Eur J Appl Physiol (1985) 54:343–349

European Journal of
Applied
Physiology
and Occupational Physiology

The increase of perceived exertion, aches and pain in the legs, heart rate and blood lactate during exercise on a bicycle ergometer*

Gunnar Borg, Gunilla Ljunggren, and Ruggero Ceci

Department of Psychology, University of Stockholm, S-10691 Stockholm, Sweden

Summary. This study was designed to show the general increase in perceived exertion, perception of aches or pain in the legs, heart rate (HR), and blood lactate, and the covariance between these variables during bicycle ergometer work, and to describe individual differences both within and between power levels by testing a large group (28 male students).

Estimates of perceived exertion and feelings of aches or pain in the legs were recorded using Borg's category-ratio scale (CR-10). The subjects were tested with a stepwise increase of power levels with 40 W increments up to a voluntary maximum.

Though HR increases fairly linearly with power, the other variables follow positively accelerating functions with exponents of about 1.6–2 for the perceptual variables, and an exponent of about 3 for blood lactate.

The results from the 8 most fit subjects could be described in the same way as for the whole group except for blood lactate, where there was a need to include a threshold value (b), that, together with a rest value (a), shows the starting point of the function ($R = a + c(W - W_0)^n$).

The data support the idea that a combination of heart rate and blood lactate is a better predictor of perceived exertion and feelings of aches and pain in the legs, than is each of the single physiological variables taken alone.

Key words: Perceived exertion — Aches and pain in the legs — Heart rate — Blood lactate — Psychophysiology — Physiological functions — Individual differences — Category-ratio scaling — Psychophysics

Introduction

The relationship between perceived exertion (PE) and heart rate (HR) during heavy bicycle work of an aerobic character is well established. There is a high correlation between these two strain variables, but general variation with physical power for each of the variables is different. While HR increases linearly with power, PE grows according to a positively accelerating power function with an exponent of about 1.6 (Borg 1962, 1972).

The common scale of PE for studying individual differences is the RPE-scale (ratings of perceived exertion, Borg 1970). The RPE-scale is constructed so that the rating increases linearly with increasing power and HR during an exercise test on the bicycle ergometer. Sometimes this linear relationship is taken as a sign of a causal relationship between PE and HR, but it is only an artifact of scale construction.

There are many physiological variables that should be taken into account when we want to predict how PE increases with power, e.g. sensations from working muscles, joints and from the skin, and from the cardiovascular and respiratory systems (Borg 1962; Borg and Dahlström 1962; Ekblom and Goldbarg 1971).

In spite of the sensory-physiological complexity involved in PE, much of its variance can be statistically explained by HR. It seems possible, however, that even more of the variance can be statistically explained if representative factors of both central and peripheral functioning are in-

Offprint requests to: G. Borg at the above address

* This study was supported by The Bank of Sweden Tercentenary Foundation, No. 84/64:1

cluded. Therefore, a both valid and simple way to predict the general variation of PE and the differences between individuals seems to be created by combining HR and muscle lactate (ML) or blood lactate (BL) (Borg 1962; Noble et al. 1983).

At this stage, there is no scientific agreement as to how ML and BL increase with physical power during ergometer cycling. In most investigations the increase in BL is described in two stages (Wassermann et al. 1973; Davis et al. 1979). However, a 3-stage model has also been proposed (Skinner 1981).

The variation in BL has also been described as one simple, monotonously increasing function which, according to Borg (1962), may be described as fitting both physiological and perceptual responses, and has the following general form:

$$R = a + c(S - b)^n$$

Here (R) is the response depending upon the stimulus (S) and (n) is the exponent. The basic noise level or rest value, (a), gives, together with the physical b-constant, the starting point of the function and (c) is the measure constant. In most cases (b) is equal to zero and the increase starts at the beginning of the work. However, in some groups of individuals such as well-trained athletes it seems necessary to include a b-value. By analyzing data from Holmgren and Ström (1959), Borg (1962) found that during a bicycle ergometer test, BL (in mmol $\times\, l^{-1}$) increased according to the following function in a group of normal, male subjects: $BL = 1.3 + 7 \times 10^{-6} \times S^{2.2}$. In a second group of racing cyclists a b-value of $S = 300$ kpm/min (50 W) had to be inluded, but the exponent was approximately the same.

In order to make it possible to determine both general variations over power levels and differences between individuals, a new psychophysical method has been developed by Borg. This is a category scale with ratio properties, giving power functions of the same kind as ordinary ratio scales (Borg 1982).

