Original Article

Relationship between subjectively perceived exertion and objective loading in trained athletes and non-athletes

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Abstract:

The aim of this study was to compare the relationship between the subjective perception of exercise intensity and the physiological response by elite endurance athletes and the non-athlete population.

The research sample consisted of elite-level short triathlon athletes from the Czech Republic (n = 23; 14 men and 9 women) and non-athletes who were students (n = 15; 9 men and 6 women). The data were collected according to a graded exercise test using a bicycle ergometer. At the end of each section, a blood sample was collected from the fingertip of an upper extremity for blood lactate level analysis, and the current HR was measured. To assess the subjective perception of objective exercise intensity, the participants were asked to evaluate the exercise intensity at the end of each section using the Borg RPE scale (rated from 6 to 20).

The curve estimation method was used to evaluate the relationship between subjective and objective fatigue in both groups. The model of the subjective perception of fatigue does not lend itself to objectivisation. Using a cubic model, we detected a significant association between heart rate and the Borg Scale of Fatigue score in the non-athlete group (69%) but not in the athlete group (40%). Therefore, for non-athletes, the Borg Scale may be used as a tool for the objectivisation of physical loading as evaluated by heart rate; however, this method does not apply to elite endurance athletes. For elite endurance athletes, the most predictive parameter is the blood lactate level. Here, the cubic model also accounted for the highest percentage of the variance (65%). For the non-athlete population, the cubic model (75%) and the exponential model (78%) accounted for higher percentages of the total variance.

Key words: Borg rating of perceived exertion scale, curve estimation, heart rate, blood lactate, triathlon.

Introduction

Objective information about the psychological and physiological processes occurring during physical activity is essential for modulating the intensity and volume of loading and for determining limits under extreme load. Because the importance of controlled physical activity to the general population has increased with the progress of so-called civilisation diseases, it appears to be essential to evaluate the relationship between subjectively perceived exertion and objective loading.

The amount of loading during physical exercise can be evaluated using both biomedical and pedagogical-psychological methods. To control physical activity in field settings, both the intensity of loading and the length of rest during repeated loading must be affected, based on objectivised data obtained as the body responds to physical exertion.

The following three fundamental methods are recommended by the Centers for Disease Control and Prevention (CDC) to control the intensity of loading: target heart rate (HR), the talk test and perceived exertion, which is determined using the Borg rating of perceived exertion (RPE) scale (Centers for Disease Control and Prevention, 2011).

Biomedical methods, such as HR and blood lactate (LA) monitoring, have been used successfully during the training process of athletes for many years. These methods provide information about the metabolic processes involved during loading, thus facilitating the objectivisation of athletic training control. However, the studies are characterised by a singular focus on the achieved performance with respect to objective biomedical data; the feelings of the person involved (i.e., the psychological response to locomotor loading) were not addressed. These studies lack information about the subjective perception of loading (i.e., the effort exerted to achieve the respective level of performance). In 1962, Borg began studying the differences between subjectively perceived effort during exercise and subjectively perceived exhaustion (Tanenbaum Eklund, & Kamata, 2012). One difficulty appeared to be the objectivisation of the subjective perception of physical exertion, as this is complex information that incorporates signals from the peripheral muscles and joints, as well as the cardiovascular, respiratory and central nervous systems (Borg, 1982).

The advantage of evaluating subjective feelings during the controlled training process is the additional information provided that is related to the perception of bodily processes by the athletes themselves. Functional

diagnostics measured in the laboratory neglect psychological variables that also affect physical activity. The subjective perception of HR, as well as changes in the acid-base balance and blood pressure, during sport performance provides important information to both athletes and coaches (Čechovská & Dobrý, 2008).

