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ORIGINAL ARTICLE

Resting metabolic rate changes over 4 months of elite general roller ski training

Variations de la valeur de la dépense énergétique de repos chez des skieurs de fond lors d'un entraînement de 4 mois

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RMR;
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Summary
Background. — The aim of the study is to provide new data regarding the main factors that influence resting energy expenditure (REE) value, by analysing daily training activity and cardiopulmonary adaptation during 4 months of general cross country roller skiing training.
Methods. — Three different training stages, defined as P1, P2, and P3 were analysed. In order to program the training, one maximum oxygen consumption (VO_2max) test was conducted at the beginning of the second stage (P2), while three RMR analyses were performed at an interval of 40—42 days period, between each of the analysed stages (P1—P3).
Results. — An increased Z5 effort time (17.55%), during P2, was associated with an elevated VT (0.66 l/min) (0.59—0.80) during the RMR test ($P = 0.0095$). Increased VT determined a reduction in RQ ($r = 0.75$, 95%CI = −0.09 to −0.02, $P = 0.01$), with an increased REE value ($r = 0.64$, 95%CI = 0.07 to 0.89, $P = 0.03$). Changes in REE were identified during P1 and P3 stages unlike P2 ($P = 0.0212$). During the analysed periods, changes in EE were significantly correlated with high intensity effort time (90—100% of FC_{max}) conducted over the predetermined training stages ($r = 0.81$, 95%CI = 0.39 to 0.95; $P < 0.01$). Increased training intensity was correlated with an increased resting VO_2 ($r = 0.97$, 95%CI = 0.69 to 0.97, $P = 0.01$), related to REE changes.
Conclusions. — Changes were recorded in the RMR results over 48 hours from the last training session, during both low and high intensity effort. RMR evolution was related to the effort intensity and the cardiopulmonary adaptation, as a result of training. An increased effort intensity over 42 analysed days, was associated with an important elevation in VE, $PetO_2$, following a VT drop and an increased resting VO_2, influencing REE values thorough important changes in RQ.

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MOTS CLÉS
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Résumé

Contexte. — Le but de cette étude est de fournir des nouvelles DATA en ce qui concerne les facteurs principaux qui influencent la valeur de la dépense énergétique du repos (REE) par l'analyse des entraînements quotidien et de l'ajustement cardiopulmonaire pendant 4 mois de formation générale en ski de fond.

Méthodes. — Il y a 3 stages différents d'entraînement qui ont été définis comme P1, P2 et P3, et qui ont été analysés. Afin de programmer la formation, la consommation maximale d'oxygène (VO_2max) a été déterminée au début de l'étude. Puis, le rythme métabolique au repos (RMR) a été analysé trois fois, avec un intervalle de 40—42 jours entre les étapes d'analyse (P1—P3).

Résultats. — Le prolongement de l'effort anaérobique pendant P2 a été associé avec des taux élevés du volume courent (VC) (0,66 L/min) (0,59—0,80) pendant le test de RMR (p = 0,01). L'augmentation du VC a déterminé la réduction du ratio de l'échange respiratoire (RER) (r = 0,64, IC 95 % = 0,07 à 0,89, p = 0,03) Les changements de la dépense énergétique du repos ont été identifiés pendant l'entraînement de phase P1 et P3, mais pas pendant le P2 (p = 0,0212). Pendant la période analysée, les changements de la dépense énergétique ont été significativement corrélés avec le temps d'effort de haute intensité (90—100 % of FC_{max}) pendant chaque des trois étapes d'entraînement prédéterminés (r = 0,97, IC 95 % = 0,69 à 0,95, p < 0,01). L'intensité d'entraînement a été corrélée avec une augmentation du VO_2 de repos relatif à la dépense énergétique du repos.

Conclusion. — Les changements ont été enregistrés dans les résultats du RMR plus de 48 heures après l'entraînement, pendant des efforts de haute ou de basse intensité. L'évolution du RMR a été corrélée à l'intensité de l'effort et à l'adaptation cardiopulmonaire induite par la formation. L'augmentation de l'intensité d'effort pendant les 42 jours analysés a été associée avec une élévation importante de la ventilation et de la pression partielle de l'O_2, suivant la baisse du VC et l'augmentation du repos de VO_2, qui a influencé la valeur REE par des changements importants du RER.

