

The validity of regulating blood lactate concentration during running by ratings of perceived exertion

By: Nancy M. Stoudmire, [Laurie Wideman](#), Kimberly A. Pass, Christina L. McGinnis, Glenn A. Gaesser, and Arthur Weltman

This is a non-final version of an article published in final form in:

Stoudemire, N., Wideman, L., Pass, K.A., McGinnes, C.L., Gaesser, G.A., and Weltman, A. 1996. The validity of regulating blood lactate concentration during running by ratings of perceived exertion. *Medicine & Science in Sport & Exercise* 28(4): 490-495. PMID: 8778555

*****© 1996 The American College of Sports Medicine. Reprinted with permission. No further reproduction is authorized without written permission from Lippincott, Williams & Wilkins. This version of the document is not the version of record. Figures and/or pictures may be missing from this format of the document. *****

Abstract:

We examined whether ratings of perceived exertion (RPE) observed during an incremental (response) protocol could be used to produce target blood [HLA] of 2.5 mM and 4.0 mM during a 30-min treadmill run at a constant RPE. RPE (15.3, 17.6, 19.1), oxygen uptake ($\dot{V}O_2$) (3.31, 3.96, 4.00 l·min⁻¹), velocity (V) (198, 218, 223 m·min⁻¹), and heart rate (HR) (179, 185, 190 bpm) at blood [HLA] of 2.5 mM and 4.0 mM, and peak were determined for nine subjects (5 males, 4 females) during incremental exercise. Subjects then completed two 30-min runs at the RPE corresponding to blood [HLA] of 2.5 mM (RPE 2.5 mM) and 4.0 mM (RPE 4.0 mM) measured during the incremental protocol. For both 30-min runs, $\dot{V}O_2$ was not different from $\dot{V}O_2$ corresponding to either 2.5 or 4.0 mM blood [HLA] during the incremental test. During the 30-min run at RPE 2.5 mM: (a) only during minutes 25-30 was the blood [HLA] significantly different than 2.5 mM (3.2 ± 0.6 mM, $P < 0.05$), (b) for the first 20 min HR was significantly lower than the HR at 2.5 mM during the incremental protocol, and (c) V did not differ from V at 2.5 mM during the incremental protocol. During the 30-min run at RPE 4.0 mM: (a) blood [HLA] was not significantly different from 4.0 mM, (b) HR at every time point was significantly lower than HR 4.0 mM during the incremental protocol, and (c) V was decreased over time by an average of 24.6 m·min⁻¹ ($P < 0.05$). Because RPE from the response protocol was able to produce a blood [HLA] close to the criterion value during each 30-min run, we conclude that RPE is a valid tool for prescribing exercise intensities corresponding to blood [HLA] of 2.5 mM and 4.0 mM.

Keywords: lactate threshold | rpe | exercise | exercise prescription

Article:

We and others have reported that ratings of perceived exertion(RPE) may be a useful tool for exercise prescription(3,4,6,9,12-14,17,20,22-24) and may serve as adjunctive measures to standard physiological responses associated with the lactate threshold (LT) and various blood

lactate concentrations (blood [HLA])(3,5,9,24). RPE at the LT and various blood [HLA] do not appear to be affected by gender (5), training state (5,7,23) exercise modality(2,7,12), specificity of training(4), or training intensity (9). Thus, it has been suggested that RPE may be an effective tool to estimate LT and blood [HLA] when determining exercise intensity(24).

We recently reported that RPE associated with LT and blood [HLA] of 2.5 mM and 4.0 mM observed during a 3-min/stage incremental running protocol reasonably reflect RPE associated with these blood [HLA] during running exercise of up to 30 min in duration (24). However, in this study we employed a response protocol rather than a psycho-physiological estimation-production paradigm (6). If RPE is to be an effective tool for exercise prescription based on the LT or a given blood [HLA] it is important that exercise at a given RPE produce the desired blood [HLA]. RPE and blood [HLA] seem to rise in parallel during exercise at a constant velocity (24). Therefore, it can be hypothesized that if subjects exercise at a constant RPE, it will be necessary to reduce treadmill velocity during exercise in order to maintain a constant blood [HLA]. Thus the purpose of the present study was to test this hypothesis and further evaluate the utility of exercise intensity based on RPE for eliciting a predetermined blood [HLA].

