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ORIGINAL ARTICLE

Self-regulation of exercise intensity by estimated time limit scale

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Abstract The purpose of this study was to evaluate the validity of the estimated time limit scale (ETL), which deals with a subjective prediction of how long the current exercise intensity can be maintained, for regulating exercise intensity using typical estimation–production procedure. Thirty-six male athletes performed a continuous incremental test and two discontinuous tests with randomized workloads (estimation tests at 65, 75, 85 and 95% of the maximal power output, and production tests: subjects have to use the ETL values which were collected for each power during the estimation test in order to manually product the corresponding workload). The intraclass correlation coefficient for the power output between estimation and production tests is good for exercises at 75, 85 and 95% MAP (0.81, 0.85 and 0.96, respectively). Moreover, mean differences both for power output and cardiorespiratory data were not significantly different between estimation and production tests for exercises at 85 and 95% MAP. Consequently, the validity to prescribe an exercise intensity from the ETL scale is attested in these athletes particularly for high exercise intensities on cycloergometer.

Keywords Perceived exertion · Prescription · Validity · Cycloergometer

Introduction

The first scale for measuring perceived exertion is developed in the early 1960s by the psychologist Gunnar Borg at the University of Stockholm. This psychophysiological measure is defined as the intensity of subjective effort, strain, discomfort, and fatigue that one feels during exercise (Robertson 2004). The perceived exertion is used for clinical, ergonomic, pedagogical and sporting applications (Robertson and Noble 1997). During these last 50 years, numerous scales have been developed to evaluate the perceived exertion (Watt and Grove 1993) but the rating of perceived exertion scale of Borg (RPE, 6–20, Borg 1970) remains the most frequently used one.

The heart rate (HR) is often used to prescribe exercise intensity. As there is a strong linear relationship between HR, oxygen uptake (VO_2) and the perceived exertion measured by RPE scale (Borg 1973; Robertson 1982; Ueda and Kurokawa 1995; Chen et al. 2002), this scale can be used independently or in conjunction with the physiological variables to regulate exercise intensities in various populations with different modes and intensities of exercise

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(Smutok et al. 1980; Eston et al. 1987; Dunbar et al. 1992, 1994; Marriott and Lamb 1996), and consequently to prescribe exercise intensity (Robertson and Noble 1997). This prescription requires the utilization of a target RPE estimated during an incremental test in order to produce corresponding target exercise intensity during training or rehabilitation programs by adjusting the exercise intensity (Robertson 2004). In this typical estimation–production procedure, Robertson et al. (2002) proposed two components of intensity self-regulation model: the prescription congruence comparing power output and cardiorespiratory data recorded during the estimation and production tests, and the intensity discrimination comparing cardiorespiratory data recorded during the production trials. Moreover, some authors noticed that subjects may use two production strategies (Weiser et al. 2007). They may overshoot the target power output at the beginning of exercise and decrease intensity to achieve the prescribed power output as exercise continues (Weiser et al. 2007). Conversely, they may undershoot the target power output at the beginning of exercise (Weiser et al. 2007).

Garcin et al. (1998) had noted a large variability in the RPE values at the same percentage of voluntary exhaustion time (Tlim) among subjects performing the same relative constant workload. Consequently, Garcin et al. (1999) proposed associating the RPE scale with a second scale based on subjective estimation of Tlim (estimated time limit scale, ETL) to understand further how the subject is feeling. The ETL scale allows a subjective estimation of Tlim that can be maintained at an intensity and at a given instant. These scales are complementary tools because the RPE scale is concerned with the current status of the subject (how hard he/she feels the exercise currently is) whereas the ETL scale deals with a subjective prediction of how long the current exercise intensity can be maintained. The concurrent validity of the ETL scale has been studied through the HR (Garcin et al. 1999) and exercise relative intensity in various populations (Garcin et al. 1999, 2003, 2004; Garcin and Billat 2001). Moreover, the reliability of the ETL scale has been established during incremental and constant velocity runs in physical education students (Garcin et al. 2003) and during field tests in trained male runners (Coquart and Garcin 2007). However, to our knowledge, no study has yet dealt with the subjective regulation of exercise intensity by the ETL scale.

