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Rating of perceived exertion and blood lactate concentration during submaximal running

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ABSTRACT

STEED, J., G. A. GAESSER, and A. WELTMAN. Rating of perceived exertion and blood lactate concentration during submaximal running. *Med. Sci. Sports Exerc.* Vol. 26, No. 6, pp. 797–803, 1994. We examined whether the relation between of ratings of perceived exertion (RPE) and exercise intensities associated with the lactate threshold (LT) and blood lactate concentrations (BLC) of 2.5 and 4.0 mM, established with an incremental protocol, held during 30-min treadmill run at constant velocity (V). RPE (11.6, 14.9, 16.8, 18.9), oxygen uptake ($\dot{V}O_2$) (3.2, 3.7, 3.9, 4.2 $l \cdot min^{-1}$), and V (168, 196, 215, 227 $m \cdot min^{-1}$) at LT, BLC of 2.5, and 4.0 mM and peak were determined for nine males during incremental exercise. Subjects then completed three 30-min runs at the V associated with LT and BLC of 2.5 and 4.0 mM, with RPE, $\dot{V}O_2$, and blood [HLa] determined every 5 min. After min 10 during the 30-min runs, RPE, $\dot{V}O_2$, and BLC were not significantly different from corresponding values observed during the incremental protocol. Regression equations predicting BLC from RPE were generated from results obtained during the incremental protocol. RPE values from the 30-min runs were used to predict BLC, and the measured BLC was used to validate the use of RPE as a predictor of BLC. Correlations ranged from r = 0.79 to r = 0.98 [total error (TE) ranged from 0.6–1.3 mM]. We conclude that RPE is a physiologically valid tool for prescribing exercise intensity when the intent is to use LT and/or BLC as the intensity criterion.

LACTATE THRESHOLD, RPE, EXERCISE, EXERCISE PRESCRIPTION

Recent evidence suggests that the lactate threshold (LT) and exercise intensities corresponding to various blood lactate concentrations (BLC; i.e., 2.5, 4.0 mM) are accurate predictors of endurance performance and useful for exercise prescription (11,12,14,16,17,23,27,30,32). It has also been suggested that training above LT may result in greater physiological adaptations than training at LT (30,31).

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Ratings of perceived exertion (RPE) have also been suggested to be a useful tool for prescription of exercise intensity (3,5,6,8,13,19,25) and may serve as adjunctive measures to standard physiological responses associated with blood lactate concentration (blood [HLa]) (3,7,13,24). It has been shown that RPE at LT and/or BLC is not affected by gender (7), training state (7,10,26), exercise modality (2,10,15), specificity of training (4), or training intensity (13). Thus, ratings of perceived exertion may be an effective tool to estimate LT and BLC when determining exercise intensity.

Previous studies of the relation between RPE, LT, and BLC have utilized incremental exercise protocols (3-min stages). If RPE is linked to LT and BLC, one could hypothesize that the relation between RPE, LT and BLC would hold for exercise durations more typically used for training (i.e., 30 min). For example, during running at a constant velocity (which is typically used for training), as blood [HLa] changes over time there should be a concomitant (and predictable) change in RPE. Thus, the purpose of the present study was to examine whether the relation observed between RPE, LT, and BLC during an incremental protocol remained stable during 30-min constant-velocity exercise bouts.

METHODS

Subjects. Nine healthy, recreationally active males (mean age 24.7 ± 3.8 yr; mean weight 82.4 ± 8.7 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.

Incremental protocol. Subjects completed a continuous, incremental, level running treadmill protocol to determine the oxygen uptake ($\dot{V}O_2$) and velocity (V) associated with LT and BLC of 2.5 mM and 4.0 mM, and

peak (33). The initial treadmill velocity was set at 130 $m \cdot min^{-1}$. The velocity during each subsequent 3-min stage was increased by 10 $m \cdot min^{-1}$. Measurements of $\dot{V}O_2$, heart rate, blood [HLa], and RPE were recorded during the last min of each stage. $\dot{V}O_{2peak}$ was determined as the highest 1-min value attained during the test. The test was terminated by the investigators when the subject could no longer exercise owing to fatigue.

