ORIGINAL ARTICLE

Caloric restriction improves perceived exertion while conserving immunity, fatigue, inflammation, and physical performance in male professional soccer players: A controlled randomized trial

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ABSTRACT

Purpose: In athletes, caloric restriction (CR) improves physiological mechanisms, although its effects on professional soccer players are unclear. This study aims to evaluate the effects of CR on physical performance, fatigue, and inflammation in male professional soccer players compared with a no-restriction diet. Methods: This was a controlled, randomized, parallel-group study with 28 participants. The experimental group received a CR diet (−25% of recommended energy intake; mean caloric intake: 2650 kcal/d). Controls received a normal caloric (NC) diet (mean caloric intake: 3500 kcal/d). Both groups received a protein supplement. Six weeks of intervention were followed by 6 weeks without intervention. Thereafter, the participants were allowed to eat ad libitum. The study evaluated leukocytes, lymphocytes, creatine phosphokinase (CPK), urea, testosterone, lactate dehydrogenase (LDH), rate of perceived exertion (RPE), countermovement-jump (CMJ), and squat jump (SJ). Results: Average age was 27.6 ± 4.4 years. After 6 and 12 weeks, differences between the two groups were insignificant in terms of the immune response, fatigue (CPK, urea, testosterone, and cortisol), and inflammation (LDH) ($p > .05$). The CR group had lower RPE levels at 12 weeks (0.01 vs. 0.62 points; $p = .001$) than the NC group. Conclusion: CR is an effective intervention for male professional soccer players, because it decreased RPE while preserving biochemical parameters.

Keywords: Sport medicine, Immune response, Biochemical parameters, High performance, Elite sport, Caloric restriction, Fatigue.

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INTRODUCTION

Soccer is characterized by a diversity of movements and muscle contractions. These factors comprise physiological mechanisms to enhance exercise adaptation and recovery after workouts and optimize physical performance. Compared to other disciplines, soccer generates a significant impact on the biomarkers of muscle damage, inflammation, and fatigue. These factors are directly related to physical performance (Berriel et al., 2020; Khaitin et al., 2021; Silva et al., 2018; Souglis et al., 2015). Athletes aim to enhance their performance and optimize their movement efficiency (Pons et al., 2018). Caloric restriction (CR) is highly effective in accomplishing these objectives. CR restricted dietary energy intake while maintaining nutrient supply to achieve optimal nutrition and avoid malnutrition (Most & Redman, 2020; Rhoads & Anderson, 2022). CR extended lifespan and minimized disease risk (Golbidi et al., 2017). Combined with physical exercise, CR enhance the inflammatory response (Calbet et al., 2017; Hector & Phillips, 2018; Liu et al., 2021).

CR triggered biochemical processes, such as stress pathways, autophagy, reduction of advanced glycation end-products, and hormonal changes, to positively impact physical exercise (Golbidi et al., 2017; Green et al., 2022; Madeo et al., 2019). Mild and moderate CR decreased glucose supply and increased fatty acid oxidation, which are required to provide the ATP demand (Lee & Dixit, 2020; Most & Redman, 2020). These mechanisms are akin to those that occur during exercise (McGee & Hargreaves, 2020; Murphy et al., 2020; Travers et al., 2022) and induce metabolic adaptation with direct benefits for athletes, for example, increased mitochondrial energy efficiency, decreased oxidative damage to tissues, reduced leptin levels, reduced insulin resistance, and decreased energy expenditure during physical activity as a result of increased movement economy (Aragon et al., 2017; Most & Redman, 2020; J. Peos et al., 2019; Pons et al., 2018).

The benefits of CR on the immune response and physical performance have been scarcely investigated in athletes (Zouhal et al., 2020). A squash player who followed a 6-week structured resistance training regimen and moderate energy-restricted diet (70%–78% of estimated energy requirement) showed increased physical performance (Rosimus, 2018). In 12 male athletes who followed a CR of 30%–40% over 6 weeks had decreased blood lactate and decreased heart rate and maintained running rate (Pons et al., 2018). To our knowledge, only two studies have evaluated the effect of CR in professional soccer players (Hammouda et al., 2013). In one trial, 15 male professional soccer players who fasted for 4 weeks with a CR of ~20%. At the end of the intervention, the soccer players showed improved physical performance and decreased heart rate (Hammouda et al., 2013). The second study found similar results in a group of female soccer players (García-Morales et al., 2019).

A combination of exercise and CR could enhance performance and mitigate the inflammatory response in soccer players. However, evidence supporting the effectiveness of CR is scarce and caution is advised before endorsing it as standard practice for soccer players. To address this, a randomized trial was conducted to evaluate the effect of −25% of CR on physical performance, fatigue, and inflammatory response in a sample of male professional soccer players.