In an initial study with a small group of subjects, it was found that BL grew with an exponent of about 2.2, and ML (taken from muscle biopsies) with a slightly higher exponent of approximately 2.7. The psychophysical functions for PE and aches and pain also followed positively accelerating functions with exponents of about 1.6 and 1.7 (Noble et al. 1983). The main purpose of this study is to further investigate the psychophysiological relationships of PE, aches or pain in the legs, HR and BL with a large group of subjects. It is therefore of primary interest to further analyze the general physiological and perceptual functions one by one and in some combinations. A reasonable hypothesis here is that PE, which depends in part upon painless pressure on the feet and strain in the working muscles and joints, starts to increase earlier than pain perception.

Another purpose here is, by using a large group of subjects, to describe individual differences with regard both to the variation over power levels and to the variation in perceptual intensities for the same power levels. How much of the inter-individual variance of PE in a fairly normal group of male subjects is contributed to by HR, by BL and by a combination of HR and BL?

Method

Twenty-eight healthy male students in good physical condition volunteered to take part in the study. In Table 1 the means (M) and standard deviations (SD) of data characterizing the group are displayed. (Estimations of max $\dot{V}_{O_2}$ and max $\dot{V}_{O_2}$/kg were made according to Åstrand, 1960).

The tests were carried out on a bicycle ergometer with electrical brakes (Elema-Schönander model 369.4). HR was recorded on an Elema-Schönander (mingograf -61; type EM 61-142).

Table 1. Means (M) and standard deviations (SD) for age (years), height (cm), weight (kg), est. max $\dot{V}_{O_2}$ ($l \times min^{-1}$), est. max $\dot{V}_{O_2}$/kg ($ml \times kg^{-1} \times min^{-1}$), W_{170} (W) and (voluntary) W_{max} (W) for the whole group of 28 subjects and sub-group of 8 highly physically fit subjects who managed to work the full five minutes on 280 W

		Age	Height	Weight	Est. max $\dot{V}_{O_2}$	Est. max $\dot{V}_{O_2}$/kg	W_{170}	W_{max}
$N=28$	M	25.7	178.6	69.2	4.2	61.4	248.0	261.6
	SD	7.0	6.3	9.0	0.9	11.1	45.3	28.3
$N=8$	M	22.3	180.3	73.4	5.1	69.3	286.0	298.5
	SD	3.1	6.0	11.9	0.9	9.4	51.7	23.2

Finger-stick blood samples were taken for later BL analysis (Rydevik et al. 1982; Karlsson et al. 1983). Estimates of overall PE (R_e) and feelings of aches or pain in the legs (R_p) were recorded using Borg's category-ratio scale (CR-10), which is a new category scale with ratio properties (see Fig. 1).

All subjects warmed up for 5 minutes while pedalling with no load (other than the slight resistance at zero dial setting). They were then tested with a stepwise increase in power levels (at 60 rpm). Subjects pedalled with an increase of 40 W every five minutes, stopping at a voluntary maximum (a point at which they would not be excessively exhausted).

All the measurements were obtained during the last minute of exercise at each power level, beginning with ratings of PE and aches or pain in the legs. Pretest measurements were recorded with the subjects sitting on the bicycle. At the end of the testing, HR and the other ratings were recorded immediately before the subjects stopped pedalling, while BL samples were taken immediately afterwards.

0	Nothing at all	
0,5	Extremely weak	(just noticeable)
1	Very weak	
2	Weak	(light)
3	Moderate	
4	Somewhat strong	
5	Strong	(heavy)
6		
7	Very strong	
8		
9		
10	Extremely strong	(almost max)
•	Maximal	

Fig. 1. Borg's category ratio-scale (CR-10) with ratio properties

Results and discussion

The main results of the experiment are given below in Tables 2 and 3, and in Figs. 2—5. All calculations in the following are based on geometric means (GM); in these calculations the number 0 is set to 0.1.

It can be seen from Table 2 that the means increase systematically for all variables, but with slightly different rates of acceleration. The standard deviations are slightly higher for aches and pain in the legs than for PE, indicating a less strict definition of the former.

Values obtained at 240 W were slightly lower than expected. Most of the subjects were in good physical condition and had low HR-values. (For example, one very fit subject, age 26 years, reached a HR of 152 bpm at this terminal power value (320 W).)

