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## **EFFECTS OF A 14-DAY HIGH-CARBOHYDRATE DIET ON EXERCISE PERFORMANCE OF A LOW-CARBOHYDRATE ADAPTED ATHLETE – CASE STUDY**

### **VPLIV 14 DNEVNE VISOKO-OGIJKOHIDRATNE DIETE NA ZMOGLJIVOST PRI ŠPORTNIKU PRILAGOJENEM NA NIZKO-OGIJKOHIDRATNO DIETO**

#### **ABSTRACT**

A growing number of athletes utilize low carbohydrate diets (LC). The majority of to-date studies investigated the performance effects of transitioning from a high-carbohydrate diet (HC) to a LC diet. However, the effects of a contrary, LC to HC diet transition, on performance at moderate and high intensities have not been studied. Accordingly, this study investigated the effects of a 14-day HC diet on exercise performance of a LC adapted athlete. A trained male cyclist ( $VO_{2peak} = 70 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ ) following a LC diet ( $\leq 50 \text{g CHO}\cdot\text{day}^{-1}$ ) underwent a familiarization session to determine the baseline  $VO_{2peak}$  value and calculate the training intensities. Two testing sessions were performed following 14-days of LC and HC diet, respectively. The training loads were kept identical during both periods. Each testing consisted of a moderate (65%  $VO_{2peak}$ ) and high-intensity (90%  $VO_{2peak}$ ) constant-power tests (CP) to exhaustion. Minute ventilation ( $V_e$ ) and oxygen uptake ( $VO_2$ ) were determined by indirect calorimetry and blood samples were collected to determine glucose, ketone and lactate capillary concentrations. Following the HC diet, time to exhaustion decreased in the moderate-intensity CP (+9%) but increased in the high-intensity CP (-3%). Lactate levels were lower during both CP tests following the LC as compared to HC period. Glucose and ketone responses were similar. Higher  $V_e$  and  $VO_2$  values were observed during the CP tests following the HC diet. Collectively, these results suggest that introduction of a HC diet to a LC adapted athlete results in increased ability to perform high-intensity endurance performance while it decreases moderate intensity performance.

*Key words:* Diet, Fat, Carbohydrate, Performance, Low-carb diet

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#### **POVZETEK**

Vedno več športnikov se prehranjuje z nizko-ogljikohidratno dieto (NO). Večina dosedanjih raziskav je preučevala vpliv na športno zmogljivost ob prehodu iz visoko-ogljikohidratne (VO) na NO dieto. Raziskav, ki bi preučevale obratno, torej prehod iz NO na VO z ozirom na zmogljivost pri srednjih in visokih intenzivnostih, do danes še ni bilo. Pričujoča raziskava je preučevala vpliv 14 dnevne VO diete na zmogljivost pri športniku, prilagojenem na NO dieto. Treniran kolesar ( $VO_{2peak} = 70 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ ), ki se je prehranjeval z LC dieto ( $\leq 50 \text{g OH}\cdot\text{dan}^{-1}$ ) je najprej opravil uvodno testiranje z namenom določitev  $VO_{2peak}$  vrednosti in izračuna trenajzne intenzivnosti. Dve testirani sta bili izvedeni po 14. dneh NO in VO diete. Trenažna obremenitev je bila med obema prehranskima intervencijama identična. Na vsakem testiranju je kolesar opravil srednje-intenzivno (65%  $VO_{2peak}$ ) in visokointenzivno (90%  $VO_{2peak}$ ) kolesarjenje do izčrpanja pri konstantni obremenitvi (CP). Minutna ventilacija ( $V_e$ ) in poraba kisika ( $VO_2$ ) sta bili merjeni z indirektno kalorimetrijo. Odvzeti so bili kapilarni krvni vzorci za določitev koncentracije glukoze, ketonov in laktata. Po VO prehranski intervenciji se je čas do utrujenosti pri srednjeintenzivni CP poslabšal (+9%), pri visokointenzivni CP pa izboljšal (-3%). Vrednosti laktata so bile nižje pri obeh testih po NO v primerjavi s VO dieto. Vrednosti glukoze so bile podobne.  $V_e$  and  $VO_2$  vrednosti so bile višje med obema CP testoma po VO dieti. Rezultati raziskave kažejo, da povečanje vnosa ogljikohidratov v prehrano NO adaptiranega športnika pozitivno vpliva na zmogljivost pri visoko intenzivni aktivnosti, medtem ko negativno vpliva sposobnost premagovanja srednje intenzivnega napora.