MATERIALS AND METHODS

Study design

A randomized, controlled, parallel-group, 1:1 assignment trial was conducted. The experimental group received a calorie-restricted diet (CR group), whereas the control group received a normal caloric diet (NC group). During the study, all players were encouraged to maintain their regular training program (8 h of training/week) without any changes across the competitive season. The measurements were taken at

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baseline, at 6 weeks, and at the following 6 weeks without dietary interventions and *ad libitum* dietary intake. Primary outcomes included changes in biochemical parameters, physical performance, and perceived effort. This report follows the recommendations of the Proper Reporting of Evidence in Sport and Exercise Nutrition Trials -PRESENT- statement (Betts et al., 2020).

Ethics disclosure

The study followed ethical research practices and received approval from the research ethics committee at the [Anonymous institution for peer review] (CEI 100-1873) on June 21, 2019. The study adhered to the guidelines set forth in the Declaration of Helsinki for the use of human participants in research. All participants read and signed the informed consent document.

Participants

The sample size was estimated for the difference of independent means at the end of the intervention, considering a Confidence Interval of 95%, Power of 80%, Sample Size Ratio 1 and difference of 2 kg. The calculated total sample size was 20 subjects. The players were randomly assigned to the CR and NC groups, with equal distribution of players across various game positions, including goalkeeper, central defence, wing defence, midfielders, forwards, and outside midfielders. The players were not informed about the group they would be assigned to during assignment. During the study, four players withdrew from participation: two due to injuries and two due to team changes (Figure 1).

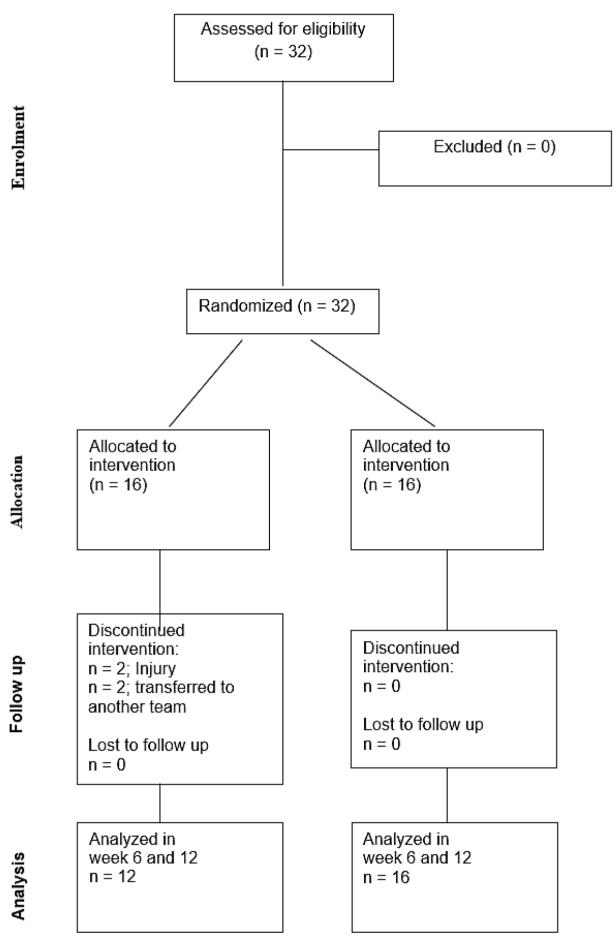

Figure 1. Flow of participants through each stage of the trial.

A total of 32 male professional soccer players from a professional division team soccer participated in this study. Exclusion criteria included players 1) with metabolic diseases, such as cardiovascular, respiratory, gastrointestinal, and thyroid-related; 2) with weight change of ±2 kg in the last month; 3) following special diets (e.g., vegetarian), 4) consuming nutritional supplements in the last month; 5) using medications to control lipids or blood glucose; 6) not complying with all the measurements (physical, physiological, nutritional, and laboratory evaluations), and 7) missing >5% of the scheduled training sessions.

Dietary intervention

Recommended energy intake (REI) was estimated by calculating resting metabolic rate using the Cunningham formula, multiplied by a factor of daily physical activity (rest days) of 1.25, and adding energy expenditure per training/competition days (5 METS -Metabolic Equivalent of Task- for training and 9 METS for competition) (Tinsley et al., 2019). Average REI was 3500 kcal/d for the NC group and 2650 kcal/d for the CR group (reaching a restriction of −25%) (Jagim et al., 2018; Thomas et al., 2016). In order to safeguard the athlete's body composition and performance, this restriction has been implemented (Aragon et al., 2017).