Despite low levels of both HR and BL, the terminal values of R_e and R_p (about 9) indicate that the subjects were fairly close to their maximal level. It should be remembered that it was not the aim of this study to force the subjects to reach their true maximal level of performance, but to interrupt the exercise when they reached their voluntary maximum, at which they were not excessively exhausted.

Figure 2 illustrates how R_e and R_p increase with power. The two functions for R_e and R_p, in

Table 2. Means (M), standard deviations (SD) and geometric means (GM) of PE ratings (R_e) and of ratings of aches and pain in the legs (R_p) as well as HR (bpm) and BL (mmol $\times l^{-1}$) for the whole group of subjects for the different power levels (watt, W), together with the terminal values recorded at the terminal power level (TW), $N=28$

Variables		Pretest	0 W	40 W	80 W	120 W	160 W	200 W	240 W	TW
	M	0.2	0.6	1.1	1.8	3.0	4.1	5.4	7.7	9.0
R_e	SD	0.3	0.6	0.9	0.9	1.2	1.5	1.6	1.8	1.4
	GM	0.2	0.4	0.8	1.6	2.7	3.8	5.2	7.4	8.8
	M	0.2	0.6	1.1	1.7	2.7	3.8	5.5	7.6	8.9
R_p	SD	0.5	0.9	1.2	1.4	1.7	2.1	2.5	2.5	2.0
	GM	0.2	0.3	0.5	1.1	2.0	2.9	4.8	7.1	8.6
	M	66.6	73.0	81.4	94.7	111.1	130.7	149.8	167.3	175.7
HR	SD	11.1	12.1	11.4	11.4	12.2	14.6	15.5	15.6	12.2
	GM	65.6	72.1	80.6	94.0	110.5	130.0	149.0	166.6	173.3
	M	1.7	1.6	1.5	1.7	2.0	2.7	3.9	6.9	8.8
BL	SD	0.9	0.6	0.4	0.5	0.7	1.1	1.2	2.8	2.0
	GM	1.5	1.5	1.4	1.7	1.9	2.5	3.7	6.5	8.6

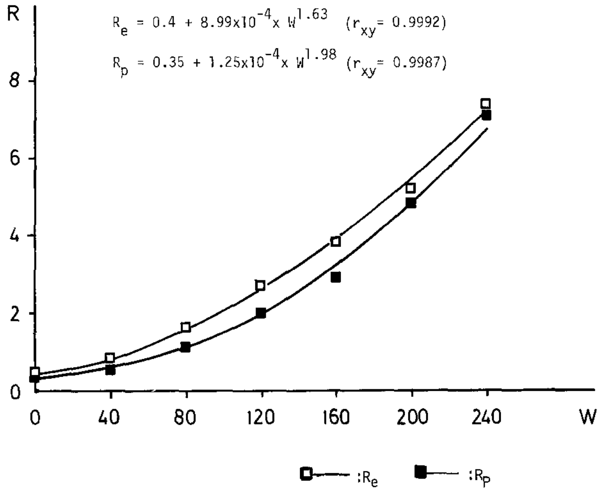

Fig. 2. The relationship between ratings of PE (R_e), of aches and pain in the legs (R_p) and power (W). $N=28$

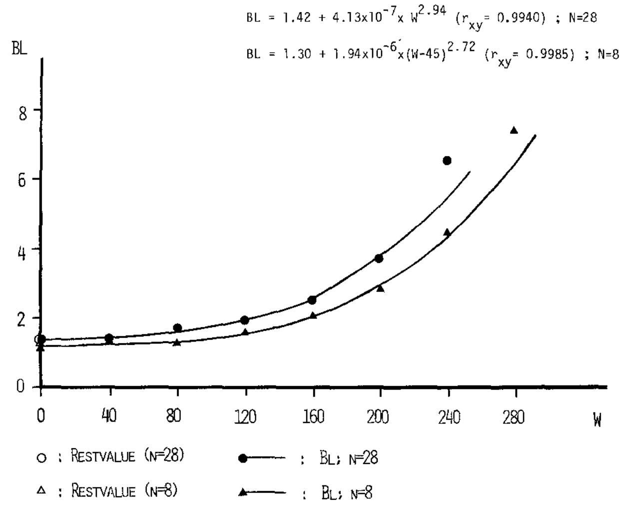

Fig. 3. The relationship between BL (mmol $\times$ l^{-1}) and power (W), ($\bigcirc, \Delta$ = pretest values), for the whole group of 28 subjects and the sub-group of 8 subjects with high physical working capacity

relation to W, correspond closely to each other. However, the curve for R_p is somewhat lower but it has a faster acceleration rate than that of R_e. This is in accordance with what can be expected, with lower power levels being less related to the perception of pain and more to exertion. At higher power levels where there is a great accumulation of BL, the subjects begin to perceive aches and pain in an accelerating manner.

