Perceptual and Motor Skills, 2006, 103, 51-66.

FACTORS ASSOCIATED WITH PERCEIVED EXERTION AND ESTIMATED TIME LIMIT AT LACTATE THRESHOLD[1,2]

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Summary.—The purpose was to identify the most predictive parameters for perceived exertion and estimated time limit responses at the velocity corresponding to the lactate concentration threshold. The former scale concerns the subject's current status (how hard he feels the exercise currently is) whereas the latter scale deals with a subjective prediction of how long the current exercise level can be maintained. Multiple regression equations were developed among physiological, psychological, nutritional, and individual parameters (subjects' characteristics and performances) as independent variables, and perceived exertion or estimated time limit as dependent variables. Independent variables were collected before or during an incremental running field test. 94 regional to national level athletes (47 endurance-trained runners, 11 sprinters, and 36 handball players) participated. Multiple stepwise regression showed that Rating of Perceived Exertion and Estimated Time Limit at the lactate threshold were mainly mediated by factors relative to the performance expressed in percentage of the maximal aerobic velocity. Secondary factors which contribute significantly as perceptual predictors were related to various classes of factors except for psychological factors.

A comprehensive theory of perceived exertion does not exist yet (Mihevic, 1981; Pandolf, 1983; Watt & Grove, 1993). Numerous studies have been done to identify the different physiological components involved in physical exertion and to find out how they vary in relation to perceived exertion (Borg & Ottoson, 1986; Borg, 1998). According to Morgan (1973), and to Noble, Metz, Pandolf, and Cafarelli (1973), the various physiological re-

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[1]This study was supported by grants from a Projet Hospitalier de Recherche Clinique (No. 98/1959).

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DOI 10.2466/PMS.103.1.51-66

sponses account for approximately two-thirds of the variance in Rating of Perceived Exertion during cycling exercise. Morgan (1973) suggested that some of the remaining unexplained variance (≈33%) may be related to factors of a psychosociological nature. Subsequently, numerous studies have shown that in field situations, a variety of social and psychological forces may significantly (independently or in association) influence individual perceptions (Rejeski & Ribisl, 1980; Morgan, 1985, 1994) and therefore may reduce the effect of physiological signals on perceived exertion (Rejeski, 1981; Pandolf, 1983). Consequently, perceived exertion is a multidimensional construct based on an integration of many sensory inputs in concert with numerous physiological, psychological, and experiential factors (Mihevic, 1981; Morgan, 1994; Hassmen, 1995; Borg, 1998). Explanatory models grouping together factors which may mediate perceived exertion have been suggested (Hassmen, 1995; Noble & Robertson, 1996).

Many kinds of scales have been used to estimate perceived exertion. The rating scale of perceived exertion (RPE from 6–20), which was reported by Borg (1970), is the most commonly used one for clinical, ergonomic, pedagogical, and sporting applications (Robertson & Noble, 1997; Borg, 1998). Recently, Garcin, Vandewalle, and Monod (1999) proposed another perceived exertion scale based on subjective estimation of exhaustion time, the rating scale of Estimated Time Limit which may be used in addition to the Rating of Perceived Exertion during exercise to understand further how the subject is feeling (Garcin, *et al.*, 1999; Garcin & Billat, 2001). The Rating of Perceived Exertion scale measures the current status of the subject, i.e., how hard he feels the exercise currently is, whereas the Estimated Time Limit scale requires a subjective prediction of how long the current exercise level can be maintained. These two scales may be used as complementary tools for exercise-intensity prescription purposes, e.g., a combination of the two criteria could increase the specificity of the ventilatory threshold detection (Garcin, *et al.*, 1999).