All players were provided with a specific dietary plan, comprising a high-protein, normal-fat, and carbohydrate adjusted diet. The diet was designed to be low in saturated fat and free of trans fats. The players were encouraged to consume polyunsaturated and monounsaturated fats. Carbohydrate intake was adjusted to meet the requirements of each player. The diet excluded added simple sugars. In both groups, macronutrient distribution was 18%–22% protein (1.9–2 g/kg), 22% fat (1 g/kg), and 56%–60% carbohydrate (5–7 g/kg) (Collins et al., 2021; Keen, 2018). During the study, every participant was given a whey protein supplement daily. This supplement was carbohydrate- and fat-free isolate. The participants were instructed to consume 25 g of protein after their morning workout and 12.5 g in the evening (Collins et al., 2021; Keen, 2018).

All players followed a food plan that was calculated and prescribed for them while they were at the training camp and at home. To monitor their diet, a standard menu and diet referrals were prescribed, which were based on energy and nutrient calculations for each group. To assess adherence to the prescribed diet, a dietary assessment was conducted.

Dietary assessment and adherence

Dietary assessment was conducted at the beginning and at 6 and 12 weeks of follow-up. The dietary interview was conducted by a trained nutritionist. Two methods were used to assess dietary intake: 24-h recall and food frequency questionnaire (Bailey, 2021; Salvador Castell, 2015). Artificial food models, measuring cups, and spoons were used to measure food consumed. Mealtimes were directly observed before the interview to ensure accurate information was given. The two methods considered the food types typically eaten; frequency of consumption (daily, weekly, biweekly, or monthly); time of consumption; amount consumed; food preparation method; possible substitutes used; and special characteristics, such as reduced calorie content, low-fat options, vitamin-fortified choices, or high fibre content. Local food composition tables were used for dietary analysis.

Biochemical parameters

During the initial stage of the study, a range of nutritional blood biomarkers were measured to evaluate nutritional status. These included haemoglobin, haematocrit, leukocytes, lymphocytes, ferritin, total protein, albumin, and globulin. Markers of fatigue (creatine phosphokinase [CPK], urea, and total testosterone) and inflammatory response (cortisol and lactate dehydrogenase [LDH]) were assessed at the baseline and follow-up stages. All blood samples were collected in the morning after an 8-h fast with no prior exercise. The samples were processed on the day of collection at a reliable clinical laboratory.

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Physical test
The length of vertical jump capacity was used to estimate physical performance, incorporating jump without impulse (squat jump [SJ]) and countermovement-jump (CMJ) tests. Jumps used the "*AXON JUMP*" platform. These tests were performed in the morning, with a prior sleep period of at least 7 h, usual breakfast consumption, room temperature of 24–26 ºC, and humidity between 70%–72%. The tests were performed by a specialized sports doctor and the medical staff of the soccer team.

Perceived exertion test
The evaluation of psychological perception of effort was quantified using the Borg test (rate of perceived exertion [RPE], scale 1–10). The test was administered by a specialized sports doctor and researchers and performed during the first week of training, at baseline, and at follow-up stages, on three alternate days, and after the morning training session. Values were means of the measures in 1 week.

Statistical analysis
Categorical variables were described by frequencies and percentages. Quantitative variables were described by mean and standard deviation. Normal Gaussian distribution of data was verified by the Shapiro–Wilk test. An independent samples *t*-test, the *U* Mann–Whitney test, or χ^2 test, were used to examine differences between groups (CR and NC).

Changes within each group were assessed by comparing follow-up measurements at 6 and 12 weeks. To account for multiple comparisons, Bonferroni's adjustments were applied and all differences were considered statistically significant at $p < .002$. Stata V.14 was used for statistical analysis.

RESULTS

The study enrolled 28 male professional soccer players (average age: 27.6 ± 4.4 years). At baseline, the CR and NC groups showed similar values of nutritional status biomarkers (Table 1).

Table 1. Baseline description of 28 male professional soccer players.

Variable	**Caloric restriction Group**	**Normal diet Group**	***p*-value**
	n = 12	n = 16	
Age, years ◊	27.8 (4.4)	27.5 (4.6)	.86
Position: ƒ			
Goalkeeper	1 (8.3)	1 (6.3)	
Centre back	2 (16.7)	2 (12.5)	
Wing back	2 (16.7)	2 (12.5)	
Centre	4 (33.3)	5 (31.3)	
Winger	3 (25.0)	6 (37.5)	
Nutritional biomarkers ƒ			
Haemoglobin (g/dL)	15.0 (0.8)	14.9 (0.9)	.949
Haematocrit (%)	45.3 (2.6)	46.1 (2.7)	.443
Ferritin (ng/mL)	163.5 (69.4)	158.1 (58)	.837
Total proteins (g/dL)	7.0 (0.4)	7.1 (0.6)	.454
Albumin (g/dL)	4.2 (0.3)	4.3 (0.4)	.413
Globulins (g/dL)	2.7 (0.5)	2.8 (0.4)	.879

Note. ◊ Values are presented as mean ± SD (standard deviation). ƒ Values are presented as frequency and percentage respect to the intervention.

During the first 6 weeks, the CR group followed the interventions with great adherence ($p < .001$), which were maintained