1. Introduction

The resting metabolic rate (RMR) together with several influencing factors create the human energy expenditure (EE). During a variable period of time, the EE undergoes changes according to the training phase [1].

The RMR represents the minimum amount of energy needed to maintain the body's main functions [2], being measured as the resting energy expenditure (REE). The RMR can represent as much as 70% of the total energy needs. Physical activity, with values up to 25%, and thermogenesis, with values stated between 5—10%, complete the energy requirements of the human body [3].

Over a 30 days period, the energy requirements will vary with values up to 15% of the initial testing result. Daily changes in energy demands can be related to the RMR [4], for which estimation methods are well known at this moment. The most accurate method is the Indirect Calorimetry analysis, which measures EE based on O_2 consumption and CO_2 production. Equations such as Harris Benedict's, including age, height, weight, and physical activity level are also used in estimating the EE [5].

The most elevated EE values are measured in active subjects and athletes. The testing methodology is of particular importance in estimating RMR during different training phases. The time passed between the last training and the test is variable from one paper to another [4]. Therefore, the general testing protocol recommends 48 hours between the last intensity training and the test [6]. In order to obtain a clear RMR result by Indirect Calorimetry analysis, the lack of food and supplements consumption in the 12 hours preceding the test is of particular importance. Any differences in the methodology can influence the test results and its reproducibility.

Energy expenditure evolution is variable along one year of training. Recent results showed that a significant increase in REE is associated with the training volume [7], while a reduction in RMR can be recorded as a result of increased training intensity.

Documenting REE changes, based on training evolution, has the potential to allow EE estimation in the absence of a method such as Indirect Calorimetry, which involves the use of expensive equipment. However, more data regarding the athletes' functional adaptation and weight management should be accrued using the REE test in order to achieve this objective. The purpose of this study was to provide new data regarding the main factors that influence the REE value by analysing daily training activity and cardiopulmonary adaptation during 4 months of general cross country roller skiing training, whiting an international competitive group.

2. Methods

A cross-sectional study was conducted between May and August 2017, in Romania. The mentioned period was associated with the 2016—2017 season transition phase and the 2017—2018 season general training phase.

2.1. Study group

The study group consisted of 5 elite male cross country skiers, with representative international results. As inclusion criteria, the athletes had to pass a general medical test that confirmed the clinical health condition. All subjects included in the medical test received the consent to participate in an organized training program. In order to conduct the study and publish the current results we obtained written consent from both the athletes, the Federal Management along with the University Ethical Committee.

2.2. Study protocol

The analysis was performed during the 2016—2017 season transition and the 2017—2018 season general training period, over a period of 117 days, of which 95 were training days. In the absence of a favourable climate, the training was performed on roller skis, at a temperature of 15—25 °C.

Three different training stages, defined as P1, P2, and P3 were analysed. In order to program the training, one maximum oxygen consumption (VO_2max) test was conducted at the beginning of the second stage (P2), while three RMR analyses were performed at an interval of 40—42 days period, between each of the analysed stages (P1—P3).

The first analysed stage, defined as P1, was set during the last transition period of the 2016—2017 season, over 28 calendar days (20 training days). During P1, the effort was not conducted in an organized training centre. The athletes' recovery represented the main objective; the lowest distance and effort time were measured. The second analysed period, defined as P2, lasted 43 days (39 training days) and was associated with the first general training stage of the 2017—2018 season. During P2, the activity was initiated in an organized training centre, after the VO_2max test and RMR tests. The third analysed period (P3) lasted 44 days (37 training days) and was initiated after the second RMR test, while the third RMR analysis was performed at the end of P3, as showed in Fig. 1.