Based on the objectivisation of the perception of loading, the RPE scale was developed and subjected to various modifications. Although other types of scales appeared subsequently (e.g., CR10 and CR100), the results of many studies (Borg, 1982, 1998) indicate that the RPE scale remains the most suitable scale. The RPE scale ranges from 6 to 20, in which 6 indicates "no exertion at all" and 20 indicates "maximal exertion." For example, if an individual's RPE scale score is 12, then the HR should be approximately $12 \times 10 = 120$ beats per minute.

The majority of studies assume a primarily linear relationship between the subjective perception of exertion and the objective level of loading (Borg, 1998; Chen, Fan, & Moe, 2002; Lamb, Eston, & Corns, 1999; Marcora & Staiano, 2010). However, the relationship between HR or the lactate level and stepwise loading is linear only in energy zones up to the level of the anaerobic threshold. Once this dynamic equilibrium is broken, an uncompensated rise in the blood lactate concentration occurs; the site at which this linearity is violated is identified in relation to both HR and the blood lactate level. The HR kinetics during stepwise loading are most frequently described using an exponential function, whereas the blood lactate kinetics are described using an exponential or cubic function (Åstrand, Rodahl, Dahl, & Strøme, 2003).

In addition, none of the aforementioned studies has investigated any potential differences in the subjective perception of exertion between athletes and non-athletes. In terms of performance, significant differences have been found between athletes and non-athletes in the parameters of maximum relative performance ($P \leq 0.01$) and maximum relative oxygen consumption ($P \leq 0.01$) (Kovářová & Pánek, 2013). Conversely, athletes and non-athletes do not differ statistically in parameters associated with the final acid-base balance (Hb, pCO₂, pH, H⁺, BE, and BB), in the final blood lactate level, or in the subjective scoring of complete exhaustion using the RPE scale. Based on these findings, it may be concluded that a universal model can be used to evaluate fatigue onset and that the rate of acid-base balance breakdown depends neither on the fitness or performance level of the respective individual nor on his or her predisposition regarding endurance.

Another issue is the potential difference in the perception of subjective feelings measured not upon conclusion of the test, but rather during the test; there may also be differences in the domain of submaximal intensities between the athlete and non-athlete populations. Endurance athletes exhibit several psychological differences from the general population, which help athletes cope with the demanding exertion required during training and competition.

Psychologists have been involved in the analysis of psychological predispositions regarding long-term loading for several decades. One of the pioneers in the field of psychological predispositions regarding endurance performance was Rudik (1961), who considered internal morale and willpower to be fundamental predispositions. Rudik also assessed the attentional processes of athletes at different levels and identified essential relationships between athletic performance and attention. Numerous studies followed (Chantal, Guay, Dobrevá-Martinová, & Vallerand, 1996; Morgan & Pollock, 1977; Nideffer, Bond, Cei, & Manili, 2000; Thirer et al., 1978; Zemanová & Kovář, 2009).

The analysis of psychological predispositions regarding performance in endurance sports was specifically examined using several surveys dating back to the 1980s (Bell & Howe, 1988; Clingman & Hillard, 1987, 1988) and continuing into later years (e.g., Ziemainz, 2003). Extensive research focusing on the personality structure of elite triathletes in the Czech Republic in the 1990s was performed by Hátlová (2000). The results of this study indicated that the men and women selected for national representation teams tend to be introverted, exhibit higher levels of nervous stability and are predisposed to lower levels of anxious behaviour.

The personality structure of triathletes and gender differences, as measured by SPARO, were described in a study by Kovářová, Nováková, Kovář, & Pánek, (2013). Triathletes exhibited characteristics of variant B, corresponding to an excitable or spontaneous personality that represents internal psychic excitation (PE +). There is an inclination towards dynamic interactions between intense psychic excitation and high situational arousal (Mikšík, 2001).

The factor model of motivational structure also differs between athletes and the general population (Kovářová, Kovář, Harbichová, Pánek, & Bunc, 2014). The profile of the motivational structure of an elite endurance athlete consists of four latent factors. Three of these factors correspond to the performance structure model for the non-athlete population (ambition, independence, and motivation related to tasks), whereas the fourth factor (self-assertion) is specific to elite athletes, as it involves the dimensions of competitiveness, goal setting, dominance, confidence in success, status orientation and eagerness to learn.

