Journal of Strength and Conditioning Research, 2001, 15(1), 109–115

A New Approach to Monitoring Exercise Training

CARL FOSTER, JESSICA A. FLORHAUG, JODI FRANKLIN, LORI GOTTSCHALL, LAURI A. HROVATIN, SUZANNE PARKER, PAMELA DOLESHAL, AND CHRISTOPHER DODGE

Department of Exercise and Sport Science, University of Wisconsin–La Crosse, Wisconsin 54601.

ABSTRACT

The ability to monitor training is critical to the process of quantitating training periodization plans. To date, no method has proven successful in monitoring training during multiple types of exercise. High-intensity exercise training is particularly difficult to quantitate. In this study we evaluate the ability of the session rating of perceived exertion (RPE) method to quantitate training during non–steady state and prolonged exercise compared with an objective standard based on heart rate (HR). In a 2-part design, subjects performed steady state and interval cycle exercise or practiced basketball. Exercise bouts were quantitated using both the session RPE method and an objective HR method. During cycle exercise, the relationship between the exercise score derived using the session RPE method and the HR method was highly consistent, although the absolute score was significantly greater with the session RPE method. During basketball, there was a consistent relationship between the 2 methods of monitoring exercise, although the absolute score was also significantly greater with the session RPE method. Despite using different subjects in the 2 parts of the study, the regression relationships between the session RPE method and the HR method were nearly overlapping, suggesting the broad applicability of this method. We conclude that the session RPE method is a valid method of quantitating exercise training during a wide variety of types of exercise. As such, this technique may hold promise as a mode and intensity-independent method of quantitating exercise training and may provide a tool to allow the quantitative evaluation of training periodization plans.

Key Words: periodization, heart rate, perceived exertion, interval training, prolonged exercise

Reference Data: Foster, C., J.A. Florhaug, J. Franklin, L. Gottschall, L.A. Hrovatin, S. Parker, P. Doleshal, and C. Dodge. A new approach to monitoring exercise training. *J. Strength Cond. Res. 15(1):109–115. 2001.*

Introduction

Many studies have stressed the importance of the training load in enhancing athletic performance and the changes in performance attributable to varying periods of hard and easy training (2, 5, 6, 9, 11–15, 18–20). These practicalities are reflected in the practice of coaches who design highly detailed periodized training programs (10, 21). Unfortunately, although periodized training programs are in their essence quantitative, there has been great difficulty in finding a way to effectively quantitate training using a single term. Endurance athletes have often used the training volume (kilometers per week) as an index of training with reasonable effectiveness (13, 15). However, measurement of training volume ignores the critical importance of high-intensity training bouts (17). For athletes training for strength and/or power, the use of the volume of training is an inadequate tool because of the overriding importance of intensity.

There have been several previous attempts at developing a single term for quantitating training. In the late 1960s, Cooper (7) proposed the concept of ''aerobics points,'' which integrated exercise duration and the absolute intensity of aerobic training activities. Although this approach was highly successful in terms of guiding the nonathletic public into fitness exercise, the lack of an index of the relative training intensity (which is much more critical as an index of how likely a given exercise bout is to induce a training effect) dictated that this method would lack the ability to adequately describe the training load. Banister et al. (2, 9, 18) have developed the concept of the training impulse (TRIMP) as a strategy for integrating the components of training into a single term that allows a systems analysis approach to training. This method has shown great promise relative to understanding the training response and has been extended by Busso et al. (6), Foster et al. (11, 12, 14, 15), and Mujika et al. (19, 20). There are at least 2 important limitations to the TRIMP concept developed by Bannister et al. (2, 9, 18). First, although monitors with the capacity of integrating the heart rate (HR) responses over long periods of time are widely available, if an athlete forgets to use his or her HR monitor or if the HR monitor has a technical failure during the exercise bout, information regarding that training session is lost. Second, HR is a comparatively poor method of evaluating very high-intensity exercise such as weight training, high-intensity interval training, and plyometric training. Thus even with the most optimal HR monitoring strategy, integration of the TRIMP does not translate well to very high-intensity exercise training. We have developed a modification of the rating of the perceived exertion method (the session RPE), which uses RPE as a marker of training intensity within the TRIMP concept (11, 12, 14, 15). This method has been shown to be related to both HR and blood lactate markers of exercise intensity (14). However, our previous evaluation of the session RPE method has been based primarily on responses during 30 minutes of steady state exercise within a comparatively modest range of exercise intensities. Given the importance of both high-intensity training and extensive training bouts within the training plan of contemporary athletes, information regarding the stability of the session RPE method vs. HR methods of monitoring training during exercise other than brief steady state exercise is important. Accordingly, the intent of this study was to evaluate the relationship of the session RPE- and HR-based methods of monitoring training during different forms of exercise training.