METHODS

Subjects. Nine healthy, recreationally active males ($N = 5$) and females ($N = 4$) (mean age 25.4 ± 4.1 yr; mean height = 177.0 ± 7.7 cm; mean weight = 72.1 ± 12.9 kg) volunteered for the present study. All subjects provided written informed consent in accordance with the guidelines established by the Human Investigation Committee of the University of Virginia.

Initial protocol: $\dot{V}O_{2\text{peak}}$ /LT protocol. Subjects completed a continuous, incremental, level running treadmill protocol to determine the oxygen uptake ($\dot{V}O_2$), heart rate (HR), and velocity (V) associated with LT and blood [HLA] of 2.5 mM and 4.0 mM, and peak(29). The initial treadmill V was $110 \text{ m} \cdot \text{min}^{-1}$ for females and $130 \text{ m} \cdot \text{min}^{-1}$ for males. The V during each subsequent 3-min stage was increased by $10 \text{ m} \cdot \text{min}^{-1}$. Measurements of $\dot{V}O_2$, HR, blood [HLA] and RPE were recorded during the last minute of each stage. $\dot{V}O_{2\text{peak}}$ was determined as the highest 1-min $\dot{V}O_2$ attained during the test. The test was terminated by the investigators when the subject reached volitional exhaustion.

Metabolic Measures. Metabolic data were collected using standard open circuit spirometric techniques. Inspired ventilation was measured using a previously calibrated dry gas meter (Rayfield RAM-9200) fitted with a potentiometer. Output from the potentiometer was continuously integrated into an Apple IIe computer (Rayfield REP200). Expired ventilation traveled from a Hans Rudolph high-velocity valve through low resistance plastic tubing into a 7-l mixing chamber. The concentrations of oxygen and carbon dioxide in the mixing chamber were continuously sampled by an Applied Electrochemistry S-3A oxygen analyzer and a Beckman LB-2 carbon dioxide analyzer, respectively. Output from the gas analyzers was continuously integrated into the Apple IIe computer (Rayfield REP200). The gas analyzers were calibrated using commercial gases of known concentrations (micro-Scholander technique) before and after each test. Heart rates were determined using electrocardiographic R-R wave intervals. During all protocols the TEEM 100 portable oxygen uptake measurement system (Aerosport, Ann Arbor, MI) was used for redundancy. In $\dot{V}O_{2\text{peak}}$ /LT protocols, data from the Aerosport

system was used due to a malfunction in the Rayfield system. Our evaluation (unpublished findings) of the Aerosport system indicates that it results in the valid assessment of $\dot{V}O_2$ ($r = 0.95$, $SE = \pm 0.29 \text{ l}\cdot\text{min}^{-1}$, slope = 1.00, intercept = $-0.01 \text{ l}\cdot\text{min}^{-1}$, mean difference = $0.10 \text{ l}\cdot\text{min}^{-1}$, when compared with Rayfield, $N = 505$ observations).

Assessment of lactate threshold and blood lactate concentrations. Blood samples were obtained at rest and at the end of each stage of the incremental protocol from an indwelling venous catheter located in the back of the hand. A heparinized saline solution was infused after each blood sample to prevent clotting. Whole blood samples were analyzed immediately for lactate concentration with an automated lactate analyzer (Yellow Springs Instruments Model 23L, Yellow Springs, OH).