*Ključne besede:* Dieta, Maščobe, Ogljikovi hidrati, Športna sposobnost, Nizko-ogljikohidratna dieta

## INTRODUCTION

Diet is one of the key pillars that enable optimal sports performance. While it was long thought that diets high in carbohydrate content (HC) are superlative for endurance athletes, there is a growing interest in diets restricting the daily amount of carbohydrates to  $\leq 50$ g (i.e. low carbohydrate diet; LC) and its effects on performance. Moreover, it was recently suggested that transition from HC to LC diets might also result in performance enhancement (Noakes, Volek, & Phinney, 2014; Volek, Noakes, & Phinney, 2015). However, very few studies to-date investigated the performance indices following the LC diets.

The study of Phinney et al. (1983) is one of the first investigations into the performance changes of athletes after switching from HC to LC diet. They studied the effects of a 4-week LC diet, while maintaining normal training regimen of athletes. While the overall results showed that athletes' performance was not significantly comprised at intensities corresponding to 62–64% of the peak oxygen uptake ( $VO_{2peak}$ ), some of the athletes' performance was similar, or even slightly increased, following LC as compared to HC diet. Common result following the LC diet in all athletes was the increased fat metabolism and reduced glucose oxidation. Although the results suggest that 4-weeks of LC diet greatly improves fat oxidation rate, the data does not show that athletes improved their performance. However, the fact that a few athletes managed to perform at least as good as before indicates that LC diet does not necessarily blunt moderate intensity performance. It is also of note that, the data from Phinney et al. (1983) suggest that the overall glycogen muscle storage is lower after a LC as compared to the HC diet. Rowland and Hopkins (2002) investigated the effects of a 14-day LC diet on short- and ultra-endurance cycling performance. Similarly to the results of Phinney et al. (1983), the athletes increased fat availability and oxidation rates during exercise. Results also indicated slight improvement of ultra-performance of athletes during LC period, although this trend did not reach statistical significance. On the other hand, there was no change between LC and HC on short-duration high intensity exercise. Paoli et al. (2012) demonstrated that one week of LC positively affects body composition and does not reduce performance in various tests on elite gymnasts. Moreover, Rhyu and Cho (2014) have demonstrated that hypo-caloric LC diet is superior to hypo-caloric HC diet in Taekwondo athletes in regards to their performance. More recently, McCleary et al. (2014) demonstrated that athletes following a LC diet can improve muscular strength to a similar extend as a HC athletes. On the other hand, studies investigating the short term adaptation to LC diet (<6 days) have found that the endurance performance is significantly compromised following a LC diet (Helge, 2000).

Few studies comparing performance indices following fat-rich, lower carb diets with a HC diet also need to be mentioned. Lambert et al. (1994) showed enhanced moderate-intensity performance on a lower carb diet compared to a HC diet, while the results of the high-intensity exercise were comparable. Although these studies cannot be categorized as a LC vs. HF studies due to higher carbohydrate content, it seems that the higher the fat content in the diet the higher the fat oxidation rates are during moderate intensity exercise. This has also been shown by Helge et al. (2001) who showed that plasma low density lipoprotein-triacylglycerol and plasma fatty acids become major sources of energy during exercise after fat adaptation. There were also significant reductions in glycogen breakdown and carbohydrate oxidation, while glucose uptake stayed the same, suggesting muscle glycogen sparing. Interestingly the study by Burke et al. (2002) indicated

that only one day of HC diet following a 5-day LC diet intervention results in significant increase of muscle glycogen content.