Methods

This study was conducted in 2 separate but related parts. In the first part we chose a common conditioning activity that allowed good quantitative control of the exercise performed (cycle ergometry). This allowed an idealized approach to both steady state and interval exercise that we felt would be generally representative of a variety of conditioning activities. During this phase of the study, the subjects were 12 well-trained, recreational-level cyclists ($m = 6$, $F = 6$). In the second part, the subjects were members of a collegiate men's basketball team ($n = 14$). Each subject provided informed consent prior to participation, and the study protocol was approved by the university institutional review board. Some descriptive characteristics of the subjects are provided in Tables 1 and 2.

Part 1

Prior to the experimental protocol, each subject was evaluated during maximal incremental exercise on an electrically braked cycle ergometer (Lode, Gronningen, Netherlands). The subjects pedaled at freely chosen revolutions per minute (rpm's) within the range of 60–80. The test began at a power output of 50 W for men, 40 W for women over 60 kg body weight, and 30 W for women under 60 kg body weight. The power output was increased by the same increment every 3 minutes until the subject could no longer continue. The peak power output was interpolated based on the proportional time achieved during the terminal stage. Oxygen uptake ($\dot{V}O_2$) was measured using open-circuit spirometry (Quinton Q-Plex, Seattle, WA). Peak $\dot{V}O_2$ was defined as the highest continuous full minute $\dot{V}O_2$ observed during the test. HR was measured by radiotelemetry (Polar Electro Oy, Port Washington, NY). Blood lactate was measured in capillary blood obtained from a fingertip at rest, at the end of each stage of exercise, and at 1, 3, 5, and 10 minutes postexercise using an enzyme electrode system (YSI Sport, Yellow Springs, OH). The individual anaerobic threshold (IAT) was calculated on the basis of the exercise and recovery blood lactate concentrations according to Stegmann et al. (22).

Subsequently, each subject performed 8 randomly ordered exercise training bouts, which included a reference 30-minute steady state bout at a power output equivalent to 90% of the IAT, 2 additional steady state exercise bouts at the same power output but of 60- and 90-minutes duration, and 5 interval bouts at the same mean power output. The interval bouts were 30 minutes in duration and included variations in interval

Table 1. Mean ($\pm SD$) characteristics of the subjects in part 1.*

	Men	Women
Age (yr)	23.0 ± 3.6	21.3 ± 1.5
Height (cm)	177 ± 4	165 ± 8
Weight (kg)	70.8 ± 7.2	63.8 ± 4.3
Percent fat	11.1 ± 4.8	20.9 ± 2.7
Peak power output (W)	315 ± 34	237 ± 33
Peak power output (W·kg^{-1})	4.52 ± 0.52	3.68 ± 0.38
Peak $\dot{V}O_2$ (L·min^{-1})	3.84 ± 0.30	2.94 ± 0.34
Peak $\dot{V}O_2$ (ml·min^{-1}·kg^{-1})	54.6 ± 2.4	46.2 ± 3.5
Peak HR (b·min^{-1})	198 ± 10	186 ± 7
IAT power output (W)	228 ± 25	188 ± 48
IAT power output (W·kg^{-1})	3.28 ± 0.65	2.94 ± 0.61
IAT HR (b·min^{-1})	174 ± 19	159 ± 16

* HR = heart rate; IAT = individual aerobic threshold.