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 was channeled 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.

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. Blood samples during exercise testing were obtained by having subjects rest their hands on the rails of the treadmill. 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).

The LT was determined by examining the blood [HLa]-velocity relation observed during the incremental protocol (33). The highest velocity attained that was not associated with an elevation in blood [HLa] above baseline (preexercise) was designated as V-LT. This always occurred just prior to the curvilinear increase in blood lactate that was 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 velocity) was designated as the $\dot{V}O_2$ associated with the LT ($\dot{V}O_2$LT), and the heart rate at this velocity was defined as the heart rate associated with LT (HR-LT). Velocities associated with BLC of 2.5 mM and 4.0 mM were determined from the plot of blood [HLa] vs running velocity (33). $\dot{V}O_2$ and HR values associated with these BLC were determined in a manner identical to that described for V-LT. A single investigator determined LT and BLC for all subjects.

Ratings of perceived exertion. Prior to the treadmill test and before each subsequent running bout standardized directions for RPE were read to each subject (22). Subjects were instructed to give an overall rating of perceived exertion using Borg's 6–20 point scale. Perceptual scale anchors were established as reported previously (3). 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 also completed three running bouts lasting 30 min at the velocities associated with LT and BLC of 2.5 mM and 4.0 mM (as determined from the incremental treadmill protocol). RPE and blood [HLa] measurements were taken every 5 min and $\dot{V}O_2$ and heart rate were determined continuously using the same measurement procedures for these variables as described earlier.

Statistical analyses. A one-way analysis of variance with repeated measures was used to determine significant differences between the $\dot{V}O_2$, RPE, and blood [HLa] observed during the 3-min incremental protocol and those values observed during the 30-min treadmill runs. The present study examined similarities in $\dot{V}O_2$, RPE, and blood [HLa] responses measured during a 3-min incremental protocol compared to values obtained during 30-min of running at the velocities associated with LT and BLC of 2.5 and 4.0 mM. Where significant ($P < 0.05$) F ratios were observed, *post-hoc* comparisons made were between 5, 10, 15, 20, 25, and 30 min and the corresponding value from the incremental protocol. Tukey's *post-hoc* procedure was used with the Bonferroni correction for multiple comparisons.

The relation between RPE and the blood [HLa] response during the incremental protocol was determined for each subject using regression analysis (validation equations) where blood [HLa] was predicted from the RPE value. The RPE values obtained during the 30-min treadmill runs were then used to predict blood [HLa] (using the equation developed from the incremental protocol). The relation between the predicted blood [HLa] values (from the RPE-blood [HLa] regression equations determined from the incremental protocol) and the actual blood [HLa] observed during the 30-min running bouts, were examined by 1) correlating the actual and predicted blood [HLa], 2) examining mean differences via paired t-tests, and 3) determining the standard (total) error (SE).

RESULTS

The mean (± SEM) data for $\dot{V}O_2$, HR, velocity, and RPE at the LT and BLC of 2.5 mM, 4.0 mM and peak during the incremental protocol are presented in Table 1. The mean $\dot{V}O_2$ values at LT, 2.5 mM, and 4.0 mM oc-

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

Variable	Mean (SE)			
	LT	2.5 mM	4.0 mM	Peak
$\dot{V}O_2$ ($l \cdot min^{-1}$)	3.20 (0.52)	3.69 (0.56)	3.86 (0.11)	4.21 (0.14)
HR (beats·min^{-1})	167.8 (3.2)	182.1 (3.1)	190.7 (1.8)	195.2 (1.8)
Velocity ($m \cdot min^{-1}$)	167.8 (6.0)	195.9 (8.3)	214.8 (6.8)	226.7 (5.3)
RPE	11.6 (.69)	14.9 (.72)	16.8 (.45)	18.9 (.56)

curred at 76.2%, 87.6%, and 91.7% of $\dot{V}O_2$peak, respectively. The mean HR values at LT, 2.5 mM, 4.0 mM, and peak occurred at 85.8%, 93.3%, and 97.7% of HR_{peak}, while for RPE the mean values at LT, 2.5 mM, 4.0 mM and peak ranged from 11.6–18.9.