Previous investigators have only dealt with the physiological responses which may account for the Rating of Perceived Exertion during cycling exercise (Noble, Metz, Pandolf, & Cafarelli, 1973; Pandolf, Billing, Drolet, Pimenthal, & Sawka, 1984) or the contribution of differentiated ratings of perceived exertion to overall exertion while swimming (Ueda, Kurokawa, Kikkawa, & Choi, 1993). Only Garcin (1997) studied both physiological and performance variables for Rating of Perceived Exertion and Estimated Time Limit especially at the intensity corresponding to the ventilatory threshold. All these authors used a forward selection multiple regression analysis for 8, 12, 5, and 10 independent physiological variables, respectively. Pandolf, *et al.* (1984) only considered the final Rating of Perceived Exertion value (at 60 min.) at one exercise intensity (60% VO_2 peak), whereas Garcin (1997) recorded values at the ventilatory threshold during a cycling graded exercise. Ueda, *et al.* (1993) collected values at the end of exercise (within 1 or 2 min. after finishing the 5-min. test) and calculated the differentiated Rating of Perceived Exertion at 20, 30, 40, 50, 60, 70, 80, 90, and 100% VO_2 max. Only Noble, Metz, Pandolf, and Cafarelli (1973) used Rating of Perceived Exertion values taking into account exercise intensity and duration (at 5, 15, and 30 min. at 48, 60, and 68% VO_2 max).

That numerous factors such as environment (social context, intensity, duration, frequency, and mode of exercise, nutrition, and drugs), psychological factors (personality, motivation, attention, emotions), and interindividual differences (depending on age, sex, or fitness) may affect somatic responses has been reported (Borg, 1998). As more is known scientifically about some physiological and performance variables than about others (Borg, 1998), chosen here concurrently were physiological, psychological, nutritional, and individual parameters which may play a role in the determination of the overall perceived exertion. Since Morgan (1973), no studies have used a global personality model to evaluate how psychological factors influence perceived exertion. Morgan used a three-factor model of personality (Neuroticism, Extraversion-Introversion, and Psychoticism), but recent research has shown a better global model with the Five-Factor Model of personality (McCrae & Costa, 1996). According to Pennebaker (2000), negative affectivity, both state and trait, are linked to somatic perception and could influence perceived exertion. Moreover, it has been shown that coping was a psychological factor moderating the link between negative affectivity and perceived exertion (Tenenbaum, 2001). Consequently, in this study the influence of psychological dispositional variables (personality, emotional state, coping) were examined on perceived exertion rating. Finally, such investigation has not yet been realized on the Estimated Time Limit scale. Therefore, the purpose of this study was to identify, through the use of multiple regression analyses, some of those parameters accounting for the greatest variability in Rating of Perceived Exertion and Estimated Time Limit responses, especially at the velocity corresponding to the lactate concentration threshold currently prescribed during programs for training or rehabilitation (Boutcher, Seip, Hetzler, Pierce, Snead, & Weltman, 1989; Okura & Tanaka, 2001; Garcin, Mille-Hamard, & Billat, 2004). Taking into account previous research (Garcin & Billat, 2001; Garcin, Mille-Hamard, Devillers, Dufour, Delattre, & Billat, 2003; Garcin, *et al.*, 2004), one may suppose that, like Rating of Perceived Exertion, Estimated Time Limit is probably a multidimensional construct based on an integration of many sensory inputs in conjunction with numerous physiological, psychological, and experiential factors.

Method

Participants

Ninety-four regional to national level athletes (M_{age} = 19.5 yr., SD = 2.6; M_{mass} = 63.2 kg, SD = 9.9; M_{height} = 173.7 cm, SD = 8.8) participated. This sample was made up of 58 men and 36 women. They were 47 endurance-trained runners, 11 sprinters, and 36 handball players. All athletes trained between three and five times per week and had practised their respective activities for at least 8 years. These athletes were chosen to represent endurance activity (runners), speed (sprinters), and a combination of both (handball players). The subjects were medically examined before they signed an informed consent form about the purpose and procedures of the experiment. Approval was obtained for the experimentations from the Comité Consultatif de Protection des Personnes pour la Recherche Biomédicale de Lille (CP 00/10).

Procedure

The subjects performed a graded exercise up to exhaustion on an outdoor running track (400 m) to assess their maximal aerobic velocity (Mav) and the velocity associated with their lactate concentration threshold (vLT). According to the performances of these athletes, the initial speed was set at 8 km.hr.$^{-1}$ for the women and 10 km.hr.$^{-1}$ for the men and increased by 1 km.hr.$^{-1}$ every 3 min. until voluntary exhaustion. Each stage was separated by a 30-sec. rest period to allow blood sampling. Each subject was verbally encouraged to give maximum effort. Two days later, the subjects performed a constant run exercise up to exhaustion at vΔ50 to assess time to exhaustion at this velocity (tlimvΔ50). Velocity delta 50 (vΔ50), which is the speed halfway between Mav and vLT, was calculated as follows: vΔ50 = vLT + [(Mav − vLT)/2]. This speed is known to be sustainable for about 10 min. and allows subjects to elicit maximal oxygen uptake at the end of a run (Billat, Slawinski, Bocquet, Demarle, Laffite, Chassaing, & Koralsztein, 2000). Each subject was verbally encouraged to continue for as long as possible. These two exercises were performed on the same running track and at the same time of day.