While the above studies investigated the acute and chronic effects of HC to LC diet transition on performance, no study to date scrutinized the opposite transition (i.e. from a LC to a HC diet). Accordingly, the present case-study aimed to determine the effects of transition from LC to HC diet in trained athlete on the moderate (65%  $\text{VO}_{2\text{peak}}$ ) and high-intensity (90%  $\text{VO}_{2\text{peak}}$ ) endurance performance. Since increases in fat oxidation rates have been demonstrated previously as a result of LC diet, we hypothesize that LC-adapted athlete would improve, both moderate and high-intensity performance following transition from LC to HC diet, as the fat oxidation rates would still be elevated and the glycogen storage replenished.

## METHODS

### Participant

Recreationally trained, healthy male cyclist (Age: 21 yrs., Stature: 166 cm, Body mass: 62 kg,  $\text{VO}_{2\text{peak}}$ : 70 mL·kg<sup>-1</sup>·min<sup>-1</sup>) took part in the present study. He has been following a LC diet ( $\leq 50$ g of CHO·day<sup>-1</sup> for  $\geq 6$  months) and has been training 4-5 times per week. The athlete was informed about the nature and purpose of the study and voluntarily agreed to participate. All experimental procedures were performed in accordance with the guidelines of the Helsinki declaration and approved by the National Medical Ethics Committee of the Republic of Slovenia (108/08/09).

### Experimental outline

The athlete was tested in the laboratory on three separate occasions. The initial testing session consisted of a graded exercise test to exhaustion to attain the baseline  $\text{VO}_{2\text{peak}}$  value and determine the corresponding training intensities. The following two testing sessions, separated by exactly 14 days comprised of two constant power (CP) exercise tests to volitional exhaustion to determine performance indices during a moderate (65%  $\text{VO}_{2\text{peak}}$ ) and high-intensity (90%  $\text{VO}_{2\text{peak}}$ ) exercise loads. Between the second and the third testing session, the athlete's diet was changed from LC to HC. The athlete was on the HC diet through the 14-day period and maintained the same training levels as during the initial 14 days.

### Diet

As noted earlier the athlete followed a LC diet for at least 6 months prior to the start of the study. The targeted energy intakes throughout the study duration were based on the calculated basal metabolic rate (Mifflin et al., 1990) and multiplied by an appropriate physical activity factor depending on the athlete's daily activity.

### Exercise Training

The athlete performed five training sessions per week on a cycle-ergometer throughout the research period to mimic his habitual training levels. Each training session comprised a 10 minutes warm-up at a self selected load and cadence followed by 40 minutes of cycling at the ventilatory threshold power determined at the initial testing session. The training was not performed for at least 48-hrs before laboratory performance tests to prevent potential residual fatigue affecting the outcomes. Heart rate (HR) was continuously measured during all training sessions using a

portable rate HR monitor (Suunto Ambit 2R, Finland) and the average values for each session were subsequently calculated.

### Graded exercise test

During the initial testing session, the athlete performed a graded exercise test to voluntary exhaustion on a magnetically-controlled cycloergometer Ergo Bike Premium (Daum electronics, Germany). Resting and exercise cardiorespiratory responses were recorded using a metabolic cart (Quark CPET, Cosmed, Italy). The turbine flowmeter and gas analyzer were calibrated before each test using a 3-L syringe and two different gas mixtures, respectively. During the test the athlete breathed through an oro-nasal mask (Vmask, Hans Rudolph, USA). The testing protocol commenced with a 5-min resting period, followed by a 3-min warm up at a 60-W work rate. Thereafter the workload was increased by 30 W·min<sup>-1</sup>. The athlete was allowed to cycle at a self-selected cadence. The test was terminated when the athlete was unable to maintain the cadence > 60 rpm. In addition, a plateau in oxygen uptake and a respiratory exchange ratio (RER) > 1.1 were used to confirm the attainment of the  $\dot{V}O_{2peak}$ .  $\dot{V}O_{2peak}$  was calculated as the highest 10 s average of oxygen uptake ( $\dot{V}O_2$ ) over the course of the test. Ventilatory threshold was graphically determined, using the logarithmic ventilation graph (Gaskill et al., 2001). Two lines were graphed and the intersection between them was defined as ventilatory threshold. The power output at the ventilatory threshold was calculated using the following equation:  $W_{COMPL} + (t/60 \times 30)$ .  $W_{COMPL}$  corresponds to the last workload before intersection and  $t$  corresponds to the number of seconds during the next workload at the graphical intersection.