For the 30-min run at the velocity corresponding to LT (Fig. 1), $\dot{V}O_2$ at 5 min was significantly lower than $\dot{V}O_2$LT, and RPE observed at 5 and 10 min were significantly lower than RPE LT. No significant differences were observed for blood [HLa] when comparisons were made between the 30-min running bout at the treadmill velocity corresponding to LT and the LT measured during the incremental protocol.

During the 30-min running bouts at velocities corresponding to both 2.5 mM and 4.0 mM, $\dot{V}O_2$, RPE, and blood [HLa] increased over time ($P < 0.05$, Figs. 2 and 3). For the 30-min run at the velocity corresponding to 2.5 mM (Fig. 2), no significant differences were observed for $\dot{V}O_2$ or blood [HLa] when comparing the values during the 30-min running bout with corresponding values during the incremental protocol. For RPE, the only significant difference observed was that the RPE at 5 min was lower than the RPE at 2.5 mM during the incremental protocol.

One subject did not attain a BLC of 4.0 mM during the incremental protocol and, as a result, did not perform a 30-min running bout at this velocity. The only significant differences observed were that $\dot{V}O_2$ and blood [HLa] at 5 min and RPE at 5 and 10 min were significantly lower than the corresponding values at the treadmill velocity eliciting a 4.0 mM BLC during the incremental protocol (Fig. 3).

Table 2 presents a comparison of measured blood [HLa] during the 30-min running bouts and the predicted blood [HLa] estimated from the corresponding RPE (with the corresponding RPE used in the individual regression equations for the RPE/blood [HLa] relation observed during the incremental protocol). The correlation between actual and predicted blood [HLa] (from RPE) ranged from r = 0.79 to r = 0.98 with a mean of r = 0.90. Significant differences were observed between actual and predicted blood [HLa] for all but two subjects. However, no pattern of consistently underpredicting or overpredicting blood [HLa] was observed with an overall mean difference of 0.21 mM. The standard (total) error (SE) value ranged from 0.61–1.3 mM with an overall mean SE of 0.98 mM.