Psychological questionnaires were individually recorded only once just before the graded exhausting exercise. The time required to complete the questionnaires was about 2 hours. Although the subjects had been familiarized with both scales during previous training sessions, the scales were explained before each exercise as recommended by Noble, Metz, Pandolf, Bell, Cafarelli, and Sime (1973). Perceived exertion scales were explained before each exercise. These scales were written on a board fixed on the back of the pacer riding in front of the subject. The subjects were asked "How hard do you feel this exercise is?" and "How long would you be able to perform an exercise at this intensity to exhaustion?" Up to exhaustion for the graded exercise, the subjects had to point to a value on the perceived exertion scales at the end of each step and the ratings were collected during the 30-sec. rest. The order of Rating of Perceived Exertion and Estimated Time Limit was the same during the graded and the constant exercises for each subject but was randomised among the subjects of each group. Instructions for the scales were given directly after each other before each test. Rating of Perceived Exertion and Estimated Time Limit at the velocity corresponding to the lactate concentration threshold (RPEvLT and ETLvLT, respectively) were defined as the perceived exertion value collected during the last 30 sec. of the vLT stage.

Measures

Graded test.—The speed during the last fully completed stage corresponded to the maximal aerobic velocity (Mav) of these subjects. The velocity associated with the lactate concentration threshold (vLT) was determined from the relationship between blood lactate concentrations and velocity. It was defined as the velocity corresponding to the starting point of an accelerated accumulation of lactate in the blood. The velocity at the lactate concentration threshold was identified as the speed at which an increase in lactate concentration corresponding to at least 1 $mmol.l^{-1}$ occurred between 3 and 5 $mmol.l^{-1}$ (Aunola & Rusko, 1992).

Speed.—Velocity was checked during the graded and the constant exercises by the experimenters. On the running track, the runners followed a pacing cyclist travelling at the required velocity. The cyclist received audio cues via a Walkman (Sony©), the cue rhythm determining the speed necessary to cover 25 m. Visual marks were set at 25-m intervals along the running track inside the first lane (Billat, *et al.*, 2000). The experimenters independently measured the time required to complete 25 m to check the pacer's and runners' speed. For the graded and the constant run exercises, exhaustion was defined when the subject was unable to sustain the velocity, i.e., when the runner was more than 5 m behind the cyclist for at least 100 m.

Lactate concentration.—Fingertip capillary blood samples were collected in a capillary tube at the end of every stage (during each 30-sec. rest) for the graded exercise and were analysed for lactate concentration using a spectrophotometric method (Dr Lange®, LP20, Germany). Blood lactate concentration was determined by enzymatic oxidation analysis which had previously been validated (Kamber, 1992). The calibration was checked before each test using standard solutions in lactate concentration.

Heart rate.—During all the tests, heart rate was measured using a cardiofrequency meter Accurex+ (Polar® Kempele, Finland). Heart-rate data were recorded every 5 sec. The three highest consecutive values during the incremental test defined the maximal heart rate (HR max), whereas heart rate at the velocity corresponding to the lactate concentration threshold (HRvLT) was defined as the average value from the three highest consecutive values during the last 30 sec. of the vLT stage.

Rating of Perceived Exertion (Shephard, Vandewalle, Gil, Bouhlel, & Monod, 1992).—The perception of exertion was expressed according to a French translation of the Rating of Perceived Exertion scale (RPE) which is most commonly used for perceived exertion (Borg, 1970). The scale, which is a psychophysical equidistant interval scale (Borg, 1998), consisted of 15 assessments between 6 = very very light to 20 = very very hard. Explanation was given to the subjects that number 6 corresponded to rest, i.e., no exertion at all, and that number 20 corresponded to maximal exertion, i.e., an absolute maximum that most subjects will never previously have experienced in their lives (Borg, 1998). This scale was validated for different modes of exercise including cycling, walking, running, and swimming (Skinner, Hustler, Bereg-steinova, & Buskirk, 1973a; Robertson, 1982; Ueda & Kurokawa, 1995). Moreover, some studies have established the reliability of the scale under repeated testing conditions using different kinds of procedures (Skinner, *et al.*, 1973a; Stamford, 1976; Wenos, Wallace, Surburg, & Morris, 1996).

