CASE STUDY

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The effects of a three-week restricted carbohydrate diet on exercise metabolism and performance of three cyclists

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Abstract

Introduction. Restricted carbohydrate diets (RCDs) have become popular amongst endurance athletes as a means of increasing fat oxidation and improving health outcomes. However, it is unclear if these adaptations improve exercise performance. Aim of Study. This case study investigated the effect of a three-week RCD on exercise metabolism and performance, alongside evaluating the subjective experiences, of three recreational cyclists. Material and Methods. Participants were randomly assigned to the normal diet (ND) (~50% CHO, ~30% fat, ~20% protein) or RCD (10% carbohydrate, 70% fat and 20% protein) and switched diets after three weeks. The participant's performed a weekly laboratory assessment consisting of an incremental, sub-maximal cycling step-test and a 20-minute time trial (TT). Body fat (skinfold) measures were repeated after each diet and the participants recorded their food/drink intake using a smartphone app throughout the study. Results. Whole body peak fat oxidation, measured during sub-maximal cycling, markedly increased during the RCD (ND 0.61 ± 0.1 vs RCD 1.45 ± 0.3 g/min). There was no improvement in average power output during the TT for any participant following the RCD (243 ± 5 W) versus the ND (253 ± 5 W) condition. Two participants experienced a reduction (–8% and –10%) in (∑7) skinfolds following the RCD. The participants' subjective reports indicated an improvement in general dietary habits, but there were reports of increased perceived exertion to exercise during the RCD. Conclusions. The RCD increased whole-body fat oxidation, promoted positive subjective dietary habits and decreased body fat amongst amateur cyclists. However, these outcomes did not translate into improved exercise performance.

KEYWORDS: cycling, nutrition, metabolism.

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Introduction

Restricted CHO diets (RCDs) have become popular amongst endurance athletes as a means of increasing fat oxidation during exercise, thus decreasing CHO oxidation and potentially preventing/delaying glycogen depletion [4, 5, 14, 19, 29]. Emerging evidence also suggests that a short-term RCD, such as training in a fasted/ /low glycogen state, can promote mitochondrial biogenesis [1]. Consequently, RCDs have been hypothesised as a potential means of improving performance [18, 27, 28, 30]. A chronic RCD can substantially increase fat oxidation and simultaneously decrease CHO oxidation during sub-maximal exercise – this is often referred to as becoming 'fat-adapted' [19, 28, 30]. However, when athletes are re-tested at the same absolute work rate (i.e. changes in VO_2max are not accounted for) a period of endurance training itself can increase the contribution of fat to total energy expenditure [12]. Therefore, it is unclear to what extent the changes in metabolism reported during previous studies were related to the RCD intervention, as exercise habits were not closely monitored and standardised [19, 28]. Furthermore, it is uncertain whether the participants in previous RCD studies stringently adhered to the prescribed RCD throughout the intervention, as short-term (3 day) dietary reporting can lack fidelity [16], particularly when traditional dietary assessment methods, such as self-report paper records, are used [25].

The health benefits of RCDs, such as decreased body mass, have been well documented, predominantly amongst overweight/obese individuals [15]. However, it is uncertain if health benefits established amongst untrained populations, coupled with increased fat oxidation, can improve exercise performance, particularly amongst well-trained athletes [9]. Indeed, most RCD studies have not assessed sport/exercise performance outcomes [19, 28, 29]. To address this, and dietary monitoring issues, Burke et al. (2017) investigated the effects of a three week ketogenic diet on metabolism and performance of elite race walkers. All dietary groups (high CHO, periodised CHO and ketogenic) improved aerobic capacity by 3-7%, indicating physiological markers of performance can improve following a RCD. However, in contrast to the other groups, there was no improvement in 10 km race performance (–1.6%) in the ketogenic group [5]. Conversely, McSwiney et al. (2018) reported a 12 week RCD augmented cycling performance, although this study was subject to the aforementioned dietary reporting limitations [17].

A diet must be sustainable for any potential benefits to be realised in the long-term [13]. Thus, any theoretical benefits of RCDs for athletes are immaterial if the diet is unsustainable. Previous studies have not assessed the practical implications and athletes' subjective responses whilst adopting a RCD alongside training and competing [3, 17, 19]. Indeed, very little qualitative literature exists which provides an insight into the practicality of adopting a RCD within athletic populations.