Table 2. Mean ($\pm SD$) characteristics of the subjects in Part 2.

Age (yr)	20.2 ± 1.5
Height (cm)	191.4 ± 4.9
Weight (kg)	89.3 ± 7.8
Percent fat	12.8 ± 2.8
Peak $\dot{V}O_2$ (L·min^{-1})	4.60 ± 0.50
Peak $\dot{V}O_2$ (ml·min^{-1}·kg^{-1})	51.5 ± 2.2
Ventilatory threshold (L·min^{-1})	3.32 ± 0.54
Respiratory compensation threshold (L·min^{-1})	3.71 ± 0.44
HRpeak (b·min^{-1})	182 ± 9
HR at VT (b·min^{-1})	136 ± 6
HR at RCT (b·min^{-1})	150 ± 4

* HR = heart rate.

Modification of the Category Ratio Rating of Perceived Exertion Scale

Rating	Descriptor
0	Rest
1	Very, Very Easy
2	Easy
3	Moderate
4	Somewhat Hard
5	Hard
6	.
7	Very Hard
8	.
9	.
10	Maximal

Figure 1. Modification of the category ratio rating of perceived exertion (RPE) scale for this study. The verbal anchors have been changed slightly to reflect American idiomatic English (e.g., light becomes easy; strong or severe becomes hard). Briefly, the athlete is shown the scale approximately 30 minutes following the conclusion of the training bout and asked ''How was your workout?'' In our experience, approximately 80–90% of athletes will give a single number representing the training session. The remaining athletes usually insist on fractionating and summating the component parts of the session.

magnitude (±10, ±25, and ±50% of mean power output with a constant 60-seconds/60-seconds exercise/recovery schedule) and in interval duration (0.5 minutes/0.5 minutes, 1.0 minute/1.0 minute, and 2.0 minutes/2.0 minutes with a constant ±25% difference in mean power output for exercise/recovery). Throughout each exercise bout, HR was measured by radiotelemetry. At rest and at 10-minute intervals, blood lactate was measured in capillary blood obtained from a fingertip and perceived exertion was obtained using the category ratio (e.g., 0–10) RPE scale of Borg (4). Thirty minutes following the completion of each exercise bout, the subject was shown the RPE scale with verbal anchors (Figure 1) and asked to provide a rating of the overall difficulty of the exercise bout, the session RPE. We have previously used this method in studies of monitoring exercise training (11, 12, 14, 15). This use of the RPE method is somewhat different than the conventional approach that asks the subject to rate with highly standardized verbal instructions how difficult they perceived the exercise to be at a particular moment. Rather, we explained to the subject that we wanted a global rating of the entire training bout using whatever cues they felt to be appropriate. We de-

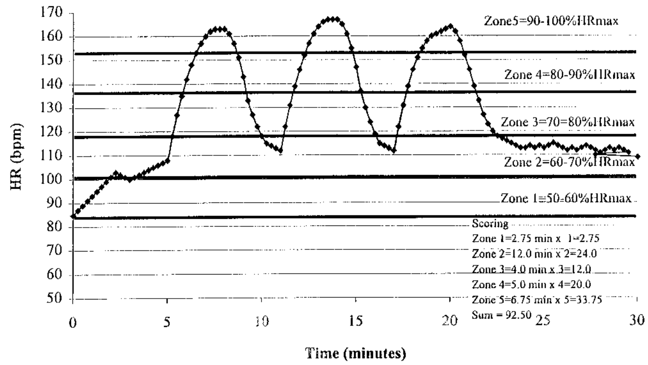

Figure 2. Schematic representation of the summated HR zone method that serves as the objective basis for comparison for the session RPE method. Five HR zones are calculated based on percentages of the HR peak: 50–60% (zone 1); 60–70% (zone 2); 70–80% (zone 3); 80–90% (zone 4); and 90–100% (zone 5). After the exercise session, the HR monitor is downloaded and the cumulated time is each zone is calculated. The time in each zone is then multiplied by the value for that zone and the results summated.

layed securing the session RPE rating for 30 minutes so that particularly difficult or particularly easy segments toward the end of the exercise bout would not dominate the subject's rating. In this context, it is important to note that the momentary RPE during the interval bouts often varied quite substantially based on the momentary activity pattern. However, the session RPE represents a single global rating of the intensity for the entire training session. We have not encountered difficulties with the subjects understanding our intent, particularly with the slightly modified verbal anchors presented in Figure 1, either in this study or in our previous work with this technique (11, 12, 14, 15).