2.3. Training analysis

A number of 131 training sessions, covering a median distance of 2500 km (2.197 to 2831 km interval), were included in the analysis. Roller skiing, running and cycling were used as training methods. During the first analysed stage (P1), 14 different training sessions were conducted. The second analysed stage (P2) consisted of 61 trainings, while during the last analysed stage (P3) a total number of 56 training sessions were conducted, with the objective to develop the general aerobic capacity.

The training database was created using Microsoft Excel software. Total exercise time (minutes), distance (km) and heart rate (HR, b/min), were measured during training using the Polar V400 device and the Polar H7 Bluetooth Cardio Frequency meter. Median HR% (0 to 100% of HR_{max}), associated to different effort zones (i.e., aerobe, mixt or anaerobe effort) was calculated for each training session, in order to confirm the fulfilment of the training objective, as described in the VO_2max protocol.

2.4. Exercise and resting cardiopulmonary analysis

The testing protocols, for both RMR and VO_2max test analyses, were applied using the same equipment. The Cosmed Quark CPET (Rome, Italy) and the Cosmed ANT + /Bluetooth cardio frequency meter were used, under different protocols, to determine the RMR and the VO_2max. The Cosmed F150 running ergometer was used to perform the maximal test during the VO_2max test. The equipment was calibrated at the start of each measurement with known O_2 (16%) and CO_2 (5%) concentrations. The flow meter was calibrated using a Cosmed Calibration Syringe (3 L) at the start of each test.

2.5. Maximal effort testing (VO_2max)

One single VO_2max test was conducted by applying the Bruce Maximal Test Protocol. The test consisted in a running effort over 7 different stages (3 minutes per stage), starting from 2.7 km/h (10% inclination), and reaching up to 9.6 km/h speed (22% inclination). The following parameters were analysed in order to describe the athletes' effort capacity: maximum heart rate (HRmax, b/min) ventilatory threshold 1 (VT_1), ventilatory threshold 2 (VT_2), VO_2max (ml/min), and relative VO_2max (ml/min/kg).

Based on the VO_2max test, five different effort zones were established based on the measured HRmax (%): two aerobic zones—Zone 1 (Z1, 50—60%) and Zone 2 (Z2, 60—70%); the mixt effort zone—Zone 3 (Z3, 70—80%), and two anaerobic effort zones—Zone 4 (Z4, 80—90%) and Zone 5 (Z5, 90—100%).

2.6. Resting metabolic rate analysis

The RMR was measured at three different time points, at 40—42 days interval between them (P1—P3), as shown in Fig. 1. The test was performed 48 hours after the last intensity effort, 12 hours after the last training session and after the last served meal. Lack of caffeine, sports supplements and nicotine in the 12 hours prior to the test, were also required.

The main parameters included in the RMR analysis were divided into two groups. The first group consisted of the following functional parameters: tidal volume (VT, L/min), ventilation (VE, L/min), oxygen volume (VO_2, L/min), carbon dioxide production (VCO_2, ml/min), respiratory quotient (RQ). O_2 consumption (ml/min), CO_2 (carbon dioxide, ml/min), ventilatory equivalents for oxygen (VE/VO_2, ml/min), metabolic equivalent (MET), fractional content of oxygen (FeO_2, %), arterial partial pressure of oxygen (PaO_2, mmHg), end-tidal oxygen tension (PetO2, mmHg) and end-tidal carbon dioxide tension ($PetCO_2$, mmHg),

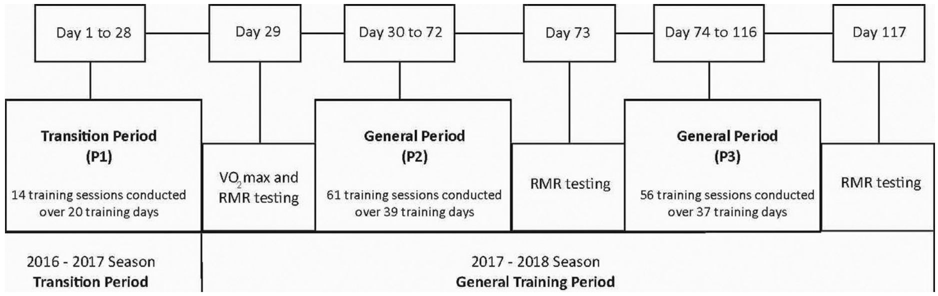

Figure 1 The study protocol applied over 117 days.

all describing cardiopulmonary adaptation to effort. The second group represented general information regarding the energy requirements: REE (kcal/min), carbohydrate metabolism consumption (CHO, %) and Fat metabolism consumption (Fat, %).