### Constant power tests

Two CP tests were performed during each testing day on the same cycloergometer as described above. The tests were always performed at the same time of the day and in the same sequence in order to reduce possible effects of circadian variation (Fernandes et al., 2014). The high-intensity CP test was performed first. Subsequently, after a standardized rest ( $\geq 2$ -hr), the moderate-intensity test was performed. Prior to both CP tests, the athlete performed a 10-minute warm-up at 80 W work load followed by an increase in the work load to his individually pre-determined level. The individual absolute work rate corresponded to the work load attained at 65% and 90% of  $\dot{V}O_{2peak}$  measured during the initial graded exercise test. The athlete was instructed to cycle at his own self selected cadence. The failure to maintain a cycling cadence above 60·min<sup>-1</sup>, following an initial verbal warning and strong verbal encouragement resulted in test termination. Time to exhaustion was determined as the number of seconds the athlete was able to maintain the assigned cycling cadence. Minute ventilation ( $\dot{V}_E$ ) and  $\dot{V}O_2$  were recorded continuously using a metabolic cart (Quark CPET, Cosmed, Rome, Italy) that was calibrated as described above. HR was continuously measured throughout the entire test using a portable HR monitor (Suunto Ambit 2R, Finland). Athlete reported his rating of perceived exertion (RPE) using a Borg scale (6-20) (Borg, Borg, Larsson, Letzter, & Sundblad, 2010).

### Blood sampling

Finger capillary blood samples were obtained before, during and after each exercise testing to determine resting, exercise and post-exercise values of glucose (Freestyle, Abbott, USA), ketones (Precision Xtra, Abbott, USA) and lactate (Lactate Plus, Nova Biomedical, USA).

## RESULTS

### Diet

As noted in Table 1, the athlete's intake of carbohydrates during the LC phase was below 50 g·day<sup>-1</sup>, protein intake around 85 g·day<sup>-1</sup> and fat intake around 155 g·day<sup>-1</sup>. During the HC phase the intake of carbohydrates was above 300 g·day<sup>-1</sup> and intake of fats around 37g·day<sup>-1</sup> while the protein intake remained almost the same.

*Table 1:* Energy intakes and macronutrient composition of the athlete's diet during the low carbohydrate (LC) and high carbohydrate (HC) phases.

Diet	Dietary intake (kcal·day <sup>-1</sup> )	Dietary intake (kJ day <sup>-1</sup> )	Protein (g·day <sup>-1</sup> )	Protein %	Fat (g·day <sup>-1</sup> )	Fat %	Carbohydrates (g·day <sup>-1</sup> )	Carbohydrates %
LC	1873±532	7837±2226	86±15	18±9	155±60	74±8	31±8	7±2
HC	1874±108	7841±452	83±8	18±3	37±12	18±5	335±57	64±4

### VO<sub>2peak</sub>

The athletes baseline VO<sub>2peak</sub> was 70 mL·kg<sup>-1</sup>·min<sup>-1</sup>. The estimated power output at 65% VO<sub>2peak</sub> was 190 W and 310 W at 90% VO<sub>2peak</sub>. The calculated power output at the ventilatory threshold was 210 W.

### Training

The average training session HR was lower during the HC period (158 beats·min<sup>-1</sup>) compared to the LC period (162 beats·min<sup>-1</sup>). Athlete also reported slightly lower RPE during the LC compared to the HC training period.

### Time to exhaustion

Times to exhaustion of both CP tests are noted in Figure 1. Time to exhaustion was reduced following the HC period during the moderate-intensity CP test (LC: 72 min; HC: 66 min), whereas it was increased during the high-intensity CP test (LC: 332 s; HC: 340 s).