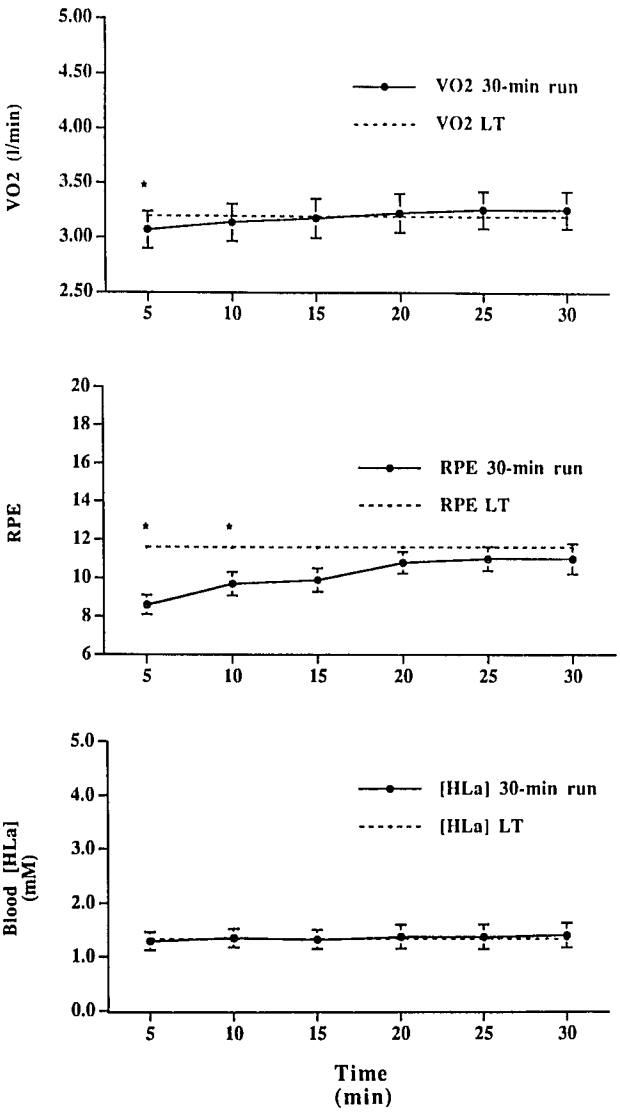

Figure 1—Comparison of $\dot{V}O_2$, RPE, and blood [HLa] measured during the 30-min run at the treadmill velocity associated with LT, and the corresponding values observed at LT during the incremental protocol (*dashed line*). * = Different than the LT value observed during the incremental protocol; $P < 0.05$.

DISCUSSION

Exercise intensity is typically prescribed as a percent of $\dot{V}O_{2max}$ and/or HR max (1). Because the blood [HLa] response to exercise may be a more sensitive measure of relative metabolic stress than either $\dot{V}O_2$ or HR, it has been suggested that the LT and BLC be taken into consideration when deriving an exercise prescription (14,23,29,30,35). As the determination of LT and BLC necessitates invasive procedures, a number of alternative, noninvasive techniques, including running performance

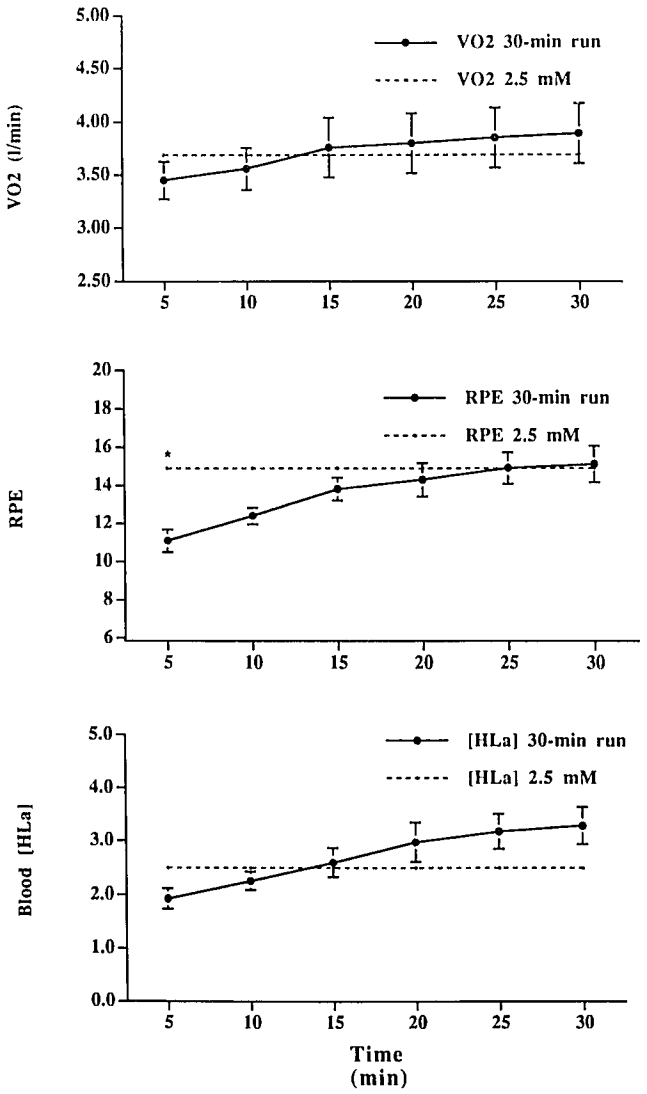

Figure 2—Comparison of $\dot{V}O_2$, RPE, and blood [HLa] measured during the 30-min run at the treadmill velocity associated with 2.5 mM, and the corresponding values observed at 2.5 mM during the incremental protocol (*dashed line*). * = Different than the 2.5 mM value observed during the incremental protocol; $P < 0.05$.