In the current study, we compared the relationship between the subjective perception of exercise intensity and the physiological response to exercise in elite endurance athletes and the non-athlete population using a stepwise loading test. We examined whether athletes undergoing regular intensive physical exercise would be "adapted" to the perception of unpleasant states associated with exertion and would, thus, subjectively "underestimate" fatigue. In non-athletes, we expected that the stress caused by unusually intensive loading would lead to a subjective "overestimation" of exertion compared to the objective loading. The subjectively perceived exertion during physical activity of high to very high intensity appears to be a significant barrier to the continuation of the activity or to the maintenance of the locomotor intensity, particularly among non-athletes. In

the trained athlete population, higher levels of adaptation to these states (resistance) or a greater motivation to persist in the activity was expected. Therefore, it is unclear whether the model of the subjective perception of fatigue differs or remains consistent for the entire population.

Method

Participants

The research sample consisted of the following two groups of participants:

1. Short triathlon athletes who represent the Czech Republic ($n = 23$; 14 men and 9 women) in the youth, junior and K23 categories, with a mean age of 18.7 ± 1.78 years; and
2. Non-athletes who were students of the Faculty of Humanities at Charles University, CU ($n = 15$; 9 men and 6 women), with a mean age of 19.5 ± 1.84 years.

Thus, the first group consisted of participants exhibiting a high level of endurance adaptation to a limited type of loading, whereas the second group was composed of non-athletes without any experience in any elite or high performance sport; this condition was a requirement for inclusion in the latter group, along with the absence of any type of endurance sport in their previous experience. The survey was approved by the Ethics Committee FFUS CU.

Test protocol

The data were collected according to a graded exercise test using a bicycle ergometer. The test was performed under standard conditions on a Cyclus 2 laboratory device, which enables the use of an actual bike frame. The exercise intensity in the first section of the test was determined according to the following calculation:

$$\text{Athlete group (men): Power (W) = participant's weight (kg) * 2.5} \quad [1]$$

$$\text{Athlete group (women): Power (W) = participant's weight (kg) * 2.0} \quad [2]$$

$$\text{Non-athlete group (men): Power (W) = participant's weight (kg) * 1.5} \quad [3]$$

$$\text{Non-athlete group (women): Power (W) = participant's weight (kg) * 1.0} \quad [4]$$

Procedures

The length of each test section was 3 minutes, and the intensity of loading increased by 25 W at the beginning of each subsequent section. At the end of each section, a blood sample was collected from the fingertip of an upper extremity for blood lactate level analysis, and the current HR was measured. To assess the subjective perception of objective exercise intensity, the participants were asked to evaluate the exercise intensity at the end of each section using the Borg RPE scale (rated from 6 to 20).

Statistical analysis

The data were first analysed using fundamental exploratory data analysis. The curve estimation method was used to evaluate the relationship between subjective and objective fatigue in both groups. Based on a literature search of available sources, the following three fundamental models were selected for our analysis:

$$\text{Linear: } y = b_0 + b_1x + \varepsilon \quad [5];$$

$$\text{Exponential: } y = b_0 \exp(b_1x) + \varepsilon \quad [6];$$

$$\text{Cubic: } y = b_0 + b_1x + b_2x^2 + b_3x^3 + \varepsilon \quad [7].$$

The data were processed using the SPSS PASW Statistics 22 programme.

Results

Table 1 presents the basic statistics of the objective fatigue perception parameters (HR, LA) for both analysed groups (athletes and non-athletes), which are listed according to each rating on the Borg RPE scale (rated from 6 to 20).