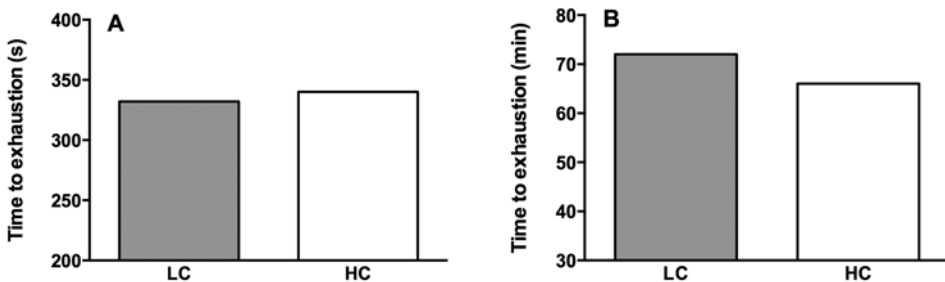


Figure 1. Time to exhaustion following both low carbohydrate (LC) and high carbohydrate (HC) diet during the high-intensity (A, left panel) and moderate-intensity (B, right panel) constant power tests.

### Moderate intensity CP test

Ketone values after the moderate intensity test have only risen following the LC (Pre: 0.3 mmol·L<sup>-1</sup> Post: 0.8 mmol·L<sup>-1</sup>), while the glucose concentration stayed at the same level through the testing after both diet interventions. The average RPE was higher after the HC (17) as compared to LC (15). Lactate concentration was lower throughout the test following the LC as compared to HC diet (Figure 2). The average HR was similar during both diet interventions with 161 beats·min<sup>-1</sup> following the LC and 159 beats·min<sup>-1</sup> following the HC diet. Higher values of  $V_e$  and  $\dot{V}O_2$  were noted throughout the CP tests following the HC diet (Figure 3).

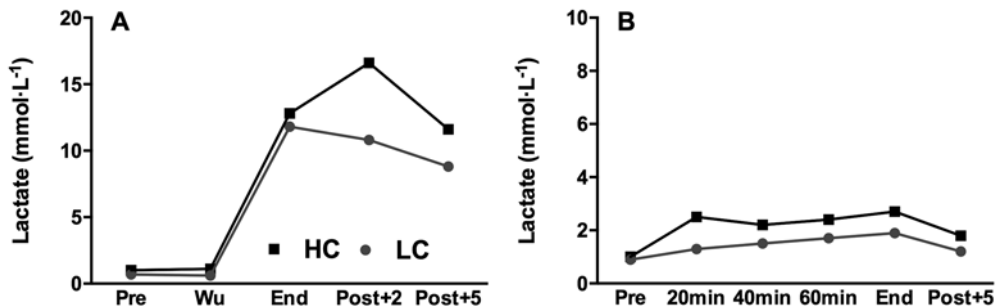


Figure 2. Capillary lactate concentration before (Pre), during (Warm up (WU), 20 min, 40 min, 60 min & End) and after (Post+2, Post+5) the high-intensity (A, left panel) and moderate-intensity (B, right panel) constant power tests following both low carbohydrate (LC) and high carbohydrate (HC) diet.

### High intensity CP test

Ketone values before the high-intensity CP tests were 0.6 mmol·L<sup>-1</sup> for LC and 0 mmol·L<sup>-1</sup> for HC period. Ketone concentration has not changed after the high-intensity testing, being 0.5 mmol·L<sup>-1</sup> and 0.1 mmol·L<sup>-1</sup>, respectively. Glucose concentration has risen after both tests, from 4.6 mmol·L<sup>-1</sup> to 6.3 mmol·L<sup>-1</sup> and 5.1 mmol·L<sup>-1</sup> respectively.

As noted in Figure 2, the most notable changes in the lactate concentration were observed 2 and 5 minutes after the test cessation. There were no differences in the RPE at exhaustion (LC: 18, HC: 18). The average HR was slightly lower following the HC period with 165 beats·min<sup>-1</sup> pm compared to 170 beats·min<sup>-1</sup> following the LC, with peaks at 172 beats·min<sup>-1</sup> and 177 beats·min<sup>-1</sup>, respectively.  $V_e$  and  $\dot{V}O_2$  values were slightly higher following 14-days of HC diet during the latter stages of the CP test (Figure 3).

## DISCUSSION

The results of this case study indicate that the athlete's exercise performance was altered by introducing larger relative amounts of carbohydrates into his daily nutrition. In particular, the high-intensity exercise performance was improved by almost 3%. On the other hand, moderate-intensity performance was worsened by 9%. Interpreting only the time to exhaustion results, we can see that the athlete's ability to perform high-intensity efforts was slightly increased, while the performance of the medium intensity effort was decreased.