An exercise score (e.g., TRIMP) for each bout was computed by multiplying the duration of the exercise bout by the session RPE for that bout. As an objective reference method for quantitating each exercise bout, the HR monitor was downloaded using software that allowed evaluation of the accumulated time in each of 5 HR zones based on 50–60%, 60–70%, 70–80%, 80–90%, and 90–100% of HRpeak, as suggested by Edwards (8) and used in our previous work (11, 12, 14, 15). An exercise score (e.g., TRIMP) for that bout was then computed by multiplying the accumulated duration in each HR zone by a multiplier for each zone (50–60% = 1; 60–70% = 2; 70–80% = 3; 80–90% = 4; and 90–100% = 5) and summating the result (Figure 2).

Part 2

Prior to the experimental protocol, each subject was evaluated during incremental treadmill exercise using an Astrand protocol. Exercise was continued to volitional fatigue. $\dot{V}O_2$ was measured using open-circuit spirometry and $\dot{V}O_2$peak was defined as the highest

Table 3. Serial (mean ± *SD*) responses of the outcome measures.

	Steady state	0.5 m/0.5 m	1.0 m/1.0 m	2.0 m/ 2.0 m	±10%	±25%	±50%
Heart rate (b·min^{-1})							
Rest	79 ± 13	77 ± 11	84 ± 9	82 ± 12	79 ± 6	84 ± 9	82 ± 10
10 m	155 ± 10	137 ± 16	159 ± 9	166 ± 12*	153 ± 10	159 ± 9	155 ± 13
20 m	159 ± 11	140 ± 17	155 ± 14	169 ± 12*	158 ± 11	166 ± 14*	164 ± 11*
30 m	160 ± 13	163 ± 16	169 ± 11	172 ± 14*	163 ± 9	169 ± 11*	170 ± 13*
60 m	164 ± 12	—	—	—	—	—	—
90 m	166 ± 9	—	—	—	—	—	—
Blood lactate (mmol·l^{-1})							
Rest	1.1 ± 0.5	0.9 ± 0.3	1.5 ± 0.6	1.5 ± 0.8	1.0 ± 0.2	1.5 ± 0.6	1.1 ± 0.5
10 m	2.8 ± 0.8	2.9 ± 0.6	4.4 ± 1.8*	3.7 ± 1.2*	2.7 ± 0.9	4.4 ± 1.8*	4.8 ± 1.0*
20 m	2.8 ± 0.8	3.0 ± 0.8	4.2 ± 1.4*	3.4 ± 1.5*	2.7 ± 0.8	4.2 ± 1.4*	4.9 ± 1.3*
30 m	2.5 ± 0.8	2.8 ± 0.7	3.8 ± 1.6*	3.9 ± 1.4*	2.2 ± 0.9	3.8 ± 1.6*	5.6 ± 1.5*
60 m	2.3 ± 0.7	—	—	—	—	—	—
90 m	2.2 ± 0.6	—	—	—	—	—	—
Rating of perceived exertion							
Rest	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
10 m	2.8 ± 0.8	3.2 ± 1.0	3.5 ± 0.7	4.1 ± 0.9*	3.4 ± 1.1	3.5 ± 0.7	3.9 ± 1.0*
20 m	3.8 ± 1.2	4.0 ± 1.2	4.2 ± 0.9	4.3 ± 0.8	3.6 ± 1.1	4.2 ± 0.9	4.4 ± 1.1*
30 m	3.8 ± 1.1	4.2 ± 1.5	4.2 ± 0.9	4.4 ± 1.1*	3.8 ± 1.1	4.2 ± 0.9	5.4 ± 1.2*
60 m	4.3 ± 1.0	—	—	—	—	—	—
90 m	4.9 ± 1.0	—	—	—	—	—	—