Table 1. Basic characteristics of the HR and LA values compared to the RPE values for athletes and non-athletes

Borg RPE scale	HR athletes mean (beat·min ⁻¹)	HR athletes SD (beat·min ⁻¹)	HR non-athletes mean (beat·min ⁻¹)	HR non-athletes SD (beat·min ⁻¹)	LA athletes mean (mmol.l ⁻¹)	LA athletes SD (mmol.l ⁻¹)	LA non-athletes mean (mmol.l ⁻¹)	LA non-athletes SD (mmol.l ⁻¹)
6	NM	NM	133	19	NM	NM	1.60	0.36
7	NM	NM	125	20	NM	NM	2.14	0.36
8	139	24	148	16	2.06	0.30	2.58	0.34
9	NM	NM	132	23	NM	NM	2.31	0.54
10	158	17	156	12	2.12	0.91	3.40	0.68

11	152	16	139	21	1.66	0.44	3.06	0.76
12	150	18	139	14	1.79	0.99	3.24	0.99
13	152	20	159	14	1.79	0.87	3.43	0.63
14	156	14	166	20	1.94	1.24	4.92	1.29
15	165	17	172	15	2.68	1.05	4.95	1.50
16	164	14	181	16	2.71	1.25	6.22	1.79
17	169	13	176	12	3.73	1.62	5.67	2.17
18	180	13	176	12	5.00	2.12	5.40	1.21
19	181	11	189	10	6.69	1.81	8.18	1.10
20	187	11	189	5	7.70	1.70	8.71	2.04

One interesting finding was the lack of reporting of the lowest values on the Borg RPE scale (6, 7, and 9) in the athlete group. Additionally, the HR and LA values corresponding to the rating of 8 on the Borg RPE scale were lower for the athlete group than for the non-athlete group. Therefore, it would be logical for the athletes to report the lowest values (6 and 7) on the first loading test sections. The final HR (Borg RPE scale rating of 20) was very similar in both groups (HR for athletes = 187 beat.min⁻¹; HR for non-athletes = 189 beat.min⁻¹).

The scatter plots in Figures 1 and 2 show the curves of each model (linear, cubic, or exponential) used to express the relationship between the ratings on the Borg RPE scale and HR for the athletes and the non-athletes. Table 2 presents a summary of the most important data regarding the quality and the parameters of the individual models.

Fig. 1. Curve estimations for the RPE scores and HR (athletes)

Notes:

x axis..... Borg rating of perceived exertion scale

y axis.....Heart rate (beat.min⁻¹)

Fig. 2. Curve estimations for the RPE scores and HR (non-athletes)

Notes:

x axis..... Borg rating of perceived exertion scale

y axis.....Heart rate (beat.min⁻¹)

Table 2. Model summary and parameter estimates for the RPE scores and HR (athletes and non-athletes)

Equation	Model summary					Parameter estimates			
	R-square	F	df1	df2	Sig.	Constant	b1	b2	b3
athletes									
Linear	0.377	102.364	1	169	0.000	104.068	3.983		
Cubic	0.397	36.723	3	167	0.000	159.197	-4.472	0.345	-0.002
Exponential	0.357	93.947	1	169	0.000	111.831	0.025		
non - athletes									
Linear	0.628	152.244	1	90	0.000	97.677	4.666		
Cubic	0.636	51.244	3	88	0.000	172.382	-14.618	1.529	-0.038
Exponential	0.595	132.021	1	90	0.000	105.425	0.030		

The results of the models for the athlete group (Figure 1 and Table 2) show that although all of the models reached the level of significance ($P \leq 0.001$) and are valid, the coefficients of determination are very low (0.38 for the linear model, 0.40 for the cubic model and 0.36 for the exponential model). Due to the very similar values of the coefficients of determination, we considered the models to be identical; nevertheless, the cubic model was considered to be the optimal relationship predictor, as this model accounted for the highest level of variance (40% of the total variance). The equation for this cubic model was as follows:

$$y = 159.2 - 4.5x + 0.35x^2 - 0.002x^3 + \varepsilon \quad [8],$$

where y is the HR value and x is the rating on the Borg RPE scale.