Estimated Time Limit (Garcin, *et al.*, 1999).—A second scale based on subjective Estimated Time Limit was used. It consisted of 20 assessments between 1 = "more than 16 hours" and 20 = "less than 2 minutes." This scale was designed as a function of the logarithm of the estimated exhaustion time (tlim) [ETL = 21 minus 2 n, with $n = \log_2$ (tlim) where tlim was expressed in minutes]. A base 2 logarithm was chosen to have enough assessments for exhaustion times ranging from less than 2 min. (anaerobic exercise) to many hours. For example, ETL was 19 for tlim equal to 2 min. and 15 for tlim equal to 8 min. To facilitate the use of this scale, ETL equal to 13 and 11 corresponded to 15 and 30 min. instead of 16 and 32 min., respectively. The values of ETL equal to or lower than 9 were expressed in multiples of 1-hr. The validity and the reliability of the scale have previously been attested (Garcin, *et al.*, 1999; Garcin, Mille-Hamard, Devillers, Dufour, Delattre, & Billat, 2003; Garcin, Wolff, & Bejma, 2003; Garcin, *et al.*, 2004).

NEO Personality Inventory–R (Costa & McCrae, 1992; Rolland, 1998). —This self-administered questionnaire has 240 statements plus a validity question. The main five dimensions measured by the inventory are most frequently labelled Neuroticism (N), Extraversion (E), Openness to Experience (O), Agreeableness (A), and Conscientiousness (C).

State-Trait Anxiety Inventory-Y (Spielberger, 1983; Bruchon-Schweitzer & Paulhan, 1993).—This inventory was used to assess both trait and state anxiety using 20 items to evaluate how the respondents feel at the present time (State Anxiety) and 20 to assess how they generally feel (Trait Anxiety). Although there is a high correlation between scores on State and Trait Anxiety, the two concepts are different. People who are high in Trait Anxiety may have high State Anxiety scores and thus a high correlation between Trait and State Anxiety. However, individuals with low scores on Trait Anxiety may occasionally experience high State Anxiety in an encounter perceived as dangerous or stressful.

The Ways of Coping Checklist (Folkman & Lazarus, 1988).—This measure is a well-known means of measuring coping responses derived from Lazarus's transactional model of stress. This short French version (Cousson, Bruchon-Schweitzer, Quintard, Nuissier, & Rascle, 1996) has 27 items, assessed on a 4-point scale (anchors 1: no, 2: rather no, 3: rather yes, 4: yes), which describe three types of coping: Problem Focused (10 items), Emotion Focused (9 items), and Social Support Seeking (8 items). Validation of the French version yielded Cronbach alpha of .79 for Problem-focused, .72 for Emotion-focused, and .73 for Social Support Seeking.

The Perceived Stress Scale (Cohen, Kamarck, & Mermelstein, 1983; Quintard, 1994).—This scale measures how much situations in one's life are appraised as stressful. Each of the 14 items (e.g., "In the last month, how often have you been upset because of something that happened unexpectedly?") was assessed on a 5-point scale (anchors of 0: never and 4: very often), with higher scores indicating greater stress. This scale has been used extensively in studies of stress and illness.

World Health Organization Quality of Life (WHOQOL-26).—This scale is a short version of the WHOQOL-100 (The WHOQOL Group, 1998), which is an assessment of Quality of Life used by the World Health Organization, applying 26 items representing 4 dimensions (psychological, physical, social, and environmental) and 2 general items (Leplège, Réveillère, Ecosse, Caria, & Rivière, 2000).

The Eating Disorder Inventory (Garner, Olmstead, & Polivy, 1983).—The scale is a 64-item multiscale designed to measure psychological and behavioral variables commonly found in those with anorexia nervosa or bulimia nervosa. The scale has been shown to be reliable and valid in the French population (Criquillion-Doublet, Divac, Dardennes, & Guelfi, 1995). Eight subscales include Drive for Slimness, Bulimia, Body Dissatisfaction, Ineffectiveness, Perfectionism, Interpersonal Distrust, Interoceptive Awareness, and Maturity Fears. High scores indicate greater Desire for Slimness, more bulimic-like symptoms, etc. High scores on the Interoceptive Awareness subscale indicate less awareness of internal feelings and emotions.