* $p < 0.05$ compared to steady state.

continuous 60-second $\dot{V}O_2$ during the exercise bout. Ventilatory and respiratory compensation thresholds were determined according to changes in the slopes of the $\dot{V}CO_2$ vs. $\dot{V}O_2$ and $\dot{V}E$ vs. $\dot{V}CO_2$ relationships, respectively (3). HR was measured using radiotelemetry.

Subsequently, each subject was monitored during basketball practice sessions and/or during competitive matches. The pattern of exercise during these bouts was determined either by the coach's plan or by the dictates of the competitive situation. No attempt was made to experimentally influence the pattern of exercise. HR responses were recorded during each exercise bout using radiotelemetry, downloaded, and analyzed using the summated HR zone approach as in Part 1 of the study. Thirty minutes following the conclusion of each exercise bout, the subject rated the overall difficulty of the bout using the session RPE method, as in Part 1 of the study.

Statistical Analyses

Statistical analysis focused on comparing the exercise scores obtained during each exercise bout using the session RPE and summated HR zone methods of quantitating exercise training. This was accomplished using repeated-measures analysis of variance (ANOVA). Post hoc analyses were performed using the Tukey procedure. Additionally, regression analyses were performed to relate the 2 methods of quantitating exercise training.

Results

Part 1

The serial responses of HR, blood lactate, and RPE through the course of the 8 exercise bouts are presented in Table 3. Given that the mean power output was the same at 90% IAT in all exercise bouts, the differences in HR, blood lactate, and RPE were consistent with previously established responses during interval training and during prolonged exercise (1, 16, 23). There was a consistent pattern for longer intervals, more variable intervals, and longer duration steady state exercise bouts to be associated with greater evidence of psychophysiological strain, evidenced by HR and blood lactate concentrations.

Comparisons of the overall exercise score between the summated HR zone method and the session RPE method are presented in Table 4. There were significant differences between the methods for each exercise bout, with the session RPE method consistently giving a larger exercise score than the summated HR zone method. However, regression analyses revealed that the pattern of differences was highly consistent among the various exercise bouts (Figure 3).

Part 2

The comparative exercise score using the summated HR zone method and session RPE method during basketball practices and/or games is presented in Table

Table 4. Comparison of calculated exercise TRIMP scores using the summated heart rate (HR) zone method and the session rate of perceived exertion (RPE) method.

	Summated HR zone	Session RPE
30 min steady state	110 ± 24	130 ± 57*
60 min steady state	216 ± 39	270 ± 63*
90 min steady state	350 ± 44	432 ± 67*
30 s/30 s interval	107 ± 14	131 ± 45*
60 s/60 s interval	117 ± 18	148 ± 54*
120 s/120 s interval	114 ± 17	146 ± 47*
+10% interval	114 ± 16	136 ± 60*
+25% interval	117 ± 18	148 ± 54*
+50% interval	114 ± 111	161 ± 46*
Basketball	652 ± 59	744 ± 84*

* $p < 0.05$ summated HR zone vs. session RPE.

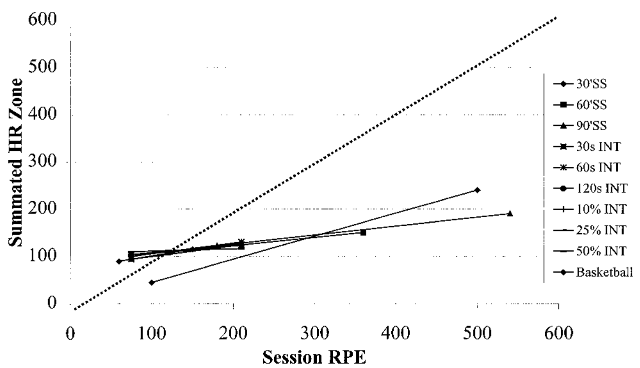

Figure 3. Regression lines comparing the relationship between TRIMP scores generated using the summated HR zone method and session RPE method of monitoring exercise during the various cycle exercise bouts and during basketball practice and competition. Note the overall similarity among the different exercise bouts, and that although different subjects are used there is a similarity of the cycling and basketball data.