The LT was determined by examining the blood [HLA]-V relation observed during the incremental protocol (29). The highest V attained that was not associated with an elevation in blood [HLA] above baseline (baseline was determined by an experienced investigator who examined blood [HLA] during the early stages of exercise) was designated as V LT. This always occurred just prior to the curvilinear increase in blood lactate observed with subsequent exercise intensities. A lactate elevation of at least 0.2 mM (the error associated with the lactate analyzer) was required for LT determination. The $\dot{V}O_2$ corresponding to V LT (from individual plots of $\dot{V}O_2$ vs V) was designated as the $\dot{V}O_2$ associated with the LT ($\dot{V}O_2$ LT), the HR at this V was defined as the HR associated with LT (HR LT), and the RPE at this V was designated as the RPE associated with LT (RPE LT). V associated with blood [HLA] of 2.5 and 4.0 mM were determined from the plot of blood [HLA] vs. running V(29). $\dot{V}O_2$, HR, and RPE associated with these blood [HLA] were determined in a manner identical to that described for LT.

Ratings of perceived exertion. Prior to the treadmill test and before each subsequent running bout, standardized directions for RPE were read to each subject (17). Perceptual scale anchors were established as reported previously (3,23). Subjects were instructed to give an overall rating of perceived exertion using Borg's 6-20 point scale (2). This rating represented an integration of all exercise sensations, and was recorded during the last 30 s of each 3-min stage of the continuous, incremental protocol.

Running bouts. Subjects returned for two additional randomly assigned testing sessions with at least 48 h between each session. These subsequent sessions consisted of a 5-min warm up at $100 \text{ m}\cdot\text{min}^{-1}$ followed by 30 min of running at the RPE associated with 2.5 mM or 4.0 mM, as determined by the initial incremental protocol. Subjects were shown the RPE scale throughout the 30-min run and were instructed to run at an intensity that produces their individually determined RPE value. Subjects were allowed to adjust the velocity of the treadmill as needed in order to produce the prescribed RPE. The control panel for the Quinton Q65 treadmill was mounted on the front handrail so that subjects could have constant control of treadmill velocity. $\dot{V}O_2$ and HR were measured continuously, V was recorded every min, and blood [HLA] measurements were determined every 5 min using the same measurement procedures for these variables as described earlier.

Statistical analysis. A one-way analysis of variance with repeated measures was used to determine significant differences among $\dot{V}O_2$, V, HR, and blood [HLA] during the initial

VO₂peak/LT estimation protocol and the subsequent 30-min running sessions at RPE associated with 2.5 and 4.0 mM (production protocols). Where significant ($P < 0.05$) F-ratios were observed *post-hoc* comparisons were made within 5, 10, 15, 20, 25, and 30 min and between 5, 10, 15, 20, 25, 30 min and the corresponding value from the incremental protocol. Preplanned mean comparisons were used with a correction for multiple comparisons. Data are presented as mean \pm SEM.

RESULTS

Responses to the Incremental Protocol: At LT and blood [HLa] of 2.5 mM and 4.0 mM, the mean $\dot{V}O_2$ values were 65.2%, 82.8% and 98.8% of VO₂peak, respectively; mean HR values were 82.2%, 94.0% and 97.4% of HR max, respectively; and the mean RPE were 12.2, 15.3 and 17.6, respectively (Table 1).

TABLE 1. $\dot{V}O_2$, velocity, heart rate (HR), and RPE values at blood lactate concentrations of 2.5 mM, 4.0 mM, and peak observed during the incremental protocol, $N = 9$.

Variable	Mean (SEM)			
	LT	2.5 mM	4.0 mM	Peak
$\dot{V}O_2$ (l · min ⁻¹)	2.61 (0.8)	3.31 (0.3)	3.96 (0.3)	4.00 (0.3)
Velocity (m · min ⁻¹)	163 (28)	198 (10)	218 (9)	223 (9)
HR (bpm)	156 (16)	179 (4)	185 (3)	190 (4)
RPE	12.2 (1.1)	15.3 (0.4)	17.6 (0.5)	19.1 (1.3)