Aim of Study

Investigate the efficacy of adopting a short-term RCD amongst amateur cyclists. This case study also provides

Table 1. Anthropometric characteristics and physiological results

	Participant			
	A	B	C	M ± SD
Age (years)	29	31	41	33.7 ± 6.4
Height (cm)	178.1	176.9	177.6	177.5 ± 0.6
Body mass (kg) ND	71.2	79.2	82.7	77.9 ± 5.6
Body mass (kg) RCD*	72.2	76.65	80.65	76.5 ± 4.2
∑ 7 Skinfolds (mm) ND	41.1	99.6	79.2	73.3 ± 29.7
∑ 7 Skinfolds (mm) RCD*	41.2	89.9	72.8	68 ± 24.7
Training frequency (sessions/week)	4	3-4	5-6	4.3 ± 1
VO_2max (ml/kg/min)	62	46	57	55 ± 8.2
MAP (W)	360	310	410	360 ± 50
LTP (W)	250	175	275	233.3 ± 52
FTP (% VO_2max)	86	76	91	84.3 ± 7.6
Peak fat oxidation (g/min) ND	0.65	0.51	0.67	0.61 ± 0.1
Peak fat oxidation (g/min) RCD*	1.22	1.34	1.8	1.45 ± 0.3
Mean oxygen uptake (ml/kg/min) ND	41.4	30.4	41	37.6 ± 6.2
Mean oxygen uptake (ml/kg/min) RCD*	42.9	34.7	49.6	42.4 ± 7.5
TT mean power (W) ND	269 ± 4	196 ± 1	294 ± 11	253 ± 5
TT mean power (W) RCD*	256 ± 5	195 ± 1	279 ± 10	243 ± 5

* Measured at week 3 of restricted CHO diet (RCD). MAP: maximum aerobic power; LTP: lactate turnpoint (2nd inflection point in blood lactate during step test); Mean oxygen uptake and peak fat oxidation recorded at week 3 of each diet intervention; TT: time trial (20 minutes). TT power values reported as the average (3 tests) during each dietary condition.

a real-life insight into the subjective experiences of endurance athletes unaccustomed to a RCD.

Material and Methods

Three male cyclists volunteered to participate in the case study, which was approved by St Mary's University's Ethics Committee. The physiological and anthropometric characteristics of the participants is presented in Table 1. The criteria for selection were: (1) five years endurance training experience, (2) performing at least three endurance training sessions/ week, (3) no prior experience of a RCD. The participants completed a medical history form and provided written informed consent before commencing the experimental procedures.

Study design

The participants attended a weekly laboratory testing session for seven weeks. The baseline assessment (week 1) consisted of an incremental cycling test, to establish metabolic characteristics during sub-maximal cycling, and a maximal test to establish maximum aerobic power. Participants were randomly assigned to the normal diet (ND) or RCD condition and switched diets after three weeks.

Nutrition plan

Each participant received a nutrition consultation before the intervention and prior to the RCD phase with a registered dietician, experienced in prescribing RCDs. A smartphone dietary tracking app (MyFitnessPal Premium) was used to optimise dietary recording accuracy and adherence [7]. Each participant was familiarised with the app and recorded food/drink intake for five days prior to the baseline tests. Total energy intake (TEI) from this period was used to prescribe the daily TEI throughout the study. The macronutrient composition during week one of the ND phase was matched during weeks 2-3 of the ND phase (Table 2). During the RCD phase the participants were prescribed a CHO intake of 10% of TEI. Each participant received a bespoke, isocaloric plan, which included macronutrient targets and recipe suggestions based on personal preferences. Dietary check-ins were performed every week, whereby the dietary records from each participant was downloaded by the investigator. The participants received email support from the dietician throughout the study.

Exercise training monitoring

Baseline training volume and intensity (load) was measured one week prior to the intervention using GPS devices (Garmin EDGE 1000 and Garmin 920XTt, Garmin, Kansas City, USA) and a recordable heart rate (HR) monitor (Polar RS400, Polar Electro, Oy, Finland). The participants were requested to replicate this weekly training load throughout the study and emailed their weekly training data to the investigator.