Dietary records.—Values for nutrient intakes were obtained from a 4-day food record kept during a training period for the athletes. As usual nutrient intakes may be specific during the week-end due to competitions, thus food record was made from Monday to Thursday. Competitions are avoided because they are not always weekly and are not always performed in the same conditions (variations according to the time of day, temperature, running at home and away events . . .). All participants received a detailed verbal explanation and written instructions about the food record. Subjects were asked to eat normally and to remain as close as possible to their usual dietary habits, and to be as accurate as possible in recording the amount and the type of food and fluid consumed, as well as the method of preparation. A list of common household measurements, such as cups, and tablespoons, and specific information about the quantity of each (grams, etc.) were given to each participant. Any questions, ambiguities, or omissions regarding the type and amount of food and beverages were resolved with individual athletes or controls via direct interviews. Moreover, subjects had to note every physical activity during this period on the 4-day food record. These records were processed with the computer programme Prodiet® (Proform, France) to obtain the average intake of nutrients and energy output. The recommended dietary allowances (RDAs) for the French population were used (Dupin, Abraham, & Giachetti, 1992; Martin, 2003). These RDAs were established according to age and sex. Energy Balance was calculated as the difference between average intake of nutrients and the average energy output.

Analyses

Statistical significance for Rating of Perceived Exertion and Estimated Time Limit at the lactate threshold was tested with a two-way analysis of variance (sex × sport). The alpha level of .05 was considered statistically significant. For statistical analyses, HRvLT, vLT, vΔ50 were also expressed as percentage of the Mav, i.e., as HRvLT%, vLT%, vΔ50%, respectively.

The 28 independent variables used in these analyses were of physiological, psychological, nutritional, and individual nature, i.e., relative to the characteristics and performances of the subjects. By no means is it thought this selection of independent variables is exhaustive. The individual predictive value of each parameter (independent variable) for Rating of Perceived Exertion and Estimated Time Limit (dependent variables) was investigated using bivariate analysis (Pearson correlation coefficient for numerical variables and student t test or analysis of variance for binary variables). The parameters significant at the .15 level were selected for further multivariate analysis. Among those, predictive parameters for Rating of Perceived Exertion and Estimated Time Limit at the lactate threshold were identified by means of linear multiple regression with stepwise selection at the .15 level. Linear regression with stepwise selection is an iterative procedure to build the "best" subset of predictive variables. The independent variable showing the largest correlation with the dependent variable is entered first in the model. Then, at each step, the procedure adds the independent variable which maximises the multiple squared correlation coefficient (R^2) between the dependent variable and the independent variables previously entered in the model. R^2 is the portion of the total variance of the dependent variable that is attributed to the model.

Statistics in this paper were performed by means of SAS® software (SAS Institute, 2006).

Results

Means and *SD*s for continuous measures are presented in Table 1. The results of the two-way analysis of variance showed no main effect on Rating of Perceived Exertion and Estimated Time Limit for sex ($F_{1,93} = 2.47$; $F_{1,93} = 0.25$, $p > .05$, respectively) or sport ($F_{2,93} = 0.10$; $F_{2,93} = 3.07$, $p > .05$, respectively) at the velocity corresponding to the lactate concentration threshold; there were no significant interactions ($F_{2,93} = 1.66$; $F_{2,93} = 0.01$, $p > .05$, respectively). The parameters significant at the .15 level which were selected for further

TABLE 1
MEANS AND STANDARD DEVIATIONS FOR CONTINUOUS MEASURES OF PERCEPTIVE, PHYSIOLOGICAL, PSYCHOLOGICAL, NUTRITIONAL, AND PERFORMANCE PARAMETERS FOR ATHLETES ($N = 94$)

