Leger, D. Mercier, F. Peronnet, and G. Thibault. New approaches to predict VO_2max and endurance from running performances. *J. Sports Med.* 27:401-409, 1987.
35. Yamani, M. H., L. Wells, and B. M. Massie. Relation of the nine-minute self powered treadmill test to maximal exercise capacity and skeletal muscle function in patients with congestive heart failure. *Am. J. Cardiol.* 76:788-792, 1995.