Anthropometry

Following height and body mass measures, body composition was assessed using the skinfold technique. Seven sites were measured with skinfold callipers (Harpenden, Baty International, West Sussex) in accordance with the International Society for the Advancement of Kinathropometry guidelines. Anthropometric measures were repeated after each diet.

Sub-maximal cycling assessment

The participants reported to the laboratory following a three hour fast and were requested to avoid strenuous physical activity and abstain from caffeine/alcohol intake 24 hours preceding each visit. Participants completed an incremental (+25 watts) step protocol consisting of four-minute stages on a cycle ergometer (SRM, SRM

Table 2. Dietary record summary

		Normal diet (ND)				Restricted carbohydrate diet (RCD)			
Participant	DRC (%)	TEI (kcal)	Fat (%)	Cho (%)	Pro (%)	TEI (kcal)	Fat (%)	Cho (%)	Pro (%)
A	99	2834 ± 173	14	64	21	2438 ± 376	44	26	30
B	100	2425 ± 162	21	55	25	2062 ± 130	37	24	39
C	90	2345 ± 153	19	61	20	2175 ± 81	38	23	39
M ± SD	96	2535 ± 262	18 ± 3	60 ± 6	22 ± 5	2225 ± 193	39 ± 7	24 ± 9	36 ± 7

TEI: total energy intake; DRC: dietary record compliance (percentage of daily food records fully completed); Cho: carbohydrate; Pro: protein

International, Jülich, Germany). The initial power output was selected (based on the reported training status) to enable the completion of a minimum of five and a maximum of seven stages before 90% HRmax was achieved. All participants completed a minimum of five stages equating to an intensity range of 50-90% VO_2max. Expired (breath-by-breath) gas measurements were recorded throughout the test using a calibrated, open spirometric system (Oxycon Pro, Jaeger, Hoechburg, Germany). Rating of perceived exertion (RPE) was measured using the Borg scale during the final 30 s of each stage.

Post test data analysis

The expired gas data was averaged over 10 s intervals and filtered so that errant breaths lying ± 4 SDs from the local mean were excluded. Oxygen uptake was calculated from the mean VO_2 recorded during the final 60 s of each stage. CHO and fat oxidation were calculated using non-protein RER values.

Maximal cycling assessment

Following a five-minute rest period, the participant performed a maximal ramp (5 W/15 s) protocol on the cycle ergometer. A familiarisation trial of the 20-minute time trial (TT) was performed 15 minutes after the maximal test.

Time trial

The cycle ergometer (Wattbike Pro, Nottingham, UK) was adjusted for each participant and the air resistance setting/cadence range was selected, according to the manufacturer guidelines, to enable the maintenance of a constant cadence and power output throughout the TT. Power data was obscured from the display to reduce pacing strategies and participants were instructed to maintain a consistent cadence and effort throughout the test. Heart rate was recorded throughout and RPE was recorded at four-minute intervals.

Results

Diet and training compliance

The dietary records were completed throughout the intervention (Table 2). The participants were not able to achieve the weekly CHO intake of 10% of TEI (CHO range: 23-26% of TEI). However, this was a substantial (>50%) reduction in CHO compared to the ND condition. The participants were unable to replicate the TEI (set from baseline) during the RCD intervention, with each participant achieving lower (A: –14%, B: –15%, C: –7%) TEI compared to the ND condition. The weekly training loads were similar (±15%) to baseline throughout the intervention. Subjective responses regarding the maintenance of training regimens during the RCD period are presented in Table 3.

Table 3. Subjective experiences prior to, during and after the RCD

Diet preconceptions / motivation
A: I had heard about top cyclists using it as a way to drop weight to improve their performance. *I'm already quite lightweight and was worried it may negatively affect my performance.*
B: I wanted to challenge myself, learn more about nutrition and lose a bit of weight. I was also fascinated by the theory that fat could be a more efficient source of fuel than carbs. *The thought of going without bread, sugar and crisps scared me, but I knew I ate far too many carbs and was really keen to see if I could cut back on them.*
C: Some friends have done it successfully, particularly from the perspective of impact on W/kg; I was motivated more by the potential for weight loss rather than endurance. Interested in reports that people experience sharper mental acuity. *I have a stressful work life and a lifelong fondness for bread and pasta. I always doubted that I'd have the self-discipline to put myself through this, and felt that the need to respect the scientific experiment would give me the rigour I would need.*
Cravings
A: *Chocolate.*
B: Amazed at how much I didn't miss bread and crisps. I also felt fuller up during the day because I was eating things like bacon and eggs for breakfast. *Missed chocolate, which was weird because I didn't really eat a lot of it prior to going RC.*
C: Not as much craving for pasta or rice as I'd imagined. *I missed beer, bread, biscuits. Roast potatoes were tough too.*