Parameter	*M*	*SD*
RPEvLT	13.4	2.1
ETLvLT	12.0	2.6
HRmax, bpm	196	8
HRvLT, bpm	185	10
HRvLT%	94.7	2.8
Neuroticism	94.5	20.8
Extraversion	118.8	17.4
Openness to Experience	108.0	16.6
Agreeableness	118.7	16.8
Conscientiousness	113.7	21.4
State of Anxiety	32.7	10.5
Trait of Anxiety	39.4	8.7
Problem-focused	27.5	5.4
Emotion-focused	22.6	5.1
Social Support-seeking	20.3	4.4
Perceived Stress Scale	34.7	8.2
Quality of Life	103.3	9.3
Eating Disorder Inventory	26.3	16.2
Energetic Balance, kcal	–366	585
Mav, km · $hr.^{-1}$	15.9	2.4
vLT, km · $hr.^{-1}$	13.9	2.4
vLT%	87.2	4.6
vΔ50, km · $hr.^{-1}$	14.9	2.3
vΔ50%	93.6	2.4
tlimvΔ50	10 min., 20 sec.	4 min., 10 sec.

Note.—RPEvLT: perceived exertion at the velocity corresponding to the lactate concentration threshold; ETLvLT: estimated time limit at the velocity corresponding to the lactate concentration threshold; HRmax: maximal heart rate; HRvLT heart rate at the velocity corresponding to the lactate concentration threshold; HRvLT%: HRvLT expressed in percentage of HRmax; Mav: maximal aerobic velocity; vLT: velocity at the lactate concentration threshold; vLT%: vLT expressed in percentage of Mav; vΔ50: velocity delta 50 which corresponds to the speed halfway between Mav and vLT; vΔ50%: vΔ50 expressed in percentage of Mav; tlimvΔ50: estimated time to exhaustion at vΔ50.

TABLE 2
SUMMARY OF PARAMETERS STATISTICALLY SIGNIFICANT ($p = .15$) DURING BIVARIATE ANALYSIS FOR RATING OF PERCEIVED EXERTION AND ESTIMATED TIME LIMIT AT VELOCITY CORRESPONDING TO LACTATE CONCENTRATION THRESHOLD ($N = 94$)

Parameter	RPEvLT	ETLvLT
Sex	.04*	>.05
Sport	>.05	.05†
Age	>.05	.12
Mass	.009	.02
Height	.003	.08
HRvLT	.02	.07
HRvLT%	.004	.04
Neuroticism	>.05	.01
Agreeableness	>.05	.004
Quality of Life	>.05	.05
Eating Disorder Inventory	>.05	.09
Energetic Balance	>.05	.08
Mav	.05	>.05
vLT	.002	>.05
vLT%	<.0001	.02
vΔ50	.001	>.05
vΔ50%	<.0001	.01
tlimvΔ50	<.0001	.01

Note.—RPE: perceived exertion; ETL: estimated time limit; HRvLT heart rate at the velocity corresponding to the lactate concentration threshold; HRvLT%: HRvLT expressed in percentage of maximal heart rate; Mav: maximal aerobic velocity; vLT: velocity at the lactate concentration threshold; vLT%: vLT expressed in percentage of Mav; vΔ50: velocity delta 50 which corresponds to the speed halfway between Mav and vLT; vΔ50%: vΔ50 expressed in percentage of Mav; tlimvΔ50: estimated time to exhaustion at vΔ50. Predictive values for each parameter were investigated with Pearson correlations for numerical variables and Student *t* test or analysis of variables for binary variables.

multivariate analysis are presented in Table 2. In Tables 3 and 4 are displayed results of the linear multiple regression with stepwise selection analyses, using Rating of Perceived Exertion or Estimated Time Limit as the dependent variable, respectively. Parameters relative to the performance (per-

TABLE 3
SUMMARY OF STEPWISE SELECTION FOR RATINGS OF PERCEIVED EXERTION AT VELOCITY CORRESPONDING TO LACTATE CONCENTRATION THRESHOLD ($N = 94$)

Variable (Order of Selection)	Partial R^2	p
vLT%	.24	<.0001
Mass	.07	.005
HRvLT	.04	.04
tlimvΔ50	.05	.01

Note.—vLT%: velocity at the lactate concentration threshold expressed in percentage of maximal aerobic velocity; HRvLT: heart rate at the velocity corresponding to the lactate concentration threshold; tlimvΔ50: time to exhaustion at velocity delta 50 which corresponds to the speed halfway between maximal aerobic velocity and the velocity at the lactate concentration threshold.

centage of the velocity at the lactate concentration threshold, time to exhaustion at a velocity corresponding to the speed halfway between maximal aerobic velocity, and velocity at the lactate concentration threshold) and to the characteristics of the subject (mass), and physiological variable (heart rate at the velocity corresponding to the lactate concentration threshold) were identified for Rating of Perceived Exertion, whereas Estimated Time Limit was linked to parameters relative to performance (percentage of the velocity corresponding to the speed halfway between maximal aerobic velocity and velocity at the lactate concentration threshold), to the characteristics of the subject (handball, sprinting), and of a nutritional nature (eating disorder and energy balance).