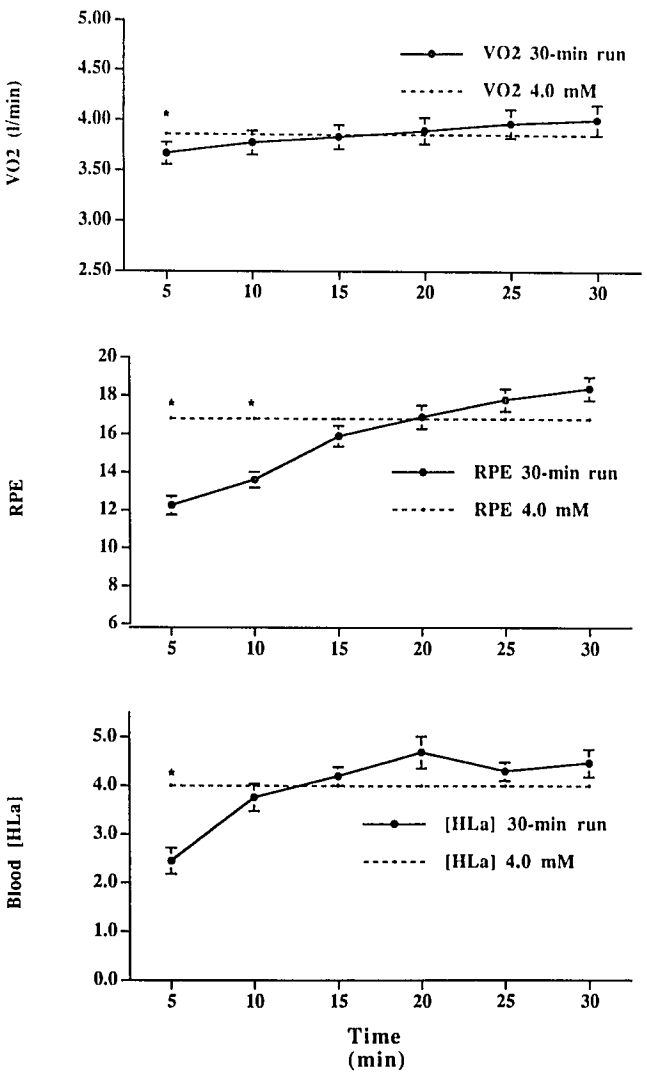

Figure 3—Comparison of $\dot{V}O_2$, RPE, and blood [HLa] measured during the 30-min run at the treadmill velocity associated with 4.0 mM, and the corresponding values observed at 4.0 mM during the incremental protocol (*dashed line*). * = Different than the 4.0 mM value observed during the incremental protocol; $P < 0.05$

(35,36) and RPE assessment (4,7,13,15,25,26), have been proposed to estimate LT and BLC.

Although the relation between RPE and blood [HLa] during incremental exercise has been reported previously, most exercise prescription techniques are designed for continuous exercise bouts between 20 and 60 min (1). Consequently, if RPE is to be used as an indicator of exercise intensity, particularly if intensity is defined in terms of blood [HLa], it seems warranted to determine whether the RPE-blood [HLa] relation observed during incremental exercise holds true for constant-load exercise.