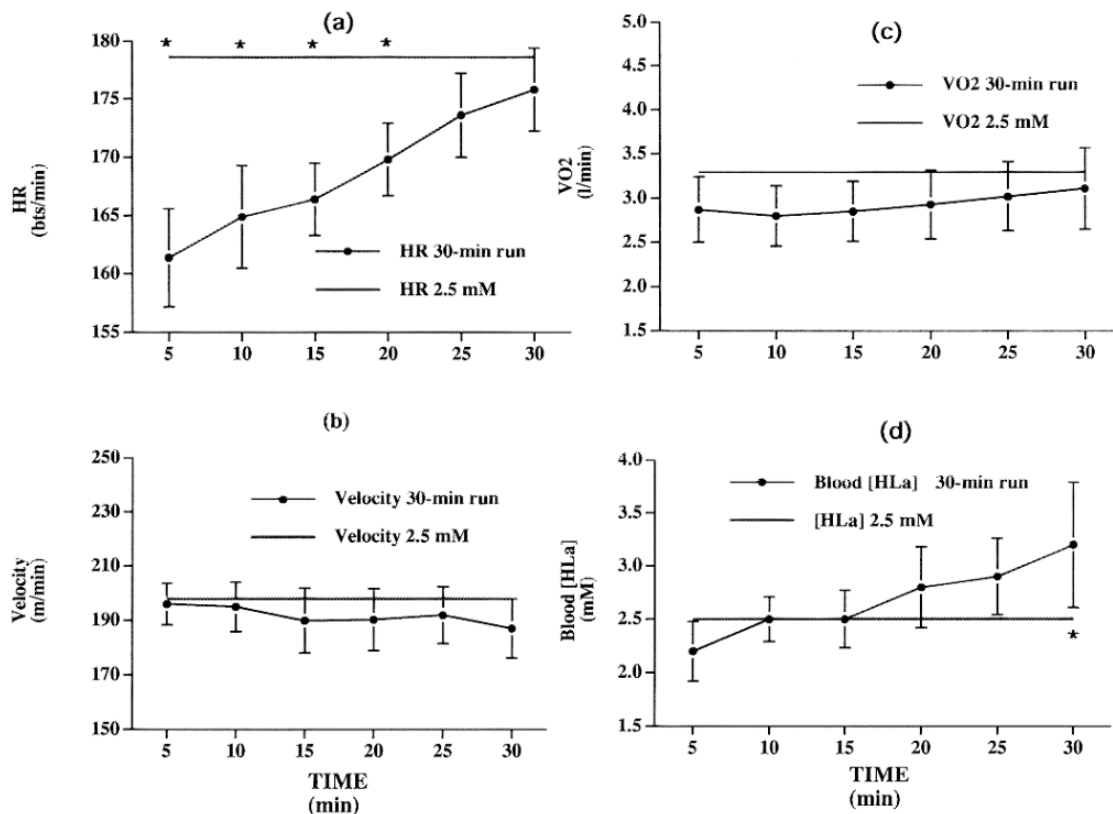


Figure 1. HR (a), velocity (b), $\dot{V}O_2$ (c), and HLa (d) values (\pm SEM) during the 30-min run at the RPE corresponding to a blood[HLa] of 2.5 mM (from the incremental protocol).

Responses to the 30-min run at the RPE corresponding to the incremental exercise blood [HLA] of 2.5 mM. Figure 1 shows the HR, V, $\dot{V}O_2$, and blood [HLA] values during the 30-min run at the RPE corresponding to 2.5 mM (elicited during the incremental protocol, see Table 1). HR increased significantly over time, from 161 ± 4 bpm at min 5 to 179 ± 4 bpm at min 30 ($P < 0.05$). During minutes 0-20 of the 30-min run, HR was significantly lower than the HR at 2.5 mM measured during the incremental protocol ($P < 0.05$). No significant differences in V or $\dot{V}O_2$ were found between the 30-min production protocol at an RPE corresponding to a blood [HLA] of 2.5 mM and the 2.5 mM V and $\dot{V}O_2$ measured during the incremental protocol (Fig. 1). Blood [HLA] increased significantly over time, from 2.2 ± 0.3 mM at min 5 to 3.2 ± 0.6 mM at min 30 ($P < 0.05$). Only the blood [HLA] at min 30 (3.2 ± 0.6 mM) of the 30-min run was significantly higher than 2.5 mM ($P < 0.05$, Fig. 1).