The main purpose of the current investigation was to evaluate the validity of the ETL scale for regulating exercise intensity using typical estimation–production procedure. For this, we examined (1) the prescription congruence, (2) the intensity discrimination and (3) the production strategy supporting the undershoot or overshoot of target power output and cardiorespiratory data at the beginning of each production trial (Weiser et al. 2007). We hypothesized that as for RPE, participants can regulate their target exercise intensity using the ETL scale.

Methods

Subjects

To perform this study, we researched athletes who practiced endurance sports and who were so supposed well to use the ETL scale. Consequently, we contacted the local Physical Education University and numerous local clubs specialized in endurance sports. Only the physical education students and the clubs of triathlon answered the call and thus thirty-six endurance-trained male athletes volunteered to take part in this study. Taking account the characteristics of these two populations (physical education students who practised various activity sports among which endurance sports vs. athletes who practiced only swimming, cycling and running endurance activities), two groups were established: physical education students at the University Lille 2 ($N = 12$) and triathletes ($N = 24$) (Table 1). All subjects signed an informed consent form about the purposes and procedures of investigation prior the first test. This study was approved by the consultative committee for participant's protection in clinical research of Lille (France) (n° CPP Nord-Ouest IV: 09/49).

Table 1 Anthropometric and performance data at the end of the incremental test (mean ± SD)

Groups	Age (years)	Height (m)	Weight (kg)	VO_{2max} (ml min^{-1} kg^{-1})	HR$_{max}$ (bpm)	Power (W)	Training volume (h week^{-1})
Entire group of athletes ($N = 36$)	25.3 ± 3.3	1.80 ± 0.06	74.5 ± 9.2	51.4 ± 6.0	184 ± 16	321 ± 36	9 ± 5
Triathletes ($N = 24$)	26.2 ± 3.3*	1.79 ± 0.05	71.9 ± 7.3*	52.8 ± 6.2	184 ± 18	325 ± 36	9 ± 4
Physical education students ($N = 12$)	23.6 ± 2.7	1.81 ± 0.06	79.7 ± 10.8	48.7 ± 4.9	185 ± 8	313 ± 37	8 ± 6

VO_{2max} maximal oxygen uptake, HR_{max} maximal heart rate

* Triathletes are significantly different from physical education students $P < 0.05$

Materials

The tests were conducted on the same electromagnetically braked cycloergometer (Ergoselect, Medisoft®, Sorinnes, Belgium), which maintained the set power output by adjusting the resistance with variations in pedal rate.

HR values were continually recorded with a 12-lead electrocardiogram (Medcard, Medisoft®, Sorinnes, Belgium) linked with the respiratory gas analysis system and averaged during the last 30 s of each min.

The respiratory gas analysis was carried out throughout each test via a breath-by-breath system using an open-circuit metabolic card (Ergocard, Medisoft®, Sorinnes, Belgium). The software used was Exp'air (Medisoft®, Sorinnes, Belgium). The system of respiratory gas analysis was calibrated before each test in accordance with manufacturer's guidelines using a 3-1 syringe (Calibration pump, Medisoft®) for volume calibration, and using ambient air and a gas of known oxygen and carbon dioxide concentrations (16 and 4%, respectively) for gas calibration. The subjects breathed through a mouthpiece. During the tests, the respiratory variables were recorded breath by breath and then averaged during the last 30 s of each min.

The perception of exertion was expressed according to a scale based on estimated Tlim (estimated time limit, ETL, Garcin et al. 1999). The ETL scale comprises twenty numerical ratings (between 1 and 20) from 1 (more than 16 h) to 19 (2 min). This scale is designed as a function of the logarithm of the estimated Tlim ($\mathrm{ETL} = 21 - 2n$, with $n = \log 2 \times \mathrm{Tlim}$, where Tlim is expressed in minutes). A base 2 logarithm was chosen in order to have enough assessments for Tlim ranging from less 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. In order 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. Similarly, the values of ETL equal to or lower than 9 are expressed in multiples of 1 h. During all tests, this scale written on a board was presented to the participants (Garcin et al. 1999). The subject was asked, "How long would you be able to perform an exercise at this intensity to exhaustion?". ETL values were collected during the last 30 s of each stage or period.

Experimental design

All the tests were preceded by a 3-min rest period (sitting on the cycloergometer) followed by 8-min warm-up period at 90 W, then a 5-min passive recovery period.