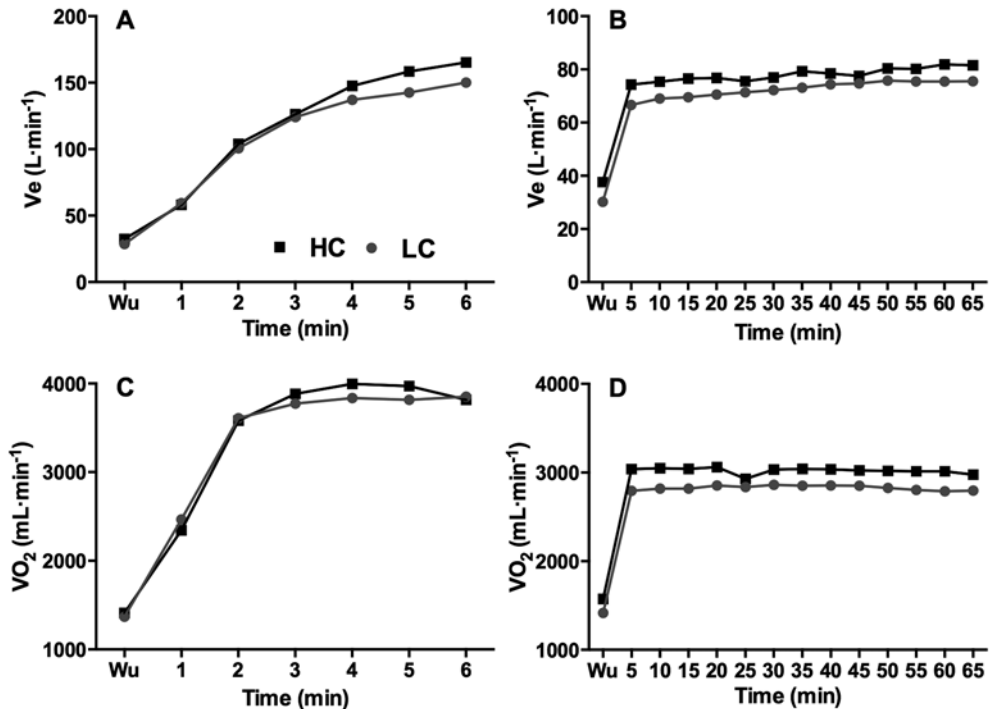


Figure 3. Minute ventilation ( $V_e$ ) and oxygen uptake ( $VO_2$ ) values during the high-intensity (A, C, left panel) and moderate-intensity (B, D, right panel) constant power tests following both low carbohydrate (LC) and high carbohydrate (HC) diet.

There was no difference between the RPE during the high-intensity CP test between both nutritional states and exercising blood lactate concentrations were also very similar. However, the recovery lactate kinetics was higher after the HC, which can indicate two things. Firstly, the difference could be underlined by the change in glycolysis rate and carbohydrate use, which could be explained by the limited carbohydrate stores resulting from a LC diet (Phinney, 2004). Secondly the produced lactate might have been up-taken by other cells at a faster rate during LC. It was previously shown that LC diet induces changes in the mitochondrial density within the cells (Holloszy, 1967), which could provide an explanation for the lower recovery blood lactate concentration observed in the present study. Although we cannot identify which of the above explanations might underlie the observed changes, it is clear that in terms of lactate removal, our athlete showed better results on a LC diet before the HC diet intervention. It could be hypothesized that the higher lactate values during the recovery periods (i.e. slower lactate clearance) might result in slower recovery rates during training sessions following HC as compared to LC.