The increase in HR (bpm) with rising power (W), fits well to a straight line. Using the basic HR obtained at rest, linear regression gives the following equation: $HR=60.3+0.439$ W ($r_{xy}=0.9983$). The increase can also be described by a power function of the following formula: $HR=71.3+0.073+W^{1.31}$ ($r_{xy}=0.9998$). The fairly high exponent reflects the high initial values that are interpreted as depending on initial test anxiety.

The relation between BL and power (W) for both the total group of 28 subjects and for a smaller sub-group of 8 subjects (who managed to pedal the full 5 minutes on 280 W) is shown in Fig. 3. As the data fit well to a monotonously increasing power function (from zero watt), it is not necessary for the group of 28 subjects to include a b-value in the descriptive function: $BL=1.42+4.13\times10^{-7}\times W^{2.94}$ ($r_{xy}=0.9940$), which is roughly, $BL=1.4+3.639\times10^{-7}\times W^3$.

The sub-group of 8 subjects, who worked the full five minutes at 280 W, all showed very good physical working capacity. The means (M) and standard deviations (SD) for this group can be found in Table 1. In further analysis it was necessary to include a b-value in the BL-function for these highly fit subjects. It appears as if the starting point of the function may depend partly upon the work capacity of the individual. The function, illustrated in Figure 3, for the sub-group of 8 subjects was: $BL=1.3+1.94\times10^{-6}\times(W-45)^{2.72}$ ($r_{xy}=0.9986$).

In order to provide a general description of the BL-increase, there seems to be a need to include a b-value, i.e. $BL=a+c(W-b)^n$, according to Borg (1962).

For the sub-group, as for the whole group of 28 subjects, all variables follow positively accelerating functions, starting from zero W, with the exception of the increase in BL levels. Also in the sub-group the two functions for R_e and R_p correspond quite closely but have different acceleration rates. In this group the increase in HR with rising power is well fitted to a straight line, $HR=61.06+0.383\times W$ ($r_{xy}=0.9990$).

Individual functions

Because of statistical effects, functions for the groups of subjects may obscure the true growth functions. Therefore, individual data have also been used to study the variation of BL with power. In Fig. 4, individual functions are displayed for 6 subjects chosen to be representative of the total group and displaying the differences in curve forms.