2.7. General anthropometry

Body weight (kg) and body composition (%) were assessed before each RMR testing, during P1—P3 stages. The analyses were carried out using a calibrated scale and a Cosmed manual plicometer. Durnin and Womersley formula was applied in order to calculate inactive and active mass percentage (%) using the bicipital (mm), tricipital (mm), subscapular (mm), and suprailiac (mm) skinfolds, represented as (Σ 4*ST*1), along with the body weight (kg), height (m), age (years) and gender [8].

Durning—Womersley Equation: Body density = $1.1765 - 0.0744 \log_{10} (\Sigma\ 4ST1)$

2.8. Statistical analysis

GraphPad Prism 5.0 software was used for statistical analysis. Standard deviation (SD), the coefficient of variation (CV%), along with the median were used in the descriptive analysis. The D'Agostino Pearson omnibus normality test was used to assess data normality, and the Spearman test was applied in order to assess a correlation between two parameters. We considered a P-value < 0.05 as being statistically significant, with a standard Confidence Interval set at 95% (95%CI).

3. Results

In the start of the general training period and P2, the measured relative VO_2max was determined at median value of 67.12 ml/min/kg (64.61—71.85). The VT_1 had a median value of 152 b/min (140—153), and VT_2 had a median value of 185 b/min (170—193). Using these results, the training program over both P2 and P3 training periods (76 days) was scheduled for each subject with an identical predetermined effort objective, but with changes in effort characteristics due to individual effort capacity differences.

3.1. Training analysis

During the first analysed training period (P1) the athletes covered a median distance of 214.7 km over 14 training sessions, and 1.201 minutes of effort. Since the main activity objective, during P1, was general recovery, aerobic training was conducted over 73% of the effort time, with 156.73 km performed in effort zones 1 and 2 (50—70% of HR_{max}).

Significant differences regarding the total effort time were recorded in the P2 compare to the P1 stage. During P2, a median distance of 1.275 km (P = 0.01) was conducted over 61 training sessions and 5.216 min (P < 0.01). During P2, effort zone 2 was reached over 1322.25 min (25.35%), while effort zone 1 was performed over 2663.81 min (51.07%). As against P1, general aerobic training time was significantly different over P2 training period (P = 0.004). Yet, aerobic training represented 76.42% of the total effort, being conducted over 974.35 km.

Important differences regarding the total effort time and distance were also noted between P1 and P3. During P3, a median distance of 984.5 km was conducted over 4862 min and 56 training sessions. The distance was significantly higher than the one measured during P1 (P = 0.01), but lower than the P2 stage distance (P = 0.01). During P3, effort zone 2 was conducted over 720.54 min (14.82%), while effort zone 1 was conducted over 4152.14 min (85.40%), as presented in Table 1.

3.2. Resting metabolic rate and secondary measurements analysis

Body weight values during P1 were similar with the baseline body mass value. The athletes' median weight, during P1, was 73.6 kg (71—77), with the inactive mass representing 9.85%.

At the beginning of P2, during the first RMR test, a median REE of 1975 kcal/min (1533—2534) was determined. $PetCO_2$ measurement had a median value of 37.31 mmHg (33.67—39.26), along with 0.57 L/min (0.52—0.78) VT. Fat metabolism was recorded at 59.81% (52.12—61.5), while carbohydrate metabolism reached only 40.18% (38.49—47.87) of the energy requirements based on the RQ value (0.82). Ventilation was measured at 7.42 l/min (6.25—8.66), with a proportional increase in VE/VO_2 of 26.04 l/min (23.61—28.53), with a median for METS of 1.11 (0.81—1.47) and a CO_2 of 24.24 ml (23.07—31.02).