Continuous incremental test

In a first session, the participants performed an incremental test on a cycloergometer (Ergoselect, Medisoft®, Sorinnes, Belgium) to measure their maximal aerobic power (MAP). The initial power output was set at 120 W for 3 min then increased by 30 W every 3 min until volitional exhaustion. The participants were instructed to develop the highest possible level of power. As utilized by Faulkner et al. (2007) and as described by Cooke (2001), exhaustion was attested by a plateau phenomenon in VO_2, the attainment of a HR within ±10 bpm of the age-predicted maximum, a respiratory exchange ratio that was equal to or exceeded 1.15, failure to maintain the required pedaling rate, or if the participant reported volitional exhaustion.

Discontinuous tests with randomized workloads

Estimation test

The first test with randomized workloads consisted of alternating 5-min pedaling period with 8-min passive recovery periods. A pedaling duration of 5 min was chosen in order to reach a "steady state" of cardiorespiratory data (HR and VO_2) (Coquart et al. 2009), whereas the passive recovery periods were included to limit the fatigue effect (Coquart et al. 2009). After each recovery period, the workload was progressively increased for 1 min until the desired power output was reached. During the pedaling periods, the workloads were 65, 75, 85 and 95% MAP, in a randomized order. To avoid the possibility of a subject knowing the actual power output, the computer screen was hidden from the subject's view at all times.

Production test

The second test with randomized workloads consisted of 4 alternating 5-min pedaling period with 8-min passive recovery periods. Subjects have to use the ETL values which were collected during the last 30 s of each period during the estimation test in order to manually product the corresponding workload. The controlled workload during the 5 min decomposes in three periods. During the first minute, the subjects had to adjust the power output so that the exercise intensity corresponds to their target ETL. Then, during the next 3 min, they had to refine the regulation of the power output. During the last minute of the period, the athletes were instructed not to regulate power output anymore. Workloads values were collected at the end of each minute. To avoid the possibility of a subject knowing the actual power output, the computer screen was hidden from the subject's view at all times.

Test standardization

Before the incremental test, the seat and the handlebar heights were set by each subject and kept constant for the last two sessions. At the end of the warm-up period, the perceptually based and cardiorespiratory data (ETL, HR, VO_2…) were collected to check that the subjects were in the same conditions before each test. During the three tests, the subjects were asked to select a pedal rate between 60 and 70 rpm. Subjects were only verbally encouraged during the incremental test. Consumption of water was not permitted. The temperature of the air-conditioned room was always maintained between 20 and 24°C. The tests were conducted at the same time of day with a period of 2–7 days between the three tests. Participants were asked to maintain their normal diet during the day preceding the tests and to refrain from alcohol consumption 24 h before each test and caffeine on the test days. Similarly, the participants were asked to avoid strenuous physical activity during the 2 days prior to the tests and not to exercise on the day of a test.

In a preliminary session, the subjects were familiarized with the ETL scale using the exercise anchoring procedure (Robertson 2004) and a copy of the scale was provided for each subject to use during training sessions. Instructions on the scale were read by the subjects and explained before each test as recommended by Noble et al. (1973). Furthermore, at the end of the warm-up period, ETL was measured so that the participants could refer to this and thus avoid a lack of perceptual references during the first workload of the test with randomized workloads, as reported previously by Skinner et al. (1973).

Calculations

Prescription congruence was accepted when the power output and physiological response did not significantly differ between estimation and production tests. Intensity discrimination was accepted when physiological responses between various self-regulated exercise intensities were significantly different between trials producing different target ETLs.

Statistical analysis

Quantitative variables were described by mean and 95% confidence interval. Reproducibility between the estimation and production test was assessed with intraclass correlation coefficient (ICC) for continuous variables. The scale used for interpretation of this concordance was that described by Fleiss (1986). A concordance value of 0.6–0.8 was rated moderate and a value >0.80, good. The reproducibility between the estimation and production test was also investigated by means of the mean percent error (MPE), defined as the ratio of the difference between the estimation and production test to the value of the production test. The effect of the intensity on the physiological responses was investigated with a linear mixed model. This model is an extension of the analysis of variance (ANOVA) which permits to take into account the correlation between the measures of a subject. Intensity was considered as fixed effect and the subject effect was considered as random. Post hoc analyses were done with a Bonferroni correction. For the analysis of the production strategy, the evolution of the differences between the estimation and production test was also studied by a linear mixed model with time as fixed effect. The subject effect was considered to be random and we chose a first-order, autoregressive covariance pattern to take into account the dependency between the repeated measurements. Our choice of this model was based on the likelihood ratio test. Statistical analyses were performed using the SAS System V9.2 (SAS® Institute, Inc., Cary, NC). The level of significance was set to 0.05.