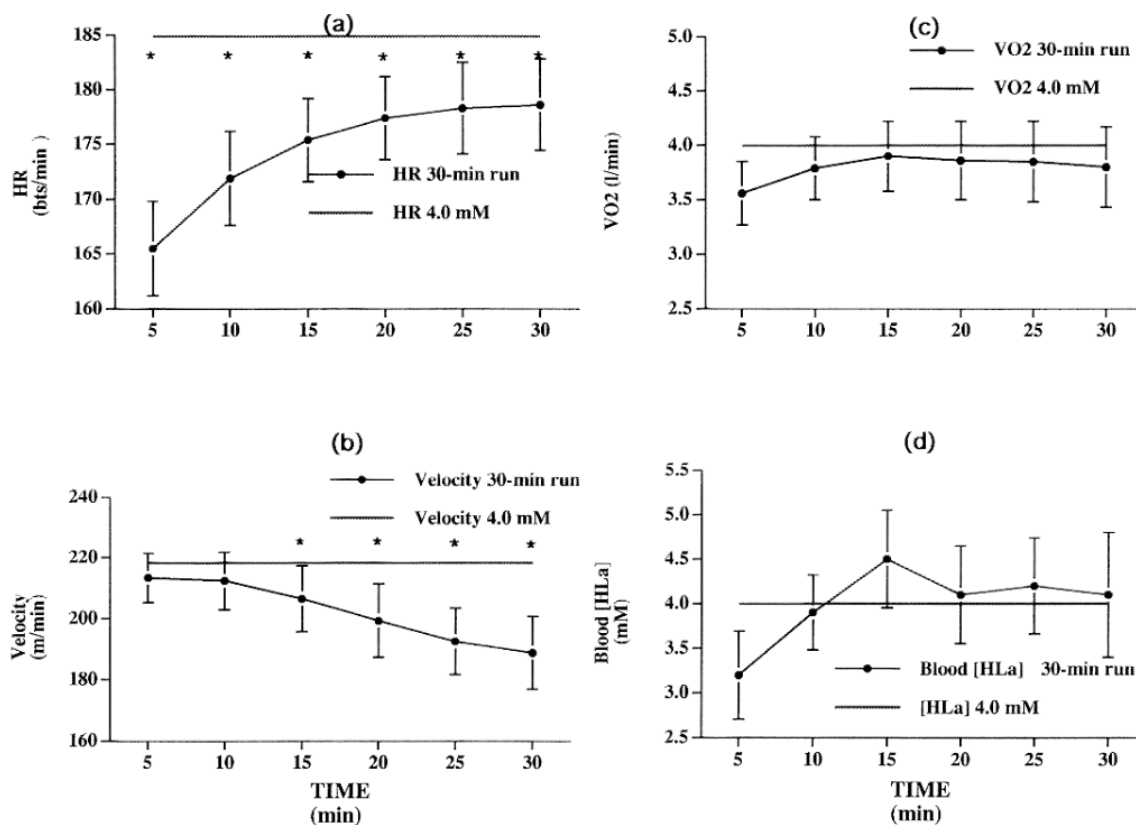


Figure 2. HR (a), velocity (b), $\dot{V}O_2$ (c), and HLA (d) values (\pm SEM) during the 30-min run at the RPE corresponding to a blood[HLA] of 4.0 mM (from the incremental protocol).

Responses to the 30-min run at the RPE corresponding to the incremental exercise blood [HLA] of 4.0 mM. One female subject did not attain a blood [HLA] of 4.0 mM during the incremental protocol and thus did not participate in the 30-min run at this intensity. HR increased significantly over time, from 166 ± 4 bpm at minute 5 to 179 ± 4 bpm at minute 30 (Fig. 2). All HR values during the 30-min run at this intensity were significantly lower than HR at 4.0 mM measured during the incremental protocol. V was reduced by $\approx 11.5\%$ during the 30-min production protocol, from 213 ± 8 m \cdot min $^{-1}$ at min 5 to 189 ± 12 m \cdot min $^{-1}$ at min 30; this was statistically significant beyond 10 min of exercise (Fig. 2; $P < 0.05$). $\dot{V}O_2$ varied between $3.56 \pm$

$0.29 \text{ l}\cdot\text{min}^{-1}$ (at min 5) and $3.90 \pm 0.32 \text{ l}\cdot\text{min}^{-1}$ (at min 15), and blood [HLA] varied between $3.2 \pm 0.5 \text{ mM}$ (at min 5) and $4.5 \pm 0.6 \text{ mM}$ (at min 15) min during this 30-min run (Fig. 2). None of these $\dot{V}\text{O}_2$ or blood[HLA] were significantly different from corresponding incremental test values.