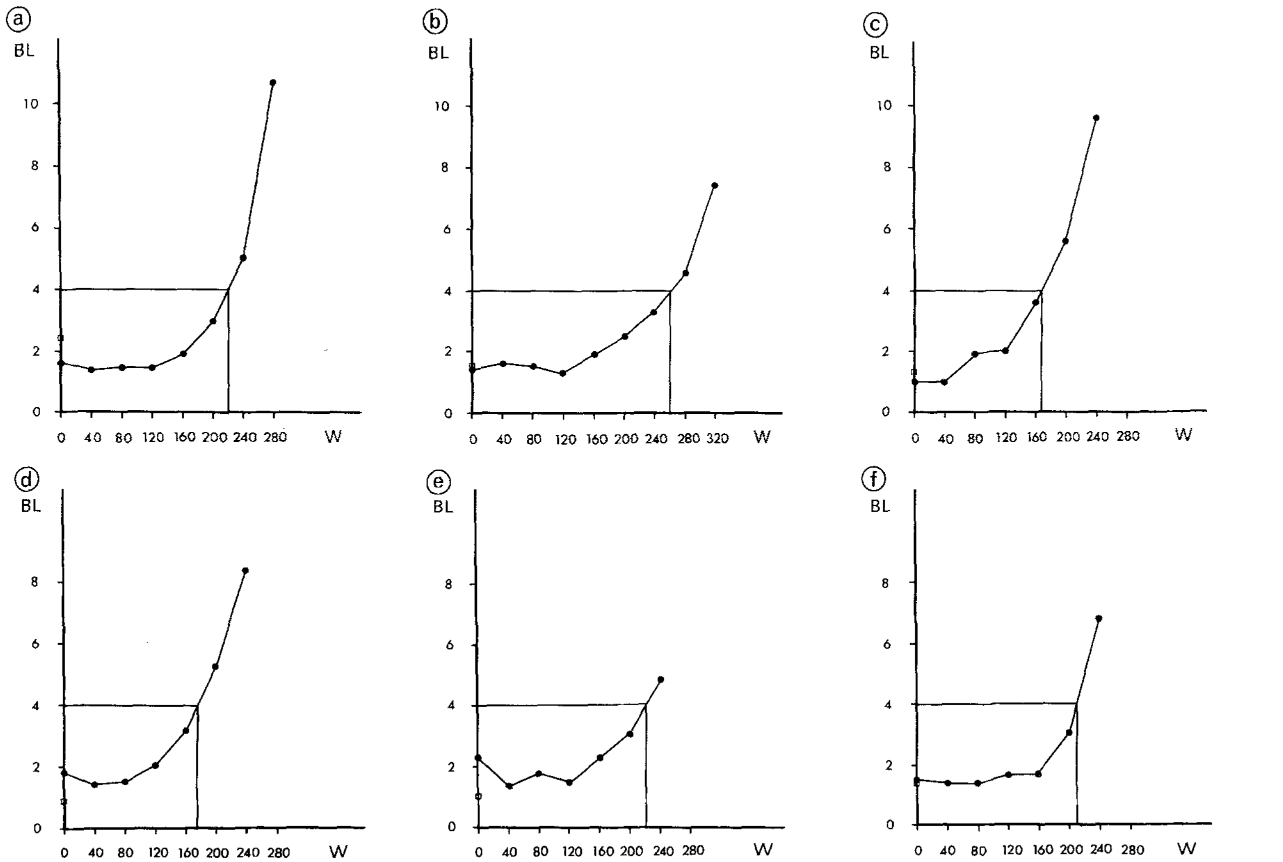

Fig. 4a–f. Individual blood-lactate (BL) functions for 6 subjects chosen to be representative for the total group (□ = pretest values). The functions were as follows: **a** $BL = 1.39 + 2.94 + 10^{-8} \times W^{3.37}$ ($r_{xy} = 0.9730$); **b** $BL = 1.76 + 3.86 \times 10^{-5} \times (W - 120)^{2.23}$ ($r_{xy} = 0.9979$); **c** $BL = 0.86 + 5.34 \times 10^{-5} \times W^{2.16}$ ($r_{xy} = 0.9827$); **d** $BL = 1.39 + 1.06 \times 10^{-8} + W^{3.72}$ ($r_{xy} = 0.9994$); **e** $BL = 1.40 + 4.50 \times 10^{-3} \times (W - 110)^{1.35}$ ($r_{xy} = 0.9984$); **f** $BL = 1.39 + 2.25 \times 10^{-7} \times (W - 50)^{3.18}$ ($r_{xy} = 0.9739$)

As can be seen the individual functions mostly correspond well with the general power function, i.e. continuously increasing in most cases. For some of the subjects it was necessary to include a *b*-value. In a few cases (see Fig. 4f), the function might better be described with a breaking point separating different functions, this being in accordance with current physiological discussions (see, e.g., Skinner 1981). For the subject displayed in figure 4f this would result in the two linear (albeit badly fitting) functions: $BL = 1.25 + 0.003 \times X$ ($r_{xy} = 0.8944$) for the power levels 40–160 W and $BL = -8.8 + 0.064 \times X$ ($r_{xy} = 0.9677$) for 160–240 W.

In Fig. 5 the relative responses for R_e (RR_e), R_p(RR_p), HR (RHR) and BL (RBL) for the entire group of 28 subjects are plotted against W. The relative values are obtained by expressing the empirical values as percentages of the individual ranges for each variable, respectively. The curves

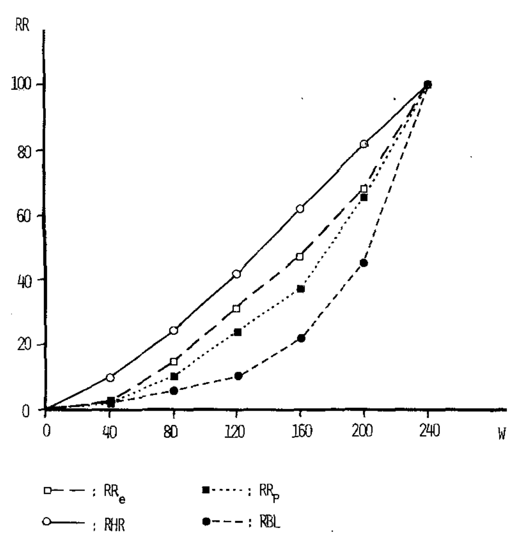

Fig. 5. Relative R_e (RR_e), relative R_p (RR_p), relative HR (RHR in bpm) and relative BL (RBL in $mmol \times l^{-1}$) plotted against power (W). $N = 28$