Results

Mean ETL values and 95% confidence interval for mean collected during the estimation test were equal to 9.4 (8.5–10.3), 11.5 (10.6–12.4), 14.2 (13.4–15.0) and 16.2 (15.5–16.9) for 65, 75, 85, and 95% MAP, respectively. The power output and cardiorespiratory data measured for each workload during estimation and production tests are presented in Table 2.

Prescription congruence

The ICC for the power output between estimation and production tests is good for exercises at 75, 85 and 95% MAP (ICC equal to 0.81, 0.85 and 0.96, respectively) and moderate for exercise at 65% MAP (ICC equal to 0.67) (Table 2). The ICC for HR and VO_2 between estimation and production tests is good or moderate for four workloads except for the HR coefficient at 65% MAP (Table 2). Moreover, mean differences both for power output and cardiorespiratory data were not significantly different between estimation and production tests for exercises at 85 and 95% MAP ($P > 0.05$). The difference between power output and cardiorespiratory data measured for each workload during estimation and production tests is smaller for the highest workloads, as attested by the MPE (Table 2).

The ICC for the power output between estimation and production tests is higher for triathletes than for physical education students for four workloads (Table 3). However, mean differences during estimation and production tests both for power output and cardiorespiratory data were not significantly different between triathletes and students for each workload ($P > 0.05$). Nevertheless, for power output

Table 2 Power output and cardiorespiratory data (mean and 95% confidence interval for mean) measured during estimation and production tests, intraclass correlation coefficient (ICC) between estimation and production tests, and mean percent error (MPE) for power output values and cardiorespiratory data measured for each workload ($N = 36$)

Parameters	Estimation test				Production test			ICC	MPE (%)
	Workload (% MAP)	Mean	95% Confidence interval		Mean	95% Confidence interval			
Power (W)	65	209	201	217	197	187	207	0.67*	6.9
	75	241	232	250	233	223	243	0.81**	3.6
	85	273	262	283	268	257	278	0.85**	2.3
	95	305	293	317	303	291	314	0.96**	0.8
Heart rate (bpm)	65	150	147	154	145	140	150	0.48	4.2
	75	158	155	162	155	151	159	0.60*	2.5
	85	167	164	171	165	161	169	0.68*	1.6
	95	175	172	178	173	170	177	0.75*	0.8
Oxygen uptake (ml $\min^{-1}$ kg^{-1})	65	36.6	34.9	38.2	34.9	33.0	36.7	0.71*	5.8
	75	41.9	39.9	43.9	40.4	38.2	42.6	0.80**	4.3
	85	45.9	43.7	48.0	44.8	42.3	47.2	0.81**	3.3
	95	50.7	48.5	53.0	50.3	47.8	52.6	0.79*	1.5

* Coefficient of reproducibility is moderate (between 0.60 and 0.79)

** Coefficient of reproducibility is good (between 0.80 and 1.00)

values, the MPE between estimation and production tests is smaller for triathletes compared to students whereas such trend is not always found for cardiorespiratory data (Table 3).

Intensity discrimination

The results of the one-way repeated factor ANOVA showed that exercise intensity had a significant effect both on HR and VO_2 during production test. The Bonferroni post hoc test showed significant differences between all exercise intensities ($P < 0.0001$) (Table 2).

Production strategy

During the 4-min power output adjustment-regulation period, subjects only undershoot the power output during the first 180 s for the exercise at 75 and 85% MAP, and during the first 120 s for the exercise at 95% MAP (Table 4). Both VO_2 and HR values were not significantly different from the second minute till the end of this regulation period for the exercise at 85 and 95% MAP (Table 4).