The major findings of the present study indicate RPE associated with LT and BLC of 2.5 mM and 4.0 mM observed during a 3-min incremental running protocol reasonably reflect RPE associated with these BLC during running exercise of up to 30 min in duration. That is, after the first 5–10 min of running, no statistically significant differences were observed for RPE, $\dot{V}O_2$ or blood [HLa] when comparing 30-min running protocols and the corresponding values measured at the same velocities during the 3-min incremental protocol (Figs. 1–3). These findings, combined with the strong individual relations observed between measured blood [HLa] during the 30-min running bouts and the predicted BLC (from the individual RPE-blood [HLa] relations determined from the incremental protocol) (Table 2), indicate that RPE can be used to estimate BLC during running bouts of up to 30 min. It should be noted that the present findings are limited to running duration of up to 30 min. Whether the RPE-blood [HLa] remains stable for exercise of longer

TABLE 2. Comparison of measured blood lactate concentration [HLa] for each subject, during 30-min running bouts at LT, 2.5, and 4.0 mM and the predicted blood [HLa] estimated from the RPE/blood [HLa] relationship determined during incremental exercise.

Subject	Actual [HLa] Mean (SD)	Predicted [HLa] Mean (SD)	r	SE
1	2.69 (1.4)	2.31 (1.2)	0.82	0.85
2	2.16 (1.8)	3.03 (1.9)*	0.85	1.30
3	2.73 (1.4)	1.64 (.92)*	0.94	1.25
4	2.79 (1.1)	1.74 (1.2)*	0.93	1.14
5	2.99 (1.6)	3.70 (1.3)*	0.95	0.90
6	2.95 (1.5)	2.74 (1.2)	0.92	0.65
7	2.13 (0.87)	2.83 (1.25)*	0.79	0.95
8	3.16 (0.95)	2.69 (0.93)*	0.91	0.61
9	2.89 (1.1)	1.89 (0.65)*	0.98	1.15
Mean	2.72	2.51	0.90	0.98

* Significantly different from actual [HLa], $P < 0.05$.
SE = $\sqrt{(Y-Y')^2/n}$.

duration (where glycogen depletion and/or hypoglycemia may occur) cannot be determined from the present data.

The present data support the findings of Dunbar et al. (9) regarding the validity of regulating exercise intensity by ratings of perceived exertion. They reported that RPE provided a simple and physiologically valid method of regulating exercise intensity on a cycle ergometer and treadmill at exercise intensities of 50 and 70% $\dot{V}O_{2max}$. On the average, less than a 2% difference was observed between the target intensity ($\dot{V}O_2$) and the actual intensity produced using a prescribed RPE. The authors suggested that the difference observed between actual and target intensity was less than would be expected if a target heart rate (HR) was used to produce an actual intensity.

The present data extend the findings of Dunbar et al. (9). This previous experiment (9) examined the utility of RPE to regulate exercise intensity based on $\%\dot{V}O_{2max}$ and we examined the utility of RPE to regulate exercise intensity based on blood [HLa]. Dunbar et al. (9) demonstrated that RPE may be a better regulator of exercise intensity than target HR. However, although a good relation exists between target HR and $\%\dot{V}O_{2max}$ (1), this is not the case when HR is used as an estimate of the LT or BLC (18,34,37). A number of studies have reported that the use of a percent of HRmax, HR reserve or $\dot{V}O_{2max}$ does not result in the same level of metabolic stress across subjects when the LT and blood [HLa] are used as criterion measures of exercise intensity (18,34,37). Thus, the findings of the present study have implications for exercise prescription where the goal is to exercise at the LT or a given blood [HLa], rather than at a given HR or $\dot{V}O_2$.

It should be realized that the study of Dunbar et al. (9) employed a classic psychophysical estimation-production paradigm. In their study exertional perceptions estimated during a graded exercise test were subsequently produced during inter- and intramodal testing sessions. In the present study a response protocol was used. Although response and production protocols result in a similar relationship between RPE and exercise intensity, it has been suggested that the production protocol has several advantages (21). We chose a response protocol because training intensity is frequently prescribed using constant power/velocity (4,13,14,16,17,23,30,31). In future investigations a given exercise intensity (i.e., corresponding to a predetermined blood [HLa]) should be produced using a target RPE. Physiological validation of this RPE prescription procedure can then be accomplished by comparing blood [HLa] between the estimation and production trials.