All models calculated for the non-athlete group (Figure 2 and Table 2) were also valid, as the level of significance was reached ($P \leq 0.001$). However, unlike the models created for the group of athletes, the coefficients of determination of the non-athlete models were significantly larger (0.63 for the linear model, 0.64 for the cubic model and 0.60 for the exponential model) than those for the athlete models. Due to the similar values of the coefficients of determination between the models, we again considered all three models to be very similar. Nevertheless, the cubic model was considered to be the optimal relationship predictor, as this model accounted for the highest level of variance (64% of the total variance). This cubic model equation was as follows:

$$y = 172.4 - 14.6x + 1.5x^2 - 0.04x^3 + \varepsilon \quad [9],$$

where y is the HR value and x is the rating on the Borg RPE scale.

The scatter plots in Figures 3 and 4 display the curves for each model (linear, cubic, and exponential) used to express the relationship between the ratings on the Borg RPE scale and the LA levels for the athletes and the non-athletes. In turn, Table 3 presents the summary of the most important data regarding the quality and the parameters of the individual models for both groups.

Fig. 3. Curve estimations for the RPE scores and the LA levels (athletes)

Notes:

x axis.....Borg rating of perceived exertion scale

y axis.....Blood lactate (mmol.l-1)

Fig. 4. Curve estimations for the RPE scores and the LA levels (non-athletes)

Notes:

x axis.....Borg rating of perceived exertion scale

y axis.....Blood lactate (mmol.l-1)

Table 3. Model summary and parameter estimates for the RPE scores and the LA levels (athletes and non-athletes)

Equation	Model summary					Parameter estimates			
	R-square	F	df1	df2	Sig.	Constant	b1	b2	b3
athletes									
Linear	0.480	156.023	1	169	0.000	-4.786	0.539		
Cubic	0.646	101.717	3	167	0.000	-3.098	1.700	-0.184	0.006
Exponential	0.441	133.238	1	169	0.000	0.266	0.153		
non - athletes									
Linear	0.710	220.755	1	90	0.000	-2.049	0.497		
Cubic	0.754	89.797	3	88	0.000	-0.422	0.544	-0.039	0.002
Exponential	0.782	323.403	1	90	0.000	0.922	0.110		

Because the level of significance was reached ($P \leq 0.001$), all assumed models (Figure 3 and Table 3) were considered to be valid; however, the coefficients of determination for the relationship between the Borg RPE scale scores and the LA levels were significantly higher than those between the Borg RPE scale score and HR (0.48 for the linear model, 0.65 for the cubic model and 0.44 for the exponential model). When comparing individual models, the cubic model was unambiguously considered to be the optimal model, as it accounted for 65% of the total variance. This equation for the cubic model was as follows:

$$y = -3.1 + 1.7x - 0.2x^2 + 0.006x^3 + \varepsilon \quad [10],$$

where y is the blood LA level and x is the Borg RPE scale score

The validity of all assumed models (Figure 4 and Table 3) was again confirmed ($p \leq 0.001$), and the coefficients of determination were significantly higher for this relationship than for all other relationships (0.71 for the linear model, 0.75 for the cubic model and 0.78 for the exponential model). When comparing individual models, the optimal model appeared to be the exponential model, which accounted for 78% of the total variance; the resulting equation was as follows:

$$y = -0.92 + \exp(0.11x) + \varepsilon \quad [11],$$

where y is the blood LA level and x is the Borg RPE scale score.

Discussion

The results of the present study have revealed interesting differences in the relationship between subjective perception and objective exertion in athletes and the non-athlete population.

We discovered a stronger relationship between HR and the Borg Scale of Fatigue ratings in the non-athlete group than in the athlete group. In both groups, we found that the cubic model accounted for the highest percentage of the variance; this model accounted for 69% of the total variance in the non-athlete group. In the athlete group, this model only accounted for 40% of the total variance. Therefore, although the Borg Scale can

be used as a tool for the objectivisation of physical loading as measured by HR in non-athletes, it is not an appropriate tool for elite endurance athletes.

However, in both groups, we found that the models for the relationship between the LA levels and the Borg RPE scale scores accounted for a higher percentage of the total variance than the models for the relationship between HR and the Borg RPE scale scores. All models for the non-athletes accounted for a similar proportion of the total variance (71 – 78%). For athletes, the cubic model was unambiguously the optimal model to describe this relationship (similar to that for the models for HR).

The relationship between the subjective perception of an increase in fatigue based on the graded exercise test described using these models was very similar to the relationship between the objective perception of fatigue and the increased loading.

For the group of endurance athletes, the most suitable model for both the HR and LA measurements appeared to be the cubic model. This finding corresponds to both the HR curve pattern (e.g., from the Conconi Test) and the blood LA level curve pattern (Åstrand et al., 2003).

For elite athletes, we found that the LA levels provided a substantially better explanation of the subjective evaluation of fatigue than the HR values. In particular, the cubic model for the blood LA level curves was suitable in many cases to evaluate endurance athletes. The aerobic threshold, which is important for endurance training, is typically identified as the point of the second increase in the blood LA level. For the general population and in some athlete populations, this intensity is difficult to identify and is therefore frequently set at a fixed value of 2 mmol.l⁻¹ (Neuman, Pfützner, & Hottenrott, 2000). Interestingly, in terms of the subjective perception of fatigue, the identification of this energy threshold in endurance athletes may be possible specifically using the Borg RPE scale.

Because all of the examined models accounted for very similar percentages of the variance in the non-athlete group, a linear relationship between the subjective and objective perception of fatigue may be determined, with some error, thus confirming the results of previous research (Borg, 1998; Chen et al., 2002; Lamb et al., 1999; Marcora & Staiano, 2010).

We assume that the identified differences between the groups may be the consequence of several factors, including the athletes' adaptation to the perception of the unpleasant states associated with exertion, as well as their adaptation to the endurance type of loading. In this respect, genetic predispositions for endurance performance may also apply; in the absence of these genetic predispositions, it is unlikely that these individuals could achieve the levels of performance that ensure their nomination to represent national teams.

Additional factors that may have played a role in the differences in the calculated relationships observed between the athletes and the non-athletes are psychological differences in the domains that are important for reaching maximal endurance performance (Hátlová, 2000; Kovářová et al., 2013; Kovářová et al., 2014; Zemanová & Kovář, 2009).

Based on the results of our study, it appears that the model of the subjective perception of fatigue does not lend itself to unambiguous objectivisation, as differences were found between endurance athletes and non-athletes. The relationships between the subjective perception of fatigue and the biomedical indicators of loading were stronger in the non-athlete population than in the athlete population. Large differences were identified primarily in the HR parameter. This relationship is affected by the degree of adaptation in the domain of aerobic and anaerobic metabolic systems in endurance athletes, as well as by psychological differences between the athlete and non-athlete populations.

Conclusions

Based on the results of our study, it appears that the model of the subjective perception of fatigue does not lend itself to unambiguous objectivisation, as differences were detected between endurance athletes and non-athletes. Using a cubic model, we detected a stronger relationship between HR and the Borg Scale of Fatigue ratings in the non-athlete group (69%) than in the athlete group (40%). Therefore, for non-athletes, the Borg RPE scale may be used as a tool for the objectivisation of physical loading as evaluated by HR; however, this method is not applicable for elite endurance athletes. For elite endurance athletes, the most predictive parameter is the blood LA level. Here, the cubic model also accounted for the highest percentage of the variance (65%). For the non-athlete population, the cubic model (75%) and the exponential model (78%) accounted for higher percentages of the total variance.

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