Carbohydrate intake
A: Using a calorie tracker has helped me understand how calorie dense some meals are. *I ordered a 3 bean chilli without rice, but (based on MyFitnessPal) I couldn't finish it as it was really high in carbs! Maybe I was a bit naive, but beer is also quite high in carbs as well as calories, so that was off limits unfortunately.* *The lack of convenience was the most difficult part. I'm a bit lazy when preparing breakfast and lunch so usually grab something in the shop. However, where I work there was limited low carb options so I would have to prepare meals the night before. (Eating out) was also an issue as we'd have to figure out somewhere that would have decent low carb options, or I'd just eat at home beforehand to save stress.*
B: Staggered to see the carb count in fruit. I'd been having fruit smoothies for years but I will change that now knowing how many carbs are in fruit. *Bought things like BBQ sauce to flavour up the copious amounts of chicken without checking the label. Things like that tend to have lots of sugar in which sends the carb count skyward. Had to completely rethink my weekly shop which was a hassle. Giving up beer was tough as I have quite a busy social life through the week with work events and at the weekend with friends.*
C: *The hard bit was giving up cake at the coffee stop*, although on my second big ride I didn't stop at all, and found it fine, so perhaps my endurance has increased. *I underestimated the carbohydrate content of some 'healthy' soft drinks, such as a green tea and peach drink, which had a disarming amount of carbs in it. I got caught out by Edamame and legumes too.*
Strategies
A: I've got quite a sweet tooth, especially for chocolate. I got round this by eating 80-90% dark chocolate which fought off the cravings. I also used cocoa nibs in breakfast and cleared out any sugary/sweet foods to avoid temptation.
B: (I used a) device that spiralises a courgette into noodles. I fry them and eat with flavoured chicken or fish all the time now. Also changed my milk to unsweetened almond milk and I stopped drinking instant coffee and only drink the proper stuff now with sweetener instead of sugar. The MyFitnessPal app was invaluable; being able to scan virtually everything made life so much easier in terms of logging and working out what was good and bad.
C: I've found that a good large breakfast sees me through to 1pm without feeling hungry.
Training experiences
A: It (RCD) didn't have a massive impact on my riding.
B: I didn't really notice anything, except during the first lab session.
C: *On my first long ride RC I had a shocker, bonked, despite a big egg and sausage breakfast. That was a real low point. Initially, it felt terrible, as if my HR was spiking higher during the first couple of weeks, increased salt intake perhaps? (I felt that) it was generally a lot harder.* That's improved, or maybe I've just got used to it.
Lab testing experiences
A: *During the submaximal test on low carb the higher wattages felt very difficult, like the legs were empty.* However the FTP test didn't feel much different... maybe I wasn't pushing hard enough.
B: *The first one was terrible. I remember feeling irritable at work, I had a headache and by the time I arrived at the lab I felt ready for bed. I battled through but would be staggered if that wasn't my lowest score of all the tests.* By the following week I felt back to normal.
C: (There was) one great session where I felt a lot stronger. *The first week was tough but the final one was really hard. I struggled and it felt as if I'd lost maybe 10% – I'd been spinning happily at 91-93 RPM in most sessions but in the last I was struggling to keep it above 83-84.*
Overall benefits and plans to continue the RCD
A: I'm definitely going to incorporate some aspects (of RCD) into my life. One of the biggest benefits I found, was that I had very little GI distress. I will vary meals, and have lower carb options, especially if doing low intensity training. I've been pleasantly surprised by some of the benefits and my weight actually remained stable.
B: I don't think I'll change much in terms of meals, but I will be drinking and diving into the office staples of chocolate and cake which I became extremely aware of during the RCD period. At weekends I will probably treat myself. I think the next stage will be for me to maintain it and find the best macronutrient balance and try to hit that on a daily basis.
B: I've got so used to things like this (strategies above) that I'll continue even though I've finished the testing.
C: I will (continue the RCD). I enjoy it, am losing weight and feel sharper. It remains to be seen if it'll work all the time during the summer season. Maybe I'll use it as a strategy to keep my weight in check and then strategically carb dose when I need the power. Maybe I'll be able to do some FTP building work on this regime that will be effective. Either way, I don't want to lose the fat adaptation and I'm really enjoying the food!