TABLE 4
SUMMARY OF STEPWISE SELECTION FOR ESTIMATED TIME LIMIT AT VELOCITY CORRESPONDING TO LACTATE CONCENTRATION THRESHOLD ($N=94$)

Variable (Order of Selection)	Partial R^2	p
vΔ50%	0.17	.001
Handball	0.06	.04
Sprint	0.06	.04
Energetic Balance	0.04	.07
Eating Disorder Inventory	0.04	.06
Overall R^2	.37	

Note.—vΔ50%: velocity delta 50 which corresponds to the speed halfway between the maximal aerobic velocity and the velocity at the lactate concentration threshold expressed in percent of maximal aerobic velocity.

DISCUSSION

Our aim was to identify, among all the predictive variables, i.e., of a physiological, psychological, nutritional nature, or relative to the characteristics and performance of these subjects, a subset of independent variables that best explain the differences in the determination of Rating of Perceived Exertion and Estimated Time Limit values at the velocity corresponding to the lactate concentration threshold. The main results were that Rating of Perceived Exertion or Estimated Time Limit at the velocity corresponding to the lactate concentration threshold were mainly influenced by factors relative to performance. Moreover, as hypothesized for Rating of Perceived Exertion, the Estimated Time Limit values resulted from an integration of numerous secondary factors, which differed according to the scales.

Performance expressed in percentage of Mav seem to play a substantial role in the perception of effort at the velocity corresponding to the lactate threshold (for RPEvLT, vLT% made the greatest contribution to the total accountable variance whereas for ETLvLT, vΔ50% made the greatest contribution to R^2) (Tables 3 and 4). Previous investigators have suggested the importance of the percentage of exercise intensity as a major cue in the perception of effort during exercise (Sargeant & Davies, 1973; Skinner, Hustler, Beregsteinova, & Buskirk, 1973b; Mihevic, 1981) or particularly at the intensity corresponding to the ventilatory threshold (Garcin, 1997). According to the latter, the percentage of exercise intensity at the ventilatory threshold accounted for 30.3% of the variance which is slightly higher than in this study (24%, Table 3). It would mean that the percentage of exercise intensity at the ventilatory or lactate threshold would determine the Rating of Perceived Exertion value at this intensity. This result was unexpected according to studies which have especially considered Rating of Perceived Exertion at the intensity corresponding to the lactate concentration threshold (Demello, Cureton, Boineau, & Singh, 1987; Boutcher, *et al.*, 1989; Haskvitz, Seip, Weltman, Rogol, & Weltman, 1992). These studies showed that the Rating of Perceived Exertion at the lactate threshold was quite constant and was not affected by training or fitness, even if after training the lactate threshold occurs at higher absolute or relative metabolic demands. It would mean that simply the fact of being at the lactate threshold rather than the percentage of exercise intensity at the lactate threshold would determine the Rating of Perceived Exertion value. The low partial R^2 of the percentage of exercise intensity in the stepwise selection for Rating of Perceived Exertion and Estimated Time Limit at the velocity corresponding to the lactate concentration threshold would correspond to this fact.