DISCUSSION

Although maximal oxygen uptake has traditionally been considered the criterion measure of cardiorespiratory fitness(15,26) and exercise intensity has been typically prescribed as a percent of $\dot{V}\text{O}_{2\text{max}}$ and/or HR max(1), recent studies suggest that the blood [HLA] response to exercise may be a more sensitive measure of relative metabolic stress than either $\dot{V}\text{O}_2$ or HR(8,10,18,24,25,27,28,30-32). Because the determination of blood [HLA] is invasive, several non-invasive techniques such as running performance and RPE have been proposed to estimate LT and blood [HLA](4,5,10,12,22,23,28,29).

We have previously reported that RPE provide a good estimate of blood [HLA] during 30-min of running at velocities corresponding to LT and blood [HLA] of 2.5 mM and 4.0 mM (24). In that study subjects ran for 30-min at the V associated with LT and blood [HLA] of 2.5 mM and 4.0 mM. After minute 10 during the 30-min runs at constant V, RPE, $\dot{V}\text{O}_2$, and blood [HLA] were not different from corresponding values observed during the incremental protocol. These results provided support for the use of RPE as a psycho-physiologically valid tool for exercise prescription, and indicated that RPE have particular utility for exercise prescription when blood [HLA] is used as the intensity criterion. However, in that study(24), a response paradigm was used, rather than a classic psycho-physiological estimation-production paradigm(16). The advantage of a perceptual estimation-production paradigm is that physiological/clinical responses that are measured during a graded exercise test will be the same during an individual training program provided that the prescribed “target RPE” is produced by titrating locomotor velocity. This ensures the physiological and/or clinical integrity of the prescription. The present study employed a classic psycho-physiological estimation-production protocol, in which the subject was able to control velocity of the treadmill in order to maintain a target RPE (i.e., constant effort paradigm) and thus produce a target blood [HLA].

The major findings of the present study indicate that RPE is a valid tool for prescribing exercise intensities when blood [HLA] of 2.5 mM and 4.0 mM are used as the criterion measures for exercise prescription. This is evidenced by the fact that when subjects used RPE from the estimation protocol they were able to produce blood [HLA] that reasonably approximated the desired blood[HLA] of either 2.5 mM or 4.0 mM (Figs. 1 and 2). For exercise at the higher intensity, however, blood [HLA] of 4.0 mM was produced by continuously reducing treadmill V during the 30-min run. This confirmed our hypothesis and was expected in view of our previous findings, in which RPE (as well as blood [HLA] and $\dot{V}\text{O}_2$ in most instances) rose continuously throughout a 30-min treadmill run at constant V(24). Furthermore, this was a predictable response in that the treadmill test employed a “constant effort” rather than a “constant velocity” protocol. As such, the observed response of reduced V over time, at the higher intensity, is consistent with accepted methods of prescribing exercise intensity.

The rise in $\dot{V}O_2$ and blood [HLA] during a constant-V run(24) is consistent with the concept of a slow component of $\dot{V}O_2$ during exercise at work rates above the LT (usually defined as the difference between end-exercise $\dot{V}O_2$ and $\dot{V}O_2$ at min 3 of constant-load exercise) (11,19). At constant-velocity (power output) exercise above the LT, $\dot{V}O_2$ rises to a level above that predicted by the $\dot{V}O_2$ -work rate relationship in the sub-LT domain. Associated with this reduced exercise efficiency(11) is compromised endurance(19). It also implies that, to prevent the progressive rise in $\dot{V}O_2$ at exercise intensities that are initiated above the LT, power output or V must be reduced over time. In support of this, Ribeiro et al. (21) reported that power output had to be reduced by $\approx 15\%$ during 40 min of cycle ergometer exercise in order to keep $\dot{V}O_2$ constant at $\approx 78\% \dot{V}O_{2max}$. Our results are consistent with this and demonstrate that the progressive rise in $\dot{V}O_2$ during exercise above the LT can be attenuated by holding effort (i.e., RPE) constant (thereby necessitating a reduction in running V).