For the power output, the triathletes undershoot it only during the first 120 s versus the first 180 s for the physical

Table 3 Intraclass correlation coefficient (ICC) between estimation and production tests for power output values and cardiorespiratory data, and mean percent error (MPE) for each workload in triathletes and students ($N = 36$)

Parameters	Workload (% MAP)	ICC		MPE (%)	
		Triathletes	Students	Triathletes	Students
Power (W)	65	0.71*	0.58	5.62	7.39
	75	0.86**	0.69*	2.24	5.41
	85	0.92**	0.66*	1.64	2.79
	95	0.99**	0.91**	0.26	1.69
Heart rate (bpm)	65	0.49	0.46	4.23	2.88
	75	0.58	0.67*	2.00	2.85
	85	0.69*	0.67*	0.51	3.45
	95	0.75*	0.78*	0.02	2.16
Oxygen uptake (ml kg^{-1} $\min^{-1}$)	65	0.69*	0.71*	6.00	3.09
	75	0.72*	0.90**	4.34	2.77
	85	0.82**	0.78*	1.73	5.02
	95	0.77*	0.79*	1.47	0.36

* Coefficient of reproducibility is moderate (between 0.60 and 0.79)

** Coefficient of reproducibility is good (between 0.80 and 1.00)

Table 4 Power output and cardiorespiratory data (mean and SD) measured each minute during estimation and production tests for each workload ($N = 36$)

Workload (%MAP)	Time (s)	Power (W)		VO_2 (ml min^{-1} kg^{-1})		HR (bpm)	
		Estimation	Production	Estimation	Production	Estimation	Production
65	60	209 ± 24	170 ± 27	22.0 ± 4.41	24.1 ± 6.9	123 ± 10	124 ± 14
	120	209 ± 24	182 ± 34	33.7 ± 5.4	31.3 ± 6.9	141 ± 10	136 ± 17
	180	209 ± 24	190 ± 31	35.8 ± 5.8	32.8 ± 6.6	148 ± 10	140 ± 16
	240	209 ± 24	196 ± 30	36.8 ± 5.5	34.4 ± 7.9	150 ± 10	143 ± 17
	300	209 ± 24	196 ± 30	37.2 ± 4.8	34.3 ± 8.2	151 ± 10	143 ± 18
75	60	241 ± 27	207 ± 59	25.1 ± 5.9	25.8 ± 7.4	127 ± 10	127 ± 20
	120	241 ± 27	217 ± 38	37.6 ± 5.4	35.8 ± 7.9	147 ± 10	143 ± 16
	180	241 ± 27	227 ± 37	40.8 ± 6.5	36.9 ± 7.7	153 ± 10	149 ± 16
	240	241 ± 27	235 ± 34	42.0 ± 6.2	39.9 ± 9.1	157 ± 9	153 ± 16
	300	241 ± 27	235 ± 34	42.7 ± 5.9	40.1 ± 9.0	159 ± 9	155 ± 17
85	60	273 ± 31	233 ± 45	25.9 ± 6.7	28.7 ± 7.3	130 ± 10	135 ± 12
	120	273 ± 31	246 ± 39	40.4 ± 6.3	38.7 ± 6.6	152 ± 11	150 ± 13
	180	273 ± 31	259 ± 34	44.0 ± 6.7	41.9 ± 6.9	159 ± 11	157 ± 11
	240	273 ± 31	267 ± 31	46.0 ± 6.7	43.7 ± 6.8	162 ± 11	161 ± 11
	300	273 ± 31	267 ± 31	46.7 ± 6.2	44.6 ± 7.0	166 ± 10	164 ± 12
95	60	305 ± 35	265 ± 63	29.4 ± 5.8	31.5 ± 7.7	136 ± 9	138 ± 11
	120	305 ± 35	284 ± 42	42.9 ± 6.3	41.9 ± 7.3	158 ± 9	155 ± 11
	180	305 ± 35	298 ± 41	47.2 ± 6.4	46.0 ± 7.1	167 ± 9	163 ± 10
	240	305 ± 35	301 ± 33	49.4 ± 7.2	48.4 ± 6.9	171 ± 9	169 ± 9
	300	305 ± 35	301 ± 33	51.1 ± 6.2	49.6 ± 6.9	173 ± 9	171 ± 11

VO_2 oxygen uptake, *HR* heart rate

education students for the exercise at 85 and 95% MAP. For HR, only triathlete values were not significantly different from the first minute till the end of this adjustment-regulation period for the exercise at 75, 85 and 95% MAP; physical education students' HR values were significantly different from the first minute till the end of exercise at 85% MAP and till the forth min for 95% MAP ($P < 0.05$).