Secondary factors contributing significantly as perceptual predictors were related to various classes of factors (physiology, nutrition, and parameters relative to the characteristics of the subjects or performance) except for psychological factors. The physiological parameter, which was the highest contributor to Rating of Perceived Exertion variance, corresponded to between 31.2 to 55.5% for Noble, Metz, Pandolf, and Cafarelli (1973), and 38.1 to 40.4% for Pandolf, *et al.* (1984). Similarly to the present result (Table 3), heart rate appeared between the 3rd and 5th positions for a partial R^2 of 3.4 at 5.7% for Noble, Metz, Pandolf, and Cafarelli (1973) and 5.2% for Garcin (1997), whereas it was higher for Pandolf, *et al.* (1984) with a partial R^2 of 18.2% in 3rd place. The absence of psychological factors in the prediction of perception values is unexpected as Pandolf (1983) and Morgan (1985, 1994) had shown that psychological factors may mediate individual perceptions. As suggested by Watt and Grove (1993), the influence of psychological factors would still be limited at moderate intensity and to untrained subjects only. Identified perceptual significant predictors were not the same for these two scales, except the relative exercise intensity. Type of sport (sprinting and handball) contributes significantly to Estimated Time Limit response at the velocity corresponding to the lactate concentration threshold (partial R^2 equal to 6%). Garcin, Mille-Hamard, Devillers, Dufour, Delattre, and Billat (2003) have already shown that Rating of Perceived Exertion and Estimated Time Limit were influenced by the type of training sport practised. As suggested by these authors, it seems these results are due to the sport-specificity of the exercise modes used for testing, i.e., this test remains specific for running. Consequently, type of sport parameter appears to be the reflection of past running experience (Rejeski, 1981). Moreover, both energy balance and eating disorder appear to be nutritional factors which contribute significantly to the prediction of Estimated Time Limit at the intensity corresponding to the lactate threshold (partial R^2 equal to 4%). This result may be due to the importance of nutritional status in activities of long duration and high intensity and would influence the estimation of time to exhaustion at this intensity. Taking into account the diversity of the identified significant predictors for the Rating of Perceived Exertion and Estimated Time Limit scales, it seems necessary to approach perception during exercise using both scales.

The overall R^2s which were obtained at the end of the stepwise selection for Rating of Perceived Exertion and Estimated Time Limit accounted for 40 and 37% of the prediction, respectively. Such a result is commonly described in studies with a large number of participants (overall R^2 between 9.7% and 50.5% for Kerner and Kurrant, 2003, and 43% for Annesi, 2004). Variables not selected and measured in this study may have significant affect on the accountable variance in Rating of Perceived Exertion or Estimated Time Limit (Noble, Metz, Pandolf, & Cafarelli, 1973). Since a variety of physiological factors are intimately linked with the metabolic demand, it is possible that the effect of relative maximal aerobic velocity as a perceptual cue is mediated by other, more readily monitored responses (Mihevic, 1981). Consequently, as each prediction would be, of course, dependent on the factors selected in the model, it would preferably be more pertinent to limit the study to factors which may complete models such as those suggested by Hassmen (1995) and Nobel and Robertson (1996). The intent of the explanatory models proposed by these authors was to show the relation between physical work, physiological responses, and psychological modifiers that have a combined effect on the overall rating of perceived exertion. In these models, all the inputs were combined, expressing exertional perceptions as a gestalt of the individual's internal and external environments.

One limitation of this study concerns the power of regression analysis. Examining the literature, there is no consensus on the sample size to ensure a stable solution. The answers range from 5 to 50 cases per predictor. Nevertheless, our aim was not to build a predictive model for the dependent variables but to identify a subset of variables strongly correlated to Rating of Perceived Exertion and Estimated Time Limit. In this context, Hsieh, Bloch, and Larsen (1998) proposed a formula to specify the required sample size to detect a significance effect of a specific covariate in the presence of other covariates. Using this formula, we computed the power *a posteriori*. In Table 4, the test of vΔ50% ($R^2 = .17$) had an estimated power of 95%, and in Table 3 for vLT% ($R^2 = .24$) the estimated power was greater than 99%. Moreover, whatever the power of study, the p values indicated in the different tables are adjusted for the sample size.

In conclusion, the results of the present study demonstrated that Rating of Perceived Exertion and Estimated Time Limit at the velocity corresponding to the lactate threshold did not result from externalized physiological processes which can be directly perceived (Mihevic, 1981) or from psychological factors but were mainly dependent on the performance expressed as a percentage of the maximal aerobic velocity.

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Accepted June 12, 2006.

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1. J.B.J. Coquart, J.-M. Grosbois, M. Nycz, Y. Dufour, F. Bart, M. Garcin. 2012. Relation entre la perception de l'effort au seuil d'oxydation maximale des lipides (LIPOXmax), les réponses physiologiques et le profil psychologique de cyclistes compétiteurs. *Science & Sports* **27**, 208-214. [CrossRef]