**METHODS**

**Experimental design**

A modelling longitudinal research design was used to analyze performance, fitness and fatigue over an 11-week period. An 8-week training period was implemented where subjects completed 3 interval training sessions per week. Before every third training session of the week, the subjects also performed a 3 km time trial (TT) in order to monitor the weekly changes in performance. Before the start of the training period, subjects performed an incremental exercise test to assess their fitness level and also in order to be able to individualize the training program. On the Friday before the start of the training period, they also performed a 3 km TT in order to assess the initial performance level. After the training period, there was a 3 week follow-up period where subjects stopped training and only performed the 3 km TT on Fridays so that the effect of dissipating fatigue and/or fitness could be monitored. All tests and training sessions took place in the Sport Science Laboratory—Jacques Rogge (Ghent University, Belgium), under controlled environmental conditions (18–19° C, 50% relative humidity). During all sessions, HR (H7 Sensor; Polar, Kempele, Finland) and power output (Cyclus2 ergometer; RBM Electronics, Leipzig, Germany) were continuously monitored in order to quantify TL.

**Subjects**

Ten healthy physically active men (22.0 ± 1.6 yr., 177.5 ± 4.5 cm, 73.0 ± 9.3 kg) participated voluntarily for this study. Subjects had no previous structured training in cycling but were recreationally active in different sports. Subjects had no history of disease or metabolic disorders. Participants were informed about the risks of the study and written informed consent was obtained from all subjects before participation. Before the study, each participant underwent a medical examination. Each subject was declared to be in good health and no contraindications for participation were detected. This study was approved by the Ethical Committee of the Ghent University Hospital, Ghent, Belgium. One of the subjects missed out on an entire week of the training program due to illness and was therefore excluded from further analysis.

**Exercise test**

Subjects performed a ramp incremental exercise test in order to assess their fitness levels and to individualize their training program. After a 3-min warm-up at 40 W, work rate increased continuously with 35 W.min-1. Participants were instructed to keep their cadence between 70 and 80 rpm, and strong verbal encouragement was provided throughout the test to ensure maximum effort. The protocol was terminated at voluntary exhaustion, which was defined as the inability to maintain a minimal cadence of 70 rpm for more than 5 consecutive seconds despite strong verbal encouragements. Pulmonary gas exchange (O2, CO2) was measured breath-by-breath (Jaeger Oxycon Pro; Viasys Healthcare GmbH, Höchberg, Germany). For at least 48h preceding the test, the subjects did not perform any exercise. Before the start of the test, the resting HR (HRREST) was defined as the lowest 5 s average HR when subjects lay in a supine position for 10 min in a quiet room.

**Time trials**

In the week before the training period, subjects were familiarized with the TT during 2 sessions. In those sessions they chose their preferred gear settings to perform the TTs. They also got the chance to perform the TT all-out two times to test their pacing strategy. On the Friday before the start of the training period, subjects performed a TT in order to determine the initial performance level used for the study (p\*). TTs were preceded by a standard warm-up of low intensity cycling at 100W for five minutes. After this warm-up subjects stopped pedaling for 45 seconds, giving the researchers time to set up the TT. After this short pause, the subjects started cycling again and resistance was automatically applied when they reached 60 rpm, starting the TT. Subjects were encouraged to complete the 3 km as fast as they could. The only feedback the subjects received was the cadence and the remaining distance. Strong verbal encouragement was provided throughout the test to ensure maximum effort. Gear settings were only changed when the subject explicitly asked for it during the TTs.

**Training period**

During a period of 8 weeks, subjects trained 3 times a week on Monday, Wednesday and Friday. A 45 min interval training was performed consisting of 5 bouts of 4 min cycling at a power output equivalent to the respiratory compensation point (RCP) alternated with 3 min of recovery at a power output that was associated with the gas exchange threshold (GET). Each training session included a warm-up and cool-down of 5 min at the level of GET. On Friday the training was preceded by a 3 km TT, followed by a 10 min rest period. In the 3 weeks following the training program, subjects performed a 3 km TT on Fridays and ceased training completely.