In summary, results of the present study indicate that RPE can be used to produce blood [HLA] reasonably close to the criterion levels of 2.5 mM and 4.0 mM during a 30-min running bout where the subject is free to alter treadmill V. These results support our previous work (24), and also that of Dunbar et al. (6), who demonstrated that RPE could be used to regulate exercise intensity during cycle ergometer and treadmill exercise at intensities of 50% and 70% of $\dot{V}O_{2max}$. The absolute RPE values associated with the LT (12.2), blood [HLA] of 2.5 mM(15.3) and 4.0 mM (17.6) observed in the present study are consistent with previously reported data from our laboratory(4,9,12,23,24) and support the internal consistency for the use of RPE to estimate the LT and blood [HLA]. Because it is easier to monitor and regulate RPE than HR, $\dot{V}O_2$, or blood [HLA], RPE may be preferred as a psycho-physiologically valid tool for exercise prescription, particularly when blood [HLA] is used as the criterion to establish exercise intensity.

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 in healthy adults. *Med. Sci. Sports Exerc.* 22:265-274, 1990.
2. Borg, G., P. Hassmen, 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.
3. Borg, G., and B. J. Noble. Perceived exertion. In: *Exercise and Sport Sciences Reviews*, J. H. Wilmore (Ed.). New York: Academic Press, 1974, pp. 131-153.
4. Boutcher, S. H., R. L. Seip, R. K. Hetzler, E. F. Pierce, D. Snead, and A. Weltman. The effects of specificity of training on rating of perceived exertion at the lactate threshold. *Eur. J. Appl. Physiol.* 59:365-369, 1989.
5. Demello, J. J., K. J. Cureton, R. E. Boineau, and M. M. Singh. Ratings of perceived exertion at the lactate threshold in trained and untrained men and women. *Med. Sci. Sports Exerc.* 19:354-362, 1987.

6. Dunbar, C. C., R. J. Robertson, R. Baun, et al. The validity of regulating exercise intensity by ratings of perceived exertion. *Med. Sci. Sports Exerc.* 24:94-99, 1992.
7. Ekblom, B., and A. N. Goldbarg. The influence of physical training and other factors on the subjective rating of perceived exertion. *Acta Physiol. Scand.* 83:399-406, 1971.
8. Farrell, P. A., J. H. Wilmore, E. F. Coyle, J. E. Billing, and D. L. Costill. Plasma lactate accumulation and distance running performance. *Med. Sci. Sports* 11:338-344, 1979.
9. Haskvitz, E. M., R. L. Seip, J. Y. Weltman, A. D. Rogol, and A. Weltman. The effect of training intensity on ratings of perceived exertion. *Int. J. Sports Med.* 13:377-383, 1992.
10. Henritze, J., A. Weltman, R. Schurrer, and K. Barlow. Effects of training at and above the lactate threshold on the lactate threshold and maximal oxygen uptake. *Eur. J. Appl. Physiol.* 54:84-88, 1985.
11. Henson, L. C., D. C. Poole, and B. J. Whipp. Fitness as a determinant of oxygen uptake response to constant load exercise. *Eur. J. Appl. Physiol.* 59:21-28, 1989.
12. Hetzler, R. K., R. L. Seip, S. H. Boutcher, E. Pierce, D. Snead, and A. Weltman. Effect of exercise modality on ratings of perceived exertion at various lactate concentrations. *Med. Sci. Sports Exerc.* 23:88-92, 1991.
13. Hill, D. W., K. J. Cureton, S. C. Grisham, and M. A. Collins. Effect of training on the rating of perceived exertion at the ventilatory threshold. *Eur. J. Appl. Physiol.* 56:206-211, 1987.
14. Mihevic, P. M. Sensory cues for perceived exertion: a review. *Med. Sci. Sports Exerc.* 13:150-163, 1981.
15. Mitchell, J. H., B. J. Sproule, and C. B. Chapman. The physiological meaning of the maximal oxygen intake test. *J. Clin. Invest.* 37:538-547, 1958.
16. Myles, W. S. and D. Maclean. A comparison of response and production protocols for assessing perceived exertion. *Eur. J. Appl. Physiol.* 55:585-587, 1986.
17. Pandolf, K. B., R. L. Burse, and R. F. Goldman. Differentiated ratings of perceived exertion during physical conditioning of older individuals using leg-weight loading. *Percept. Mot. Skills* 40:563-574, 1975.
18. Pierce, E. F., A. Weltman, R. L. Seip, and D. Snead. Effects of training specificity on the lactate threshold and VO₂ peak. *Int. J. Sports Med.* 11:267-272, 1990.
19. Poole, D. C., W. Schaffartzik, D. R. Knight, et al. Contribution of exercising legs of the slow component of oxygen uptake kinetics in humans. *J. Appl. Physiol.* 71:1245-1253, 1991.