Conversely to the high-intensity test, the average RPE was 2 units higher after switching from LC to HC during the moderate-intensity CP test. This is in line with the time to exhaustion which has been reduced. Interestingly we did not notice any big differences in blood lactate concentration. When comparing the HR,  $V_e$  and  $VO_2$  data during the moderate-intensity CP test, we can clearly see that following 14-days of HC, the HR values were slightly lower, while  $V_e$

and  $\text{VO}_2$  values were slightly higher, as compared to LC, at the same power outputs across the duration of the trials. This is in line with the athlete's observations of lower training HR while on HC. Interestingly, although carbohydrate metabolism is known to have greater energy yield per unit of  $\text{O}_2$  consumption as fats (approx.  $19 \text{ kJ}\cdot\text{L}^{-1} \text{ O}_2$  for fat vs.  $21 \text{ kJ}\cdot\text{L}^{-1} \text{ O}_2$  for carbohydrate) (Ferrannini, 1988; Maughan & Shirreffs, 2015), the  $\dot{V}_e$  and  $\text{VO}_2$  values were both higher after 14-days of HC diet. Given the above, one would expect that following a LC diet a corresponding increase on fat metabolism reliance (Helge et al., 2001; Phinney et al., 1983), would result in a higher  $\text{O}_2$  demand. Accordingly, the HR,  $\dot{V}_e$  and  $\text{VO}_2$  values would be higher following the LC as opposed to HC diet. However, this was only observed for the HR. Collectively these findings suggest that the cycling economy of the tested athlete was somewhat worsened following a 14-day of HC diet intervention. Moreover, lower blood lactate concentration following the LC could be explained by a lower reliance on carbohydrates as a fuel source and consequently lower rate of glycolysis, known to result in lactate production (Robergs, Ghiasvand, & Parker, 2004).

The obtained results are in contrast to the results of Phinney et al. (1983), who also tested moderate-intensity constant power cycling test to exhaustion ability with the opposite transition from a HC to a LC diet. Our data suggest that reintroducing carbohydrates into the diet results in decreased moderate-intensity endurance performance whereas the data from Phinney (1983) suggest that the removal of carbohydrates for only 14 days did not have detrimental effects on low or moderate-intensity exercise performance. We hypothesize that data comparison shows either that our athlete lost a capacity to metabolize carbohydrates while on LC, or the duration of LC diet plan plays a big role in adapting to fat metabolism.

It is important to note that the tested athlete did not experience any health issues following the change to HC diet. This is in contrast to the transition from HC to LC where many different negative consequences have previously been reported, including decrements in sport performance (Burke & Hawley, 2002; Stepto et al., 2002) and slower regeneration rates (Achten et al., 2004). However, it remains unclear, whether the athlete that switched from LC to HC for a few weeks, could go back to LC without these negative symptoms.

According to our results, the long-term LC adapted athletes could expect to see their high-intensity performance increased as a result of higher relative carbohydrate content diet, whereas slight decrements in moderate-intensity performance (i.e. worsened cycling economy) might occur. Furthermore, our results suggest that the higher fat-oxidation rates gained during LC might not be long-lasting and could be abated after only 14-days of HC diet. The fact that only a few days of LC have been shown to augment the capacity of fat metabolism and furthermore, that this is still present a few days after carbohydrate reintroduction (Lambert, Speechly, Dennis, & Noakes, 1994), suggests that there might be a short time frame, after starting the HC diet, where the fat oxidation is still enhanced while glycogen content already repleted. The data from the tested athlete might therefore suggest that the fat adaptation is acute in nature and could be abated after 14-days of HC.

The limitations of the present case-study also need to be addressed. The data obtained on a single individual obviously need to be advanced by prospective trials employing proper experimental design and sample sizes, as one cannot extrapolate the conclusions of this study to general athletic population. Furthermore, it has to be acknowledged that we only performed one pre testing session per test and a part of the change in time to exhaustion might be explained by the day-to-day performance variability (Currell & Jeukendrup, 2008), although the tests were always performed



at the exact same time of the day, thereby limiting the potential circadian effect (Fernandes et al., 2014). To explore and explain mechanisms behind observed changes, future studies should also, among others, directly assess the muscle glycogen content which has not been measured and would provide valuable information about the changes in the muscles milieu during different dietary transitions.

In conclusion, the results of this case-study suggest that in long-term LC adapted athlete a 14-day transition to HC diet can result in increased high-intensity and a decreased moderate-intensity constant power test performance. Further research is needed to additionally explore the obtained results and especially, to determine the kinetics of the observed changes in regards to acute and prolonged HC diet transitions.

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