Table 3. Correlation coefficients between R_e, R_p, HR and BL at all power levels. $N=28$

Variables/ power levels	Pre-test	0 W	40 W	80 W	120 W	160 W	200 W	240 W	All loads
R_e/P_p	0.15	0.19	0.59***	0.58***	0.70***	0.79***	0.75***	0.75***	0.91***
R_e/HR	0.19	0.28	0.18	0.11	0.41*	0.61***	0.58***	0.56**	0.91***
R_e/BL	0.55**	0.45*	0.08	0.18	0.34	0.31	0.53**	0.40*	0.81***
R_p/HR	0.00	0.12	0.14	0.05	0.33	0.44*	0.45*	0.35	0.82***
R_p/BL	0.07	−0.15	0.04	0.18	0.15	0.21	0.45*	0.39*	0.76***
HR/BL	−0.13	0.18	0.15	0.21	0.19	0.29	0.64***	0.45*	0.78***

* $p<0.05$
** $p<0.01$
*** $p<0.001$

for RR_e and RR_p fall between the curves for the two physiological variables and thus seem to be related to both. If RR_e and RR_p, respectively, are plotted against the mean combination of RHR and RBL, the linear functions are: $RR_e = 3.37 + 1.003 \times \%(\text{HR}+\text{BL})/2$ ($r_{xy}=0.9954$) and $RR_p = 1.01 + 1.024 \times \%(\text{HR}+\text{BL})/2$ ($r_{xy}=0.9961$).

In Table 3, correlation coefficients between R_e, R_p, HR and BL at all power levels are shown. As can been seen, they are very high when the responses from all loads are taken together. High correlations are also obtained from the higher power levels, while they are fairly low at lower levels. An exception is the correlation between R_e and BL which is fairly high at rest and zero W ($r_{xy}=0.55$ resp. 0.45). The level of this correlation is interesting and supports the popular idea that BL is a general indicator of fatigue and exertion.

The results make it evident that R_e correlates better with both HR and BL than does R_p at all power levels. Part of the explanation for this situation might be the larger standard deviations for pain. This may be the expression of a greater uncertainty among subjects in ratings of pain than in ratings of PE. The smaller differences at high power levels could indicate that there is less uncertainty and more agreement at these higher levels as to what constitutes aches and pain. Consequently, true relationships might be better reflected at these levels.

The multiple correlation coefficients (R) (according to Ferguson, 1966) between R_e (dependent variable) and HR/BL are at 160 W, 200 W and 240 W: $R_{160\,\text{W}}=0.62$, $R_{200\,\text{W}}=0.62$ and $R_{240\,\text{W}}=0.58$. The corresponding multiple correlations for R_p (dependent variable) and HR/BL are 0.44, 0.50 and 0.44, respectively. At all power levels the multiple correlations between R_e and HR/BL, and between R_p and HR/BL, are higher than the simple correlations in Table 3. This gives further support to the idea that a combination of HR and BL is a better predictor of R_e and R_p, respectively, than is each of the single physiological variables taken alone.

Concluding remarks

The results show that all variables can well be described by power functions. From a physiological point of view it is interesting to note that the general increase in blood lactate may be described in terms of a monotonously increasing power function. The exponent seems to lie somewhere between two and four, which is thus in good agreement with exponents obtained previously (Borg 1962; Hermansen 1971; Hermansen and Stensvold 1972; Noble et al. 1983). The size of the exponent is fairly sensitive to the magnitude of the a-value in the equation, i. e., the basic lactate level prior to the test.