Discussion

Prescription congruence

The rationale underlying the present investigation was to regulate exercise intensity according to target ETL. Our results showed that participants can regulate their target exercise intensity on cycloergometer using a target ETL recorded during the estimation test mainly for high exercise intensities (i.e. 85 and 95% MAP). The present findings with ETL values did not differ with previous studies that found greater perceptual production accuracy with RPE at higher exercise intensities when VO_2 and HR were employed as the criterion variables (Smutok et al. 1980; Eston et al. 1987). Indeed, these authors also concluded that exercise prescription by RPE resulted in safe and reliable HR responses only above 80% maximal HR (RPE 12 and above). Moreover, errors of production during our study for 85 and 95% MAP are lower to the errors of production in previous studies for power output, HR and VO_2 (Glass et al. 1992; Dunbar et al. 1992; Dishman 1994). Indeed, in these studies, errors of production from cycling or treadmill approximate 10–50 W for power output, 10–15% for HR, and are less than 5% for VO_2 whereas ours mean differences approximate only 2–5 W for power output, 1–2% for HR, and are lower or equal to 1% for VO_2 (Table 2).

As for RPE results (Smutok et al. 1980; Eston et al. 1987), we suggested that the use of ETL for the prescription of exercise below 80% MAP would result in less accurate targeted power output and physiological responses than for higher exercise intensities. Some authors hypothesized this could be explained by a lack of information (i.e. absence of perceptual anchoring) during the first workload of the incremental test (Ceci and Hassmen 1991; Dunbar et al. 1992; Glass et al. 1992; Dishman 1994). This is not the case in our study as we had taken the precaution of suppressing the lack of information during the setting up of our experimental protocol by familiarization with the ETL scale during the training sessions, reading the instructions before each test, and perceptual anchoring during the warm-up period as suggested by Robertson (2004). Moreover, there is consensus that central factors including sensations associated with increasing HR and respiratory rate play a significant role as the exercise intensity increases (Cafarelli 1982; Robertson 1982; Pandolf 1983). Consequently, the cardiorespiratory parameters would provide strong sensory cues during effort which enter in the estimation of ETL mainly for higher exercise intensities. Finally, the less accurate regulation of exercise intensity for the lowest intensities could be explained by the fact that the values of the ETL scale increase by an exponential function of the exercise power. Therefore, the lower ETL zone is, the more important corresponding power gap is (e.g. 36 W for an ETL value of 9 ± 1 vs. 20 W for an ETL value of 16 ± 1). This means that for lower exercise intensities, a target ETL 2–3 point zone corresponds to larger power ranges.

For 65 and 75% MAP, there were a small (MPE = 5.8 and 4.3%, respectively) but significant differences for VO_2 values between the estimation and production tests. However, these differences were not of clinical importance since the VO_2 values during the estimation and production tests were very similar (both mean differences at 65 and 75% MAP were lower than ½ MET, i.e. <1.75 ml min^{-1} kg^{-1}). In addition, an exercise prescription for warm-up generally utilizes a range of intensities between 60–70% of maximal VO_2 (Bishop 2003) and the disparity in VO_2 between estimation and production tests at 65 or 75% MAP was less than the usual intensity prescription range. Finally, the 95% confidence interval for mean do not overlap. Consequently, for the lowest exercise intensities (65 and 75% MAP), ETL could be also used by athletes to safety regulate the warm-up exercise intensity. Such a help could be useful for athletes after a stop of the practice (summer, injury), during the resumption of the training or for athletes who discover a new activity as it is often the case for runners, swimmers or cyclists who wish to turn to the triathlon. Such a tool can guide them to regulate the exercise intensity of the specific warm-up in each activity.