In previous reports from this laboratory (4,13,15,26), mean values for overall RPE at the LT were between 10.2 and 12.3, at a BLC of 2.5 mM between 14.1 and 15.8, and at a BLC of 4.0 mM between 16.0 and 17.6. In the present study mean values for overall RPE at LT, 2.5 mM, and 4.0 mM of 11.6, 14.9, and 16.8 are in agreement with previously reported values and suggest that RPE is a consistent indicator of LT and BLC obtained during the type of incremental exercise testing used in these studies.

Although blood [HLa] and RPE were fairly well coupled during both incremental and constant-velocity exercise protocols, we recognize that blood [HLa] itself cannot be the sole factor associated with RPE. The responses during the 30-min exercise bouts provide some insight to this conclusion. It generally required the first 10–15 min of the 30-min exercise bouts before RPE reached the value associated with the same velocity during the incremental protocol. This suggests that other factors, perhaps linked to exercise duration, are mediators for RPE at the onset of exercise. This is clearly evident in the 30-min exercise bout at the velocity corresponding to the LT (Fig. 1). Whereas blood [HLa] did not change, RPE rose from 9–11 during the 30-min of exercise. The incremental running protocol (for the determination of RPE, LT, and BLC) may also affect the relation between RPE and BLC during constant-load exercise. This protocol typically lasts 30–45 min, and the velocities associated with LT and BLC of 2.5 mM and 4.0 mM are not generally reached until well into the test (~20–40 min). Nevertheless, during the 30-min exercise bouts at the two higher intensities, RPE and blood [HLa] both rose in a parallel fashion. It should be mentioned that during the 30-min bout at the highest intensity, blood [HLa] rose to ~4.5 mM and RPE to ~18. These results point out a limitation in assigning exercise intensity in absolute (velocity) terms. Since RPE and blood [HLa] seemed to rise in parallel at the higher exercise intensities, it could be hypothesized that had subjects been instructed to exercise at a constant RPE, it would have been necessary to reduce treadmill velocity during the 30-min of exercise which presumably would have attenuated the rise in blood [HLa]. In this instance RPE would become an independent variable, unlike the present study where both blood lactate and RPE were dependent variables.

We further examined the RPE/blood [HLa] relation by

comparing the measured blood [HLa] during the 30-min exercise bout at the velocity corresponding to a blood [HLa] of 4.0 mM with the predicted blood [HLa] determined from each individual RPE-blood [HLa] relation observed during the incremental protocol. This intensity was chosen because of data which suggest that some subjects are unable to achieve a steady state blood [HLa] at this intensity (28). Correlations between measured and predicted blood [HLa] during this condition ranged from $r = 0.67$ to $r = 0.85$ with an average correlation of $r = 0.77$. This further supports the notion that RPE is a reasonable way of estimating blood [HLa]; i.e., the rise in blood [HLa] over time is associated with a concomitant increase in RPE.

In summary, results of the present study indicate that RPE provides a good estimate of BLC during 30-min of running at exercise intensities corresponding to LT and BLC of 2.5 mM and 4.0 mM. These results further support the use of RPE as a physiologically valid tool for exercise prescription and suggest that RPE have particular utility for exercise prescription when blood lactate is used as the intensity criterion.