Table 1 Descriptive data regarding P1—P3 training program, illustrated as median values (ranges).

Training characteristics	P1	*P*-value P1—P2	P2	*P*-value P2—P3	P3
No. of training sessions	14	—	61	—	56
Time (min)	1201 (861—1601)	0.01**	5216 (4649—5540)	0.17*	4.862 (4329—5007)
Distance (km)	214,7 (127—368)	0.01**	1275 (1188—1392)	0.01**	984,5 (882.3—1048)
Z5, %	5.22 (0—8.41)	0.42*	2.40 (2.09—6.30)	0.21*	0.39 (0.0—3.23)
Z4, %	4.77 (0.1—8.1)	0.57*	2.76 (2.37—12.94)	0.25*	2.07 (0.87—2.59)
Z3, %	5.50 (2.61—7.84)	0.26*	13.81 (7.47—19.45)	0.02**	2.89 (1.71—7.13)
Z2, %	27.24 (10.25—48.34)	0.90*	25.35 (25.08—31.50)	0.05**	14.82 (10.69—20.57)
Z1, %	46.17 (37.73—54.06)	0.01**	51.07 (40.84—61.72)	0.01**	85.40 (83.23—89.78)

Mann-Whitney *U* test was applied.
* $P > 0.05$.
** $P < 0.05$.

At the start of P3 training, the second RMR measurement showed a median REE value of 2233 kcal/min (2116—2345). The EE value based on RQ analysis was 57.34% (23.42—82.82) for Fat metabolism and 42.65% (17.17—76.57) for Carbohydrate metabolism. $PetCO_2$ dropped to 35.15 mmHg (30.02—36.31), in comparison with 37.31 mmHg (33.67—39.26) in P1 ($P > 0.05$), while VT reached a higher median value, of 0.66 l/min (0.59—0.80) ($P > 0.05$). METS was 1.23 (1.19—1.30) in P3, while VE was 9.27 L/min (8.12—9.76), higher than the VE value measured in P1 (7.42 L/min, $P = 0.01$). VE/VO_2 was also higher, of 28.68 L/min (31.85—37.20), while CO_2 was 30.27 ml (27.96—33.80), higher than P2 values but without a significant statistical value ($P > 0.05$). Body weight during the second RMR test was 73.65 kg (70—76.1), with an inactive mass percentage of 7.53% (6.58—8.96). No significant correlations were identified between body weight, inactive mass and REE values ($P > 0.05$).

The last RMR test (P3), revealed a median REE value of 2053 kcal/day (1881—2053). Compared to the previous tests, Fat metabolism was only 29.22% (14.99—78.30) of the energy value. A total of 70.78% (21.70—85) of the energy consumption was attributed to carbohydrate metabolism, being statistically different from both P1 ($P = 0.0024$) and P2 ($P = 0.0017$). The VT was 0.57 l/min (0.29—0.61), while VE/VO_2 touched the highest value, of 29.14 l/min (26.90—33.87 + *P*). $PetCO_2$ also reached its highest point 37.52 mmHg (25.78—39.32) during P3, compared to both P1 and P2 values (both $P > 0.05$), while METS dropped at 1.12 (0.86—1.22) and CO_2 reached 23.28 ml (10.72—25.54). The body weight was higher during P3, 73.75 kg (70—77), compared to both P1 and P2, while the inactive mass reached 8.39% (6.35—8.21) of the body weight, lower than in P1 ($P > 0.05$), but higher than in P2 ($P > 0.05$). Several differences were also identified between REE values during P1—P3 stages, as shown in Fig. 2.