4. There were significant differences between the methods, with the session RPE method giving a larger exercise score than the summated HR method. However, regression analyses revealed that the pattern of differences was consistent and similar to responses during steady state and interval cycle exercise observed in Part 1 (Figure 3).

Discussion

The results of this study are consistent with our previous observations of a highly correlated relationship between the session RPE and the summated HR zone methods of evaluating training sessions (11, 12, 14). This suggests that either method may be used as a method of creating a TRIMP score for the evaluation of exercise training. The methods are not, however, interchangeable because of differences in scale. The summated HR zone method is based on only 5 zones, so an athlete working at maximal HR for the entire duration of an exercise bout would only have their exercise duration multiplied by 5, whereas with 10 effective zones represented by the session RPE method the multiplier for exercise duration can be somewhat larger, particularly at high intensities. In this regard, it is worth noting that Banister et al. (2, 9, 18) used a nonlinear multiplier for the mean HR recorded during exercise, which is conceptually quite similar to the category ratio RPE score. Thus although the quality of information available from the session RPE method is fairly crude relative to the highly detailed data available from HR records, the present data suggests that the same critical information is contained with both methods. The simplicity of the session RPE method suggests the practical value of the technique.

Our experience with the session RPE method suggests that most athletes can use the technique fairly well with only minimal instruction, primarily by focusing on the verbal anchors associated with the RPE scale while responding to the simple question ''How was your workout?'' Approximately 20% of athletes will attempt to separately report RPE-duration scores for various phases of each training session, which may then be summated. The remaining 80% of athletes will comfortably give a single number representing the gestalt of the training session. Despite these differences, we have found that individual athletes seem to be very consistent in their own pattern of using the session RPE method, and that regardless of whether they are detail-oriented or more globally focused, there is a good relationship between their reports of training load and subsequent performance (12). Previous work, which we have done with this technique, has suggested that other data (monotony, strain) may be derived from the session RPE–derived TRIMP scores reported by the athletes (11, 15). Although one suspects that similar data may be derived from HR-based TRIMP scores, to date this has not been accomplished.

The overall consistency between objective (summated HR zone) and subjective (session RPE) methods of monitoring training during highly disparate types of exercise suggests that the session RPE method may be useful over a very wide variety of exercise sessions. Previous experience with RPE as a method of monitoring exercise suggests that muscularly strong individuals are comparatively poor at rating the intensity of aerobic exercise sessions, attending more to muscular tension than to sensations of dyspnea. However, when providing an overall gestalt with familiar modes of training, it may be that even athletes performing highly intense muscular activities can provide adequate ratings. Although ultrahigh-intensity exercise (resistance training, plyometrics) cannot objectively be evaluated using HR criteria, the pattern of responses between objective and subjective measures in the pre-

Table 5. Schematic training diary demonstrating the calculation of training load, monotony, and strain.

Day	Training activity	Session rate of perceived exertion (RPE)	Duration (min)	Load
Sunday	Cycle 100 km	5*	180	940
Monday	Jog 5 km + extensive stretch	2*	25	50
Tuesday	Skate 6 × 10 min at AT pace/5 min rec	7*	120	840
	Explosive weights + abs	7*	40	280
Wednesday	Cycle 30 km	3*	60	180
Thursday	Skate 10 × 3 min at 5 km pace/5-min rec	8*	75	390
Friday	Jog 5 km + extensive stretch	2*	25	50
Saturday	Skate 20 × 1 min at tempo/2-min rec	8*	75	390
	Explosive weights + abs	7*	40	280
	Weekly load			3400
	Monotony (× *SD*)			1.26
	Strain (load × monotony)			4284