Neither the students, nor the triathletes put into words difficulties estimating ETL values during training sessions. Nevertheless, as the MPE between estimation and production tests is smaller for triathletes compared to students, the type of training sport practiced may influence the accuracy to regulate the exercise intensity. Triathletes were probably more accustomed with time to exhaustion particularly during cycling trials. Some studies have already shown that RPE and/or ETL may be related to the type of training sport practiced during exhausting endurance exercise showing that RPE was lower for running than cycling (Thomas et al. 1995) or that RPE and ETL values were lower for runners than handball players and sprinters for a same relative maximal aerobic speed (Garcin et al. 2003). However, this result could be likely in part related to sport-specificity of the cycle exercise used for testing. Students who practiced team sports, tennis, or climbing have been probably more limited in accurately processing sensations of effort and feelings of fatigue during the tests on cycloergometer because past cycling experience was insufficient (Rejeski 1981; Pandolf 1983). Consequently, it will be interesting to attest whether this influence of type of training practiced on ETL responses is also valid on runners and cyclists during production tests on treadmill and cycloergometer.

Intensity discrimination

As expected, physiological responses were significantly different between various self-regulated exercise intensities producing different target ETLs. Such a result has been already found by Ceci and Hassmen (1991) for RPE = 11, 13 and 15, by Eston and Thompson (1997) for RPE = 9, 13, 15, 17 and by Weiser et al. (2007) for RPE = 11 and 13.

Production strategy

The athletes were instructed to adjust (during the first minute), to regulate (during the 2nd to 4th minute) and to maintain (during the 5th minute) a conscious sensation of effort at a fixed, predetermined level based on a given ETL value. The results showed that athletes undershoot the power output only at the beginning of exercise whereas there was no significant difference for cardiorespiratory data during the last 4-min exercises at 85 and 95% MAP (Table 4). As recommended, the athletes succeeded to adjust the power output within the 4 min so that both the exercise intensity and the physiological responses correspond to their target ETL. The precise mechanism by which the exercise intensity regulation is performed by the brain is not yet known. Several authors have hypothesized that a learned subconscious anticipatory/regulation system exists, known as “teleoanticipation” originating from the central nervous system (Ulmer 1996). Thereafter, Noakes et al. (2005) proposed a model of central control of exercise intensity using feed forward control. In response to afferent feedback from multiple central and peripheral sensors, the brain would pace the body during exercise specifically to ensure that the preplanned activity is completed without any loss of cellular homoeostasis. Tucker (2009) completed this central governor model suggesting that conscious perception of effort would use previous experience, anticipation of exercise duration/distance, and physiological feedback to regulate pacing strategy and ensure optimal performance (anticipatory feedback model). Recently, Marcora et al. (2008) proposed a psychobiological model of exercise performance which may provide an alternative to the anticipatory feedback model. The conscious self-regulation of submaximal power output during time trials would be determined primarily by the following cognitive/motivational factors (perception of effort, potential motivation, knowledge of the distance covered/remaining, and previous experience/memory of perceived exertion during exercise of varying intensity and duration) (Marcora 2010a). According to this author, physiological factors would only affect endurance performance indirectly if they have a significant effect on perceived exertion or the other psychological factors on which the psychobiological model is based (Marcora 2010b). Abbiss and Peiffer (2010) suggest to be careful when in the use of the terms perceived effort and perceived exertion. Perceived effort, unlike perceived exertion, may be largely centrally governed, influenced not only by sensations of discomfort but also prior experience and the ability to perform the task (Abbiss and Peiffer 2010). As the ETL scale allows a subjective estimation of Tlim that can be maintained at an intensity and at a given instant, we suggested that the ETL scale could be one of the dimensions of the perceived effort appealing in previous experience/memory of perceived exertion during exercise of varying intensity and duration, potential motivation as proposed by Marcora (2010a) but using also different feedback and feedforward systems as proposed by St Clair Gibson and Noakes (2004). Effectively, the initial exercise intensity chosen at the beginning of exercise would subconsciously calculate on the basis of prior experience. Having this information and using psychophysiological feedback, the athletes would be able to regulate the exercise intensity. We could suggest that, as for RPE, the regulation of exercise intensity may utilize the ETL value as an important mediator of production strategy (Tucker 2009). Moreover, it would seem that it was easier for the athletes to quickly and exactly regulate the power output at very high exercise intensity. These athletes were probably more familiar to these high-level exercise intensities which are now commonly used during interval-training sessions (Billat 2001).