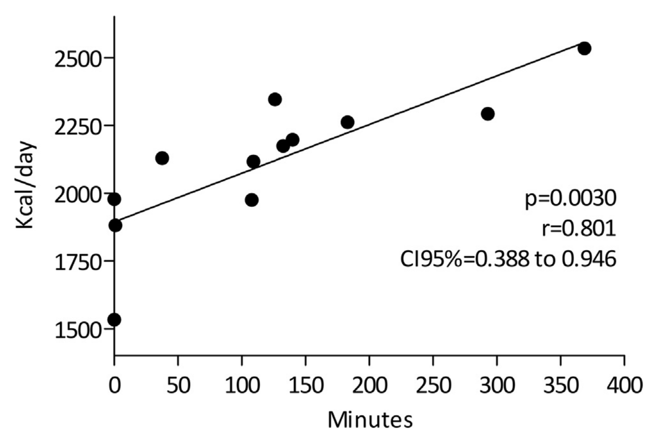

Figure 2 REE evolution in association to high intensity training (90—100% of HR_{max}) during P1—P3 analysis ($P = 0.0030$, $r = 0.801$, 95%CI = 0.388 to 0.946).

3.3. Resting metabolic rate analysis related to training evolution

The low aerobic training sessions conducted during P1 were associated with elevated VT1 and oxygen consumption ($P = 0.02$) during the VO_2max test conducted at the start of P2. During the effort analysis, the training distance was significantly positively correlated with the training time ($r = 0.96$, 95%CI = 0.86 to 0.99; $P = 0.0001$) regardless of the analysed stage. The high aerobic training volume conducted in effort zones 1 and 2 (50—70% of HR_{max}) was significantly correlated to an increased training distances ($P = 0.03$). Increased intensity training time was significantly positively correlated with CO_2 ($P < 0.01$) and REE (Fig. 3) during all three stages.

During P2, the training volume was significantly correlated with the inactive mass percentage ($r = -0.81$, 95%CI = −0.95 to −0.41; $P < 0.01$), while no significant correlations were identified between the REE and P1—P3 body mass results (all $P > 0.05$).

Changes in REE were identified during P1 and P3 stages unlike P2 ($P = 0.0212$). During the analysed periods, changes in EE were significantly correlated with high intensity effort time (90—100% of HR_{max}) conducted over all monitored stages ($r = 0.81$, 95%CI = 0.39 to 0.95; $P < 0.01$). As a result, increased intensity training was correlated with the resting VO_2 ($r = 0.97$, 95%CI = 0.69 to 0.97, $P = 0.01$), VE ($P = 0.0331$) and VCO_2 ($P = 0.02$) values, translated into REE changes, as shown in Fig. 4.

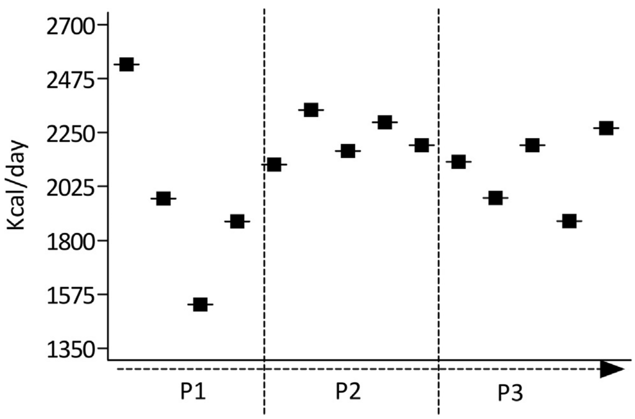

Figure 3 REE evolution during P1—P3 represented as median and interquartile range values.

Increased training intensity (95—100% of HRmax) during P1 and P2 generated important changes within the main respiratory parameters, influencing REE. An increased Z5 effort time (17.55%), during P2, was associated with an elevated VT (0.66 L/min) (0.59—0.80) during the RMR test (P = 0.0095). Increased VT determined a reduction in RQ (r = −0.75, 95%CI = −0.09 to −0.02, P = 0.01), with an increased REE value (r = 0.64, 95%CI = 0.07 to 0.89, P = 0.03). A higher RQ value reflected a lower fat metabolism contribution (≥ 60%), determining REE changes during the analysed stages.