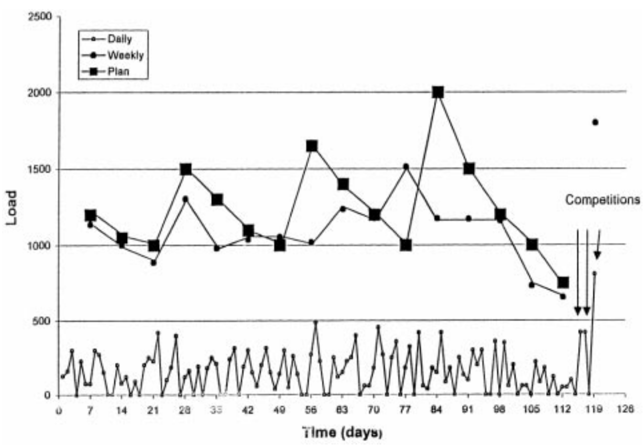

Figure 4. Schematic training periodization plan over the 17 weeks leading up to a major weekend of competition. Note the day to day variation in the training load and the weekly variation in training. With this scheme of monitoring training, the coach can appreciate how well the athlete executes the designed periodization plan. In particular, the failure of the athlete to progressively increment the ''heavy'' weeks of the training plan is very obvious and explains the less than satisfactory results at the time of the competitions.

sent data (where the power output of the ±50% ergometer trials and during basketball practice occasionally exceeded the peak aerobic power output) suggests that the session RPE method might be a valid approach to evaluating even very high-intensity exercise. If this were so, then a single method could be used to provide a quantitative basis for describing the periodization of training plans. Some support for this suggestion is provided by the relationship between training load and performance, which we have previously demonstrated with speed skaters (who do a wide variety of aerobic, interval, and ultrahigh-intensity training; 11, 12). Finally, the session RPE method has the advantage of not requiring knowledge of maximal exercise responses (e.g., HRpeak) to anchor the monitoring method. Although in athletic individuals determination of maximal HR is relatively risk-free, it still represents an additional step in designing a training monitoring scheme that is not required by the session RPE method.

Practical Applications

The present data provide support for the use of the session RPE method as a subjective estimate of training load during non–steady state exercise, including very high-intensity interval training and team sport practice and competition. As such, it suggests that this very simple method may be a useful technique for quantitating training load in a wide variety of athletic applications. In this regard, the present data suggest that the session RPE method may provide a mechanism for quantitating the exercise intensity component and allow calculation of a single number representative of the combined intensity and duration of training sessions.

The present data and our previous experience with the session RPE technique suggest that it is easy to use, quite reliable, and consistent with objective physiological indices of the intensity of exercise training. By simply asking the athlete to rate the global intensity of the exercise bout and then by multiplying by the duration of the training bout, a daily exercise score can be created. This can be put into the form of an exercise diary, which can reveal the overall weekly pattern of exercise (Table 5). From this, accessory indices of training, such as monotony and strain, can be calculated, potentially providing in index of the likelihood of untoward training outcomes. Finally, the daily and weekly training loads calculated using this technique can be presented graphically, allowing the coach to have a visual impression of the periodization plan as experienced by the athlete (Figure 4).