Similarly, Dunbar et al. (1994) and Glass et al. (1992) have related an undershoot strategy, showing that exercise intensity on cycloergometer was lower than target power output at lower exercise intensities (60% of maximal VO_2 and 75% reserve HR, respectively). At the opposite of Weiser et al. (2007) and Robertson et al. (2009), we do not find an early phase overshoot perceptual strategy production. This may be due essentially to the fact that these studies were conducted on adult patients participating in a cardiac rehabilitation program or 10- to 12-year-old girls, respectively. They consequently may lack in knowledge about their physical capacities, thus producing difficulties in accurately producing the exercise intensity from the first trial. Our athletes may be more consciously attuned to their bodies and their own effort sense as a result of greater exercise experience. They are more familiar with the signals of exertion emanating from acute cardiorespiratory, thermal and metabolic changes associated with an increase in exercise intensity than non-athletes (Garcin et al. 2011). Moreover, contrary to Weiser et al. and Robertson et al. subjects', our trained athletes have previously experienced numerous exercise intensities and duration during both trained and competition situations, and have memorized numerous subsequent information during these various situations (Marcora 2010a). Consequently, the task of interpreting these information and using them to self-regulate their exercise intensity may be less prone to error (Garcin et al. 2011).

The results showed that both triathletes and physical education students succeeded to adjust the power output in the 4-min power output adjustment-regulation period, however, the triathletes undershoot less for a long time the power than the physical education students, i.e. that the triathletes succeed in regulating exactly the power of the exercise more quickly than the students. Moreover, only the triathletes succeeded to adjust the power output from the beginning of the 4-min adjustment-regulation period so that both the exercise intensity and the cardiac responses correspond to their target ETL. As discussed in a precedent part, this could be due to the past cycling experience in the triathletes.

Practical applications

The ability of cyclists and coaches to estimate performance may be important during competitions such as time trials. The prediction of exhaustion time may allow the determination of the optimal strategy during the time trials. For example, at regular intervals during the race, the cyclist has rated an ETL value which gives at the coach a prediction of the exhaustion time at this moment and this distance of the race. Therefore, the coach may determine the mean velocity that his cyclist must maintain to perform the best performance, and he can advise his cyclist to regulate his speed until the end of the race.

After familiarization with the ETL scale, athletes may use this scale during their training sessions. This scale can be used during non-exhausting constant exercises performed in routine at the beginning and at the end of the training period in order to evaluate the improvements which have been accomplished during the training program. For example, ETL value can be decreased after training: this result means that for a given absolute power output, they felt that they could endure more after training compared to before.

Moreover, ETL values recorded during this test may also allow trainers to classify their athletes from their aerobic endurance level (which can be determined from ETL). For example, in high-level athletes with similar work capacity, trainers can rate different Tlim at a same relative power output and constitute a first group of subjects who rate ETL = 11 and a second group who rate ETL = 9 (i.e. a longer time endurance). Consequently, the ETL scale enables physical trainers to personalize the exercise intensity and duration during training programs for each athlete or for athletes' groups of different endurance capacity.

Garcin et al. (2005) suggested that RPE and ETL values enable physical trainers to personalize the exercise intensity and duration during training programs of athletes' groups of both sexes allowing individualization regarding the fitness level of the athletes. These authors proposed a summary statement about the relationships between ETL or RPE values and %v $V\text{O}_{2\text{max}}$ for the prescription of exercise intensity in athletes.

Conclusion

As for RPE, this study shows that athletes can regulate their exercise intensity on cycloergometer using a target ETL. No special training in the use of ETL appears to be necessary. The ICC and MPE demonstrate a strong trend toward greater reliability as the work becomes more intense. Consequently, the ETL scale is a valid effective technique for prescribing and monitoring exercise intensity on cycloergometer in athletes, particularly for high exercise intensities (i.e. 85 and 95% MAP). More complementary studies must be carried out using the ETL scale in conjunction with target HR or RPE to improve the accuracy of the exercise intensity prescription. It could be also interesting to compare the accuracy for regulating power output according to the employed perceptually based scale (i.e. RPE or ETL) and, testing triathletes, to evaluate the ETL validity on all 3 disciplines (i.e. cycling, running and swimming) rather than on the bike alone.

Conflict of interest The authors declare that they have no conflict of interest.

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