Low aerobic training (zone 1—2) was significantly correlated with VE/VO_2 changes. However, FeO_2 (4.92%) variations during RMR testing were significant in associating to aerobic training (r = −0.71, 95%CI = −0.91 to −0.19, P = 0.01). Their influence on REE reduction was related to METS evolution. The metabolic equivalent presented a positive correlation with the REE value (r = 0.77, 95%CI = 0.33 to 0.93, P = 0.05) and with the total activity conducted in effort zone 5 (r = 0.72, 95%CI = 0.23 to 0.92, P = 0.01). Further on, METS evolution during P1—P3 RMR testing was inversely related to VE/VO_2 value (r = −0.82, 95%CI = −0.95 to −0.45, P = 0.01). Unlike the influence of high intensity training on the respiratory parameters, during one or several analysed stages, no correlations were obtained regarding cardiopulmonary adaptation during low intensity effort (all P > 0.05).

4. Discussions

Ensuring the energy needs of an elite athlete is important during both medium- and long-term training. This general hypothesis is confirmed by our current paper. Meanwhile, Papadopoulou S.K. et al., 2012 [9] results reflected the importance of EE in describing the risk for early fatigue, improper muscle function, and failure in maintaining body weight, due to negative energy balance during different training stages.

Resting metabolic rate analysis during medium term training: Training will influence both resting and total EE. According to Falcone PH et al., 2015 [10] results, exercise EE will be increased during both intensity and long-lasting aerobic effort. In our study, intensity training was not performed during a medium or a long period of time, but in short sessions, unlike other papers with similar objectives [11]. Based on the obtained results, we can confirm that a high intensity effort (Zone 3—5) conducted over 15% of the training volume, can generate an increased REE. During the P3 period, we recorded the lowest REE. The main REE changes were obtained over a 42 days training period, including no more than 840 km, which were conducted between 50—65%

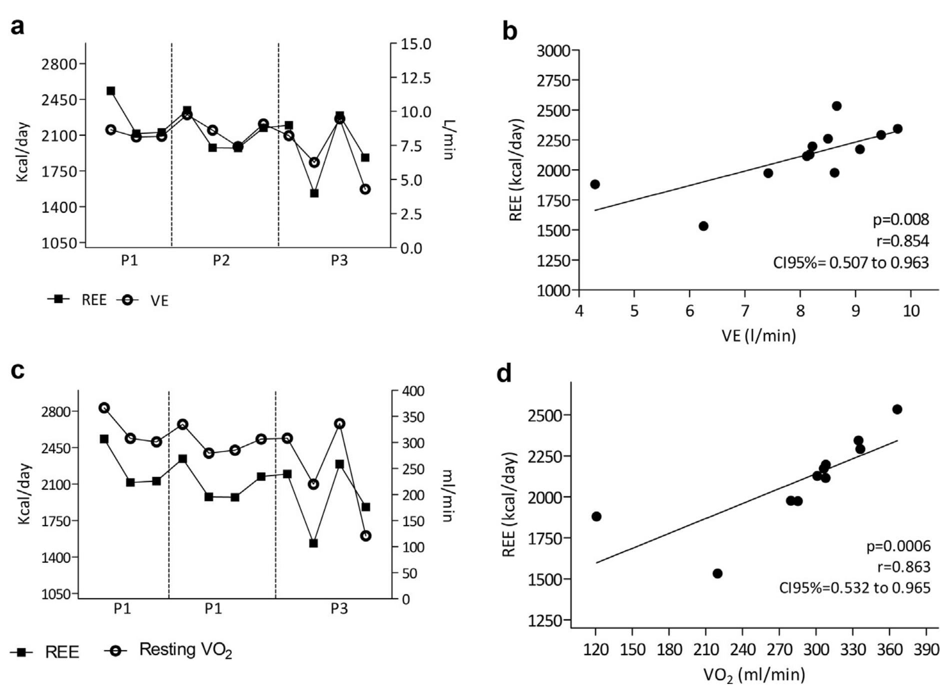

Figure 4 Resting energy expenditure (REE) related to the resting ventilation (VE) (a—b) and oxygen volume (VO_2) (c—d) over P1—P3 individual analysis.

of HR_{max} (Zone 1—2). Similar outcomes, published by Main L. et al., 2009 [2], were associated with improper adaptation due to training intensity and a negative energy balance [12].