20. Purvis, J. W. and K. J. Cureton. Ratings of perceived exertion at the anaerobic threshold. *Ergonomics* 24:295-300, 1981.
21. Ribeiro, J. P., V. Hughes, R. A. Fielding, W. Holden, W. Evans, and H. G. Knuttgen. Metabolic and ventilatory responses to steady state exercise relative to lactate thresholds. *Eur. J. Appl. Physiol.* 55:215-221, 1986.
22. Robertson, R. J. Central signals of perceived exertion during dynamic exercise. *Med. Sci. Sports Exerc.* 14:390-396, 1982.
23. Seip, R. L., D. Snead, E. F. Pierce, P. Stein, and A. Weltman. Perceptual responses and blood lactate concentration: effect of training state. *Med. Sci. Sports Exerc.* 23:88-92, 1991.
24. Steed, J., G. A. Gaesser, and A. Weltman. Rating of perceived exertion and blood lactate concentration during submaximal running. *Med. Sci. Sports Exerc.* 26:797-803, 1994.
25. Tanaka, K., Y. Matsuura, A. Matsuzaka, et al. A longitudinal assessment of anaerobic threshold and distance running performance. *Med. Sci. Sports Exerc.* 16:278-282, 1984.
26. Taylor, H. L., E. Buskirk, and A. Henschel. Maximal oxygen intake as an objective measure of cardiorespiratory performance. *J. Appl. Physiol.* 8:73-80, 1955.
27. Weltman, A., R. L. Seip, D. Snead, et al. Exercise training at and above the lactate threshold in previously untrained women. *Int. J. Sports Med.* 13:257-263, 1992.
28. Weltman, A., D. Snead, R. Seip, et al. Prediction of lactate threshold and fixed blood lactate concentrations from 3200-m running performance in male runners. *Int. J. Sports Med.* 8:401-406, 1987.
29. Weltman, A., D. Snead, P. Stein, et al. Reliability and validity of a continuous incremental treadmill protocol for the determination of lactate threshold, fixed blood concentrations, and VO_2 max. *Int. J. Sports Med.* 11:26-32, 1990.
30. Weltman, A., V. Katch, S. Sady, and P. Freedson. Onset of metabolic acidosis (anaerobic threshold) as a criterion measure of submaximum fitness. *Res. Quart.* 49:218-227, 1978.
31. Weltman, A., D. Snead, R. Seip, et al. Percentages of maximal heart rate, heart rate reserve and VO_2 max for determining endurance training intensity in male runners. *Int. J. Sports Med.* 11:218-222, 1990.
32. Weltman, A., J. Weltman, R. Rutt, et al. Percentages of maximal heart rate, heart rate reserve and VO_2 peak for determining training intensity in sedentary women. *Int. J. Sports Med.* 10:212-216, 1989.