High correlations were obtained between R_e, R_p, HR and BL at high power levels. This should not be interpreted as showing a causal relationship. Heart rate and blood lactate may be looked upon as statistical correlates and not simple causes. There are many contributing physiological factors behind these correlations which should be taken into account. It is probable that one class of causal factors is associated with peripheral stimulation in the working muscles and joints, as indicated by the blood lactate which in turn is indicative of the muscle lactate. Another class of factors is probably related to central cardiovascular and respiratory factors, as indicated by the heart rate response (Borg 1962; Ekblom and Goldbarg 1971; Cafarelli 1977; Pandolf 1978; Noble et al. 1973; Mihevic 1981; and others). To these two classes of factors should be added variables related to the central nervous system, as discussed by Kinsman et al. (1973), Pandolf (1975, 1983), etc.

As previously proposed by Borg (1962), there seems to be a very powerful prediction value of perceived exertion available from a function of increased heart rate and blood lactate.

References

Åstrand I (1960) Aerobic work capacity in men and women with special reference to age. Acta Physiol Scand 49 [suppl 169]

Borg GAV (1962) Physical performance and perceived exertion. Studia Psychologica et Paedagogica Series altera. Investigationes XI, Lund, Gleerup

Borg GAV (1970) Perceived exertion as an indicator of somatic stress. Scand J Rehab Med 2:92—98

Borg GAV (1972) A ratio scaling method of interindividual comparisons. Reports from the Institute of Applied Psychology, University of Stockholm, No. 27.

Borg GAV (1982) A category scale with ratio properties for intermodal and interindividual comparisons. In H-G Geissler and P Petzold (Eds) Psychophysical Judgement and the Process of Perception. VEB Deutscher Verlag der Wissenschaften, Berlin

Borg G, Dahlström H (1962) A pilot study of perceived exertion and physical working capacity. Acta Societatis Medicorum Upsaliensis Upsala Läkareförenings Förhandlingar, LXVII, No 1—2, pp 21—27

Cafarelli E (1977) Peripheral and central inputs to the effort sense during cycling exercise. Eur J Appl Physiol 37:181—189

Davis JA, Frank M, Whipp B, Wasserman K (1979) Anaerobic threshold alterations caused by endurance training in middle-aged men. J Appl Physiol 46:1039—1046

Ekblom B, Goldbarg AN (1971) The influence of training and other factors on the subjective rating of perceived exertion. Acta Physiol Scand 33:399—406

Ferguson GA (1966) Statistical analysis in psychology and education. Mc Graw-Hill, London

Hermansen L (1971) Lactate production during exercise. In: Muscle metabolism during exercise (Eds) B Pernow and B Saltin, New York Plenum Press, pp 401—408

Hermansen L, Stensvold I (1972) Production and removal of lactate during exercise in man. Acta Physiol Scand 86:191—201

Holmgren A, Ström G (1959) Blood lactate concentration in relation to absolute and relative work load in normal men, and in mitral stenosis atrial septal defect and vascoregulatory asthenia. Acta Med Scand 163:185—193

Karlsson J, Jacobs I, Sjödin B, Tesch P, Kaiser P, Sahl O, Karlberg B (1983) Semi-automatic blood lactate assay: experiences from an exercise laboratory. Int J Sports Med 4:52—55

Kinsman RA, Weiser PC, Stamper PA (1973) Multidimensional analysis of subjective symptomatology during prolonged strenuous exercise. Ergonomics 16:211—226

Mihevic PM (1981) Sensory cues for perceived exertion: a review. Med Sci Sports Exercise 13:150—163

Noble BJ, Borg GAV, Jacobs I, Ceci R, Kaiser P (1983) A category-ratio perceived exertion scale: relationship to blood and muscle lactates and heart rate. Med Sci Sports Exercise 15:523—528

Noble BJ, Metz KF, Pandolf KB, Bell CW, Cafarelli E, Sime WE (1973) Perceived exertion during walking and running — II. Med Sci Sports 5:116—120

Pandolf KB (1975) Psychological and physiological factors influencing perceived exertion. Wennergren Center Int Symposium Series 28:371—383

Pandolf KB (1978) Influence of local and central factors in dominating rated perceived exertion during physical work. Percept Mot Skills 46:683—698

Pandolf KB (1983) Advances in the study and application of perceived exertion. Exercise Sport Sci Rev 11:119—157

Rydevik U, Nord L, Ingman F (1982) Automatic lactate determination by flow injection analysis. Int J Sports Med 3:47—49

Skinner JS (1981) Body Energy. Mountain View. Anderson World, Inc., California

Wasserman K, Whipp BJ, Koyal SN, Beaver WL (1973) Anaerobic threshold and respiratory gas exchange during exercise. J Appl Physiol 35:236—243

Accepted March 26, 1985