Based on the current findings, general and long-term training adaptation is related to the athletes' body mass. Through our results, we confirm that an elevated aerobic workload will increase the risk of weight loss during general training period, unlike Trexler's E.T et al., 2014 results, which indicate that the risk of weight loss increases during intensity training [13]. Through our current work, we failed to confirm the effect of body mass on REE value over a 4 months period. Although REE long-term evaluation, can suggest that functional adaptations following several training stages will probably influence much more the REE values than the body mass. Recently conducted studies regarding training functional adaptations found an impaired neuroendocrine function under strict energy deficiency. Through the current literature results, it was shown that energy deficiency can reduce leptin levels, generating a direct effect on energy conservation, expenditure and thermogenesis, according to Jürimäe J. et al., 2011 [14].

The REE is related to the effort time and effort intensity, as shown in our paper through the effort influence over the REE values and the respiratory parameters adaptation. The main outcome is partially supported by the paper of Inoue A. et al., 2016 that demonstrates the influence of general training practice in establishing the final EE [15]. Drenowatz et al., 2013 indicated that an increased RMR can be related to the effort staging [16]. Based on our findings, REE values did not show major differences during P1—P3 training stages, but important differences in RQ variability were encountered during the three stages, influencing total fat and CHO metabolism. Similar to Woods AL et al., 2017 and Paoli, A. et al., 2012 results, high training load was associated with a reduction in energy demand, which in our paper was associated with an elevated RQ value [17]. In addition, REE changes were reported during both P1 and P2 periods by conducting high aerobic training, along with short repetitive high intensity efforts, unlike P3 stage. During P2, a lower body weight was measured compared to P1. In comparison, P3 analysis showed a lower REE value, but a higher body mass, thereby excluding the negative energy balance hypothesis.

Through resting $PetO_2$, VO_2 and VE evolution we consider that the RMR influence mechanism may show new information regarding the recovery status of the athlete. Resting VO_2 kinetic analysis illustrated important differences between P2 and P3 respiratory evolution. An increased resting VO_2 value was observed due to a possible O_2 deficit, as a result of the effort. However, during P1 and P2, we observed an elevated O_2 level compared to P3. Through Mezzani A et al., 2009 [18] work we have seen that an increased O_2 level is necessary in order to assure creatine rephosphorylation in the skeletal muscle. Further on, longer recovery periods with similar results will benefit from excess VO_2 due to pyruvate conversion from lactate.

During resting periods, increased ventilation was observed during P3. As a result, respiratory parameters were associated with a lower REE value. A reduced VT was associated with a high ventilation response, in order to assure CO_2 excretion rate, thus lowering the REE. $PeTO_2$ evolution is related to PaO_2 changes [19]. During both rest and exercise periods, several changes regarding the pH will be related to PaO_2 and $PetO_2$ evolution, as shown by Nielsen HB, 2003 [20]. However, an increased RQ was related to a positive change in $PetO_2$. During P3, end tidal oxygen tension was significantly correlated with VCO_2 due to extra CO_2, generating a high carbohydrate metabolism activity, compared to a lower RQ value (< 0.85).

Further studies on RMR evolution are needed in order to analyse the functional adaptation during different training stages in elite athletes. We consider that conducting similar analyses on a larger group is a necessity. However, we are limited by a low number of elite athletes.

5. Conclusions

Major changes regarding VE and VO_2 were related to P3, unlike P1 and P2 REE values. Changes were recorded in the RMR results over 48 hours from the last training session, during both low and high intensity effort. RMR evolution was related to the effort intensity and the cardio-pulmonary adaptation, as a result of training. An increased effort intensity over 42 analysed days, was associated with an important elevation in VE, $PetO_2$, following a VT drop and an increased resting VO_2. All of the mentioned outcomes determined important changes in RQ value, influencing the final REE result.

We confirm our hypothesis and further on we believe that long-term resting metabolic rate analysis can indicate important data regarding functional adaption, which can be related to the energy balance, body mass and the cardiopulmonary evolution, as a result of the training effort.

Disclosure of interest

The authors declare that they have no competing interest.

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