Text in italics represents a challenging experience.

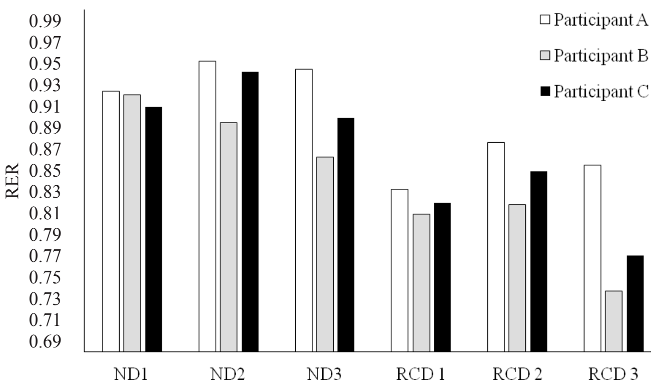
Body composition

Participant B and C experienced a decrease in body and fat mass following the RCD (Table 1).

Metabolism

The participants experienced a decrease (mean –52%) in CHO oxidation and a simultaneous increase (mean +164%) in fat oxidation between the final week of the ND and RCD. Peak rates of fat oxidation also increased during the RCD (Table 1). The mean respiratory exchange ratio (RER) during the sub-maximal cycling decreased for each participant during the RCD (Figure 1).

Figure 1. Respiratory exchange ratio during the sub-maximal step test



ND: normal diet; RCD: restricted carbohydrate diet. The number denotes the week.

Oxygen uptake during sub-maximal cycling

Relative and absolute oxygen uptake increased during the sub-maximal cycling assessment for each participant during the RCD intervention (Table 1).

Time trial performance

There was a trend for average power output to marginally decrease in two participants (A and C) during the RCD condition (Table 1). Participant B was able to maintain a consistent TT performance across the intervention, which corresponds to his subjective responses to the TT (Table 3).

Perceived exertion

The participants in the present study did not report any subjective changes in perception of exertion following the lab tests during the ND condition. However, there were mixed subjective responses to training during the RCD period (Table 3).

Discussion

The results of this pilot study indicate a three week RCD can markedly increase whole body fat oxidation during sub-maximal cycling to similar values reported in previous RCD studies [5, 11, 14, 17]. For example, two of the participants' peak rates of fat oxidation more than doubled during the RCD (Table 1), which is comparable to the values (~1.5 g/min) previously reported amongst cyclists following a six week ketogenic diet, and occurred at almost identical relative exercise intensities [19]. However, the participants' CHO intake in the present study were higher (Table 2) compared to studies that implemented ketogenic diets [5, 17, 19, 28]. These preliminary findings suggest a ketogenic diet may not be necessary to markedly increase rates of fat oxidation during sub-maximal exercise.

Advocates of RCDs propose that athletes can utilise abundant fat stores to provide the required energy to fuel sub-maximal exercise [18]. However, the majority of competitive endurance events require athletes to compete, and often train, at a high percentage of their aerobic capacity, where energy is predominantly derived from CHO fuels [24]. The increases in fat oxidation in the present study did not translate to improvements in high intensity (>75% VO_2max) exercise performance. Indeed, the RCD intervention potentially hindered, rather than enhanced, the performance of two participant's (A and C), which is in accordance with findings from previous RCD studies [5, 14, 10]. Participant B's TT performance remained consistent throughout the RCD intervention, possibly because he performed the TT at a lower relative (76% VO_2max) intensity compared to the other participants (Table 1). Therefore, athletes with a lower training status/level of cardiorespiratory fitness might be able to maintain performance following a RCD compared to athletes with higher levels of fitness.