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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 Sports 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. BURKE, E. J. Individualized fitness program using perceived exertion for the prescription of exercise in healthy adults. *J. Phys. Educ. Rec. Dance* 50:35–37, 1979.
6. CARTON, R. L. and E. C. RHODES. A critical review of the literature on ratings scales for perceived exertion. *Sports Med.* 2:198–222, 1985.
7. DEMELLO, J. J., K. J. CURETON, R. E. BOINEAU, and 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.
8. DISHMAN, R. K., R. W. PATTON, J. SMITH, R. WEINBERG, and A. JACKSON. Using perceived exertion to prescribe and monitor exercise training heart rate. *Int. J. Sports Med.* 8:208–213, 1987.
9. 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.
10. 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.
11. 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 Exerc.* 11:338–349, 1979.
12. HAGBERG, J. M. Physiological implications of the lactate threshold. *Int. J. Sports Med.* 5(Suppl.):106–109, 1984.
13. 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.
14. 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.
15. 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.* 23:80–87, 1991.
16. 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.
17. HURLEY, B. F., J. M. HAGBERG, W. K. ALLEN, et al. Effect of training on blood lactate levels during submaximal exercise. *J. Appl. Physiol.* 56:1260–1264, 1984.
18. KATCH, V, A. WELTMAN, S. SADY, and P. FREEDSON. Validity of the relative percent concept for equating training intensity. *Eur. J. Appl. Physiol.* 39:219–227, 1978.
19. MIHEVIC, P. M. Sensory cues for perceived exertion: a review. *Med. Sci. Sports Exerc.* 13:150–163, 1981.
20. 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, 1957.
21. 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.
22. 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. *Perept. Mot. Skills* 40:563–574, 1975.
23. PIERCE, E. F., A. WELTMAN, R. L. SEIP, and D. SNEAD. Effects of training specificity on the lactate threshold and VO_2peak. *Int. J. Sports Med.* 11:267–272, 1990.
24. PURVIS, J. W. and K. J. CURETON. Ratings of perceived exertion at the anaerobic threshold. *Ergonomics* 24:295–300, 1981.
25. ROBERTSON, R. J. Central signals of perceived exertion during dynamic exercise. *Med. Sci. Sports Exerc.* 14:390–396, 1982.
26. 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.
27. SJODIN B. and I. JACOBS. Onset of blood lactate accumulation and marathon running performance. *Int. J. Sports Med.* 2:23–26, 1981.
28. STEGMANN, H. and W. KINDERMANN. Comparison of prolonged exercise tests at the individual anaerobic threshold and the fixed anaerobic threshold of 4 mmol/l. *Int. J. Sports Med.* 3:105–110, 1982.
29. 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.
30. 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.
31. WELTMAN, A., J. WELTMAN, R. SCHURRER, W. S. EVANS, J. D. VELDHUIS, and A. D. ROGOL. Endurance training amplifies the pulsatile release of growth hormone: effects of training intensity. *J. Appl. Physiol.* 72:2188–2196, 1992.
32. WELTMAN, A., V. KATCH, S. SADY, and P. FREEDSON. Onset of metabolic acidosis (anaerobic threshold) as a criterion measure of submaximum fitness. *Res. Q.* 49:218–227, 1978.
33. WELTMAN, A, D. SNEAD, P. STEIN, et al. Reliability and validity of a continuous incremental treadmill protocol for the determination

of lactate threshold, blood lactate concentrations, and VO_2max. *Int. J. Sports Med.* 11:26–32, 1990.
34. WELTMAN, A., D. SNEAD, R. SEIP, et al. Percentages of maximal heart rate, heart rate reserve and VO_2max for determining endurance training intensity in male runners. *Int. J. Sports Med.* 11: 218–222, 1990.
35. 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.
36. WELTMAN, A., R. SEIP, A. J. BOGARDUS, et al. Prediction of lactate threshold (LT) and fixed blood lactate concentrations (FBLC) from 3200-m running performance in women. *Int. J. Sports Med.* 11:373–378, 1990.
37. WELTMAN, A., J. WELTMAN, R. RUTT, et al. Percentages of maximal heart rate, heart rate reserve and VO_2peak for determining training intensity in sedentary women. *Int. J. Sports Med.* 10:212–216, 1989.
38. YOSHIDA, T. Effect of exercise duration during incremental exercise on the determination of anaerobic threshold and the onset of blood lactate accumulation. *Eur. J. Appl. Physiol.* 53:196–199, 1984.