References

1. BANGSBO, J. Physiology of intermittent exercise. In: *Exercise and Sport Science* W.E. Garrett and D.T. Kirkendall, eds. Philadelphia: Lippincott, Williams and Wilkins, 2000. pp. 31–52.
2. BANISTER, E.W., T.W. CLAVERT, M.V. SAVAGE, AND T. BACH. A systems model of training for athletic performance. *Aust. J. Sports Med.* 7:57–61. 1975.
3. BEAVER, W.L., K. WASSERMAN, AND B.J. WHIPP. A new method for detecting the anaerobic threshold by gas exchange. *J. Appl. Physiol.* 60:2020–2027. 1986.
4. BORG, G., P. HASSMEN, AND M. LANGERSTROM. Perceived exertion in relation to heart rate and blood lactate during arm and leg exercise. *Eur. J. Appl. Physiol.* 65:679–685. 1985.
5. BROWN, D.D. Pulmonary responses to exercise and training. In: *Exercise and Sport Science.* W.E. Garrett and D.T. Kirkendall, eds. Philadelphia: Lippincott, Williams and Wilkins, 2000. pp. 117–134.
6. BUSSO, T., C. DENIS, R. BONNEFOY, A. GEYSSANT, AND J.R. LACOUR. Modeling of adaptations to physical training by using a recursive least squares algorithm. *J. Appl. Physiol.* 82:1685–1693. 1997.
7. COOPER, K.H. *Aerobics.* New York: Bantam, 1968.
8. EDWARDS, S. *The Heart Rate Monitor Book.* Sacramento: Fleet Feet Press, 1993. pp. 113–129.
9. FITZ-CLARAKE, J.R., R.H. MORTON, AND E.W. BANISTER. Optimizing athletic performance by influence curves. *J. Appl. Physiol.* 71:1151–1158. 1991.
10. FLECK, S.J. Periodized strength training: A critical review. *J. Strength Cond. Res.* 13:82–89. 1999.
11. FOSTER, C. Monitoring training in athletes with reference to overtraining syndrome. *Med. Sci. Sports Exerc.* 30:1164–1168. 1997.
12. FOSTER, C., E. DANIES, L. HECTOR, A. SNYDER, AND R. WELSH. Athletic performance in relation to training load. *Wis. Med. J.* 95:370–374. 1996.
13. FOSTER, C., J. DANIELS, AND R. YARBROUGH. Physiological and training correlates of marathon running performance. *Aust. J. Sports Med.* 9:58–61. 1977.
14. FOSTER, C., L. HECTOR, R. WELSH, M. SCHRAGER, M.A. GREEN, AND A.C. SNYDER. Effects of specific versus cross training on running performance. *Eur. J. Appl. Physiol.* 70:367–372. 1995.
15. FOSTER, C., AND M. LEHMANN. Overtraining syndrome. In: *Running Injuries.* G. Guten, ed. Orlando: W.B. Saunders, Co., 1997. pp. 173–188.
16. GOROSTIAGA, E.M., C.B. WALTER, C. FOSTER, AND R.C. HICKSON. Uniqueness of interval and continuous training at the same maintained exercise intensity. *Eur. J. Appl. Physiol.* 63:101–107. 1991.
17. LINDSAY, F.H., J.A. HAWLEY, K.H. MYBURGH, H.H. SCHOMEN, T.D. NOAKES, AND S.C. DENNIS. Improved athletic performance in highly trained cyclists after interval training. *Med. Sci. Sports Exerc.* 28:1427–1434. 1996.
18. MORTON, R.H., J.R. FITZ-CLARKE, AND E.W. BANISTER. Modeling human performance in running. *J. Appl. Physiol.* 69:1171–1177. 1990.
19. MUJIKA, I. The influence of training characteristics and tapering on the adaptations in highly trained individuals. A review. *Int. J. Sports Med.* 19:439–436. 1996.
20. MUJIKA, I., T. BUSSO, L. LACOSTE, A.G. BARALE, AND J.C. CHATARD. Modeled responses to training and taper in competitive swimmers. *Med. Sci. Sports Exerc.* 28:252–258. 1996.
21. ROWBOTTOM, D. Periodization of training. In: *Exercise and Sport Science.* W.E. Garret and D.T. Kirkendall, eds. Philadelphia: Lippincott, Williams and Wilkins, 2000. pp. 499–512.
22. STEGMANN, H., W. KINDERMANN, AND A. SCHNABEL. Lactate kinetics and individual anaerobic threshold. *Int. J. Sports Med.* 2:160–165. 1981.
23. VUORIMAA, T., T. VASANKARI, AND H. RUSKO. Comparison of physiological strain and muscular performance of athletes during 2 intermittent running exercises at the velocity associated with $\dot{V}O_2$max. *Int. J. Sports Med.* 21:96–101. 2000.