A number of mechanisms could explain why an increased capacity to oxidise fat does not translate into improved exercise performance following a RCD. For instance, a shift from CHO to fat oxidation (fat adaptation) increases oxygen uptake during sub-maximal exercise, due to the increased oxygen cost of ATP production from lipid vs. CHO fuels [5]. Indeed, in the present study, there was a trend of for the mean oxygen uptake to increase during the RCD period, which could have reduced ATP production from the available oxygen supply during the TT. It is also probable that the enhanced fat oxidation did not influence performance, as the energy demands of the TT could not be met through lipid metabolism. This is possibly due to decreased blood flow to adipose tissue, decreased release of FFAs into the plasma and decreased delivery of FFAs to skeletal muscle at higher exercise intensities [21]. Additionally, metabolic adaptations, such as a reduction in key enzymes involved in skeletal muscle CHO metabolism, can downregulate CHO oxidation following a RCD [23]. However, it is not evident whether the type of RCD used in the present study would elicit this type of metabolic permutation.

The participants lower TEI was likely due to the reduced sensations of appetite during the RCD period (Table 3), which is consistent with previous literature [20]. However, it is unclear whether the reductions in appetite and subsequent energy deficit were related to CHO restriction or increased dietary fat/protein intake during the RCD period (Table 2). Following a RCD, most of the total energy demand during low to moderate-intensity exercise can be met through the oxidation of lipids [28]. Therefore, proponents of RCD for athletes suggest that 'fat adapted' athletes can perform sustained periods of moderate-intensity exercise without the need for CHO ingestion [18]. However, athletes adopting a RCD who avoid CHO ingestion during prolonged exercise could exasperate an energy deficit and reduce energy availability (EA), which may cause physiological complications and performance decrements [26]. A possible solution to this issue is to ingest lipid/protein-based foods during exercise. However, this can cause gastrointestinal distress [8]. Thus, athletes and practitioners should be mindful of these fuelling issues when combining a RCD and long-durations of exercise without CHO ingestion.

There are occasions where a reduction in body fat is sought in order to improve power-weight ratio and/or to achieve specific body mass targets in weight category sports. A common reported effect of a long-term RCD is a reduction in body/fat mass [2]. Indeed, body fat decreased in two participants (A & C) in the present study following the RCD, which was likely due to the reduced TEI during the RCD condition [15]. Body fat remained unchanged in the participant with the lowest (8.8%) baseline level of body fat, which suggests athletes with low (~10%) levels of body fat should adopt caution when implementing a RCD, as the approach may not yield body composition or performance benefits.

Undertaking a three-day high fat RCD has been demonstrated to significantly increase RPE during high intensity cycling [22]; however, it could be contended that a three-day period is insufficient to become 'fat adapted' [27, 28]. The participants' average RPE during the TT was similar during the ND (17 ± 0.7) and RCD (17.4 ± 0.6) conditions. Participant B reported discomfort during the first week of the RCD, but was 'back to normal' following this. The participants were able to maintain their sub-maximal training regimens during the RCD period. However, participant C felt that his performance suffered during the first week of the RCD, but the other participants did not report any negative experiences during training (Table 3). Conversely, all of the participants reported at least one negative experience during the lab tests during the RCD period. For example, participant C found the lab tests more challenging during week one and three of the RCD (Table 3).

The RCD intervention improved the athletes' awareness of the composition and energy density of different foods and also improved general nutrition habits, such as avoiding energy dense snacks. The positive nutritional habits and subsequent reduction in body fat indicate why a RCD approach is becoming increasingly popular amongst the general population and recreational athletes. It is conceivable that health benefits, such as reduced body fat, may improve performance outcomes amongst recreational athletes, although this was not demonstrated in the present case study.

Conclusions

The results of this case study indicate a three-week RCD, where CHO is restricted to ~25% TEI, markedly increases fat oxidation during sub-maximal exercise, promotes positive dietary habits and can also decrease body fat amongst recreational endurance athletes. However, these outcomes did not translate into improved exercise performance. Athletes considering adopting a RCD should proceed with caution, particularly if their sport involves periods of high-intensity (>75% VO_2max) exercise, as a chronic RCD does not appear to enhance performance and, in some cases, could be counterproductive.

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