**Data analysis**

*Ramp incremental test*

O2peak was defined as the highest 30-s average achieved during the test. GET and RCP were determined by three independent researchers. GET was defined as the point where CO2 increased disproportionate to O2, the first departure from the linear increase in minute ventilation (E), and an increase in E/O2 without a simultaneous increase in E/CO2. RCP corresponded to the point where E increased disproportionate to CO2, the second departure from linearity in E, and an increase in both E/O2 and E/CO2. The power output at the time points corresponding to GET and RCP were adjusted for the O2 mean response time (MRT) in each individual to account for the kinetics of O2 and the delay between the muscles and the lungs inherent to a ramp incremental exercise test.20

*Training load*

TL was calculated using different methods of HR-based training impulses (TRIMP). The Banister TRIMP (bTRIMP) was calculated using the training duration, average HR and an IF using the following equation:

bTRIMP = duration training (min) x HR x 0.64e1.92x

where HR = (HRMEAN – HRREST)/(HRMAX – HRREST), e is the base of the Napierian logarithms, 1.92 and 0.64 are generic constants for males, and x = HR21. Five predefined zones (zone 1, 50-59% HRMAX, IF = 1; zone 2, 60-69% HRMAX, IF = 2; zone 3 70-79% HRMAX, IF = 3; zone 4, 80-89% HRMAX, IF = 4; zone 5, 90-100% HRMAX, IF = 5) were used to calculate Edwards’ TRIMP (eTRIMP). The time spent in each zone was multiplied by the respective IF and then summated in order to compute a total eTRIMP score22. For the calculation of the Lucia TRIMP (luTRIMP), three predefined HR zones were used. Zone 1 (IF = 1) was defined as below GET, zone 2 (IF = 2) between GET and RCP and zone 3 (IF = 3) above RCP. Again, the time in each zone was multiplied by its respective IF and then summed to provide a total luTRIMP23.

TL was also calculated according to the method of Foster, as a subjective measure of internal TL (TLRPE) . After every session, subjects were asked to rate their perceived exertion (RPE) using the CR-10 scale. TLRPE was then calculated by multiplying this RPE with the duration of the session24.

TSS was selected as an external TL measure. TSS is calculated using the following formula:

TSS = [(t × NP × IF)/(FTP × 3600)] × 100

Where t is the time, NP is normalized power and IF is the intensity factor (=NP/FTP). FTP is an individual’s functional threshold power25. For this study, FTP was assumed to be equal to the determined RCP (referentie).

*Fitting the model*

The set of model parameters was determined by fitting the model performances with actual performances using the least squares method using the Solver function in Microsoft Excel (Microsoft, Redmond, USA). The parameters of the model (equation 1) (, , and ) were determined by minimizing the residual sum of squares between modeled and actual performance (RSS):

The values of the model parameters (a vector , containing the values of , and ) of each subject were estimated by minimizing the error between the model prediction (Equation 1) and the available experimental data. This data involved, as described in the previous section, different TL quantification methods. Thus, the model parameter values were estimated for each quantification method per subject, also referred to as model calibration.

The error between model prediction () and the measured subject performance () was calculated per subject and TL quantification method as the residual sum of squares ():

,

which depicts the sum of the squared differences between the -th measured data point per subject () and the value of at the evaluated parameter values () and at the corresponding time point . The sum is taken over the total of data points in total per subject.

As several combinations of parameter values could result in a well-fitting model, a global minimization was applied, using algorithms that scan a large part of the parameter space. This avoids only finding well-fitting parameter values that are close to the initially guessed values, a drawback that occurs in local minimizations.

The minimization algorithm that was used is called Particle Swarm Optimization (PSO) 1. This global minimization technique entails that a number of particles searches the parameter space in parallel. Thus, every particle of the group, or swarm, evaluates the at each set of parameter values that it encounters. In each step of the algorithm, all particles of the swarm each evaluate a new location in the parameter space. Their searching direction is influenced by their inertia (how strongly they hold on to their original searching direction), their personal minimum and the lowest minimum found in the swarm. Respectively, these terms can be regarded as the sense for exploration (), the cognitive attraction to the personal minimum of the particle () and the social interaction by following the best particle of the swarm () 2. The PSO algorithm requires specification of the balance of these three search direction factors, for which in this study the three factors were all set at the same value of 0.5, opting for incorporating for all three mechanisms equally.

The parameter space in which the minimization was conducted is given in Table X. This space was moreover constrained in order to avoid illogical model outcomes. These are the following:

,

with the final restriction denoting that the predicted absolute change in performance over one time point (one day) cannot be larger than 0.1 or 10%.

Table 1: Model parameter space boundaries for calibration.

|  |  |  |
| --- | --- | --- |
| Parameter | Lower bound | Upper bound |
| , | 0 | 3 |
| , | 0 | 60 |

Finally, for each case (i.e. each TL quantification method per subject), 8 global minimizations were carried out.

The timeframe wherein training will contribute more to fatigue than to fitness, and thus the time where training should be avoided before competition was calculated as:

The day on which training will have the greatest positive influence on performance was calculated as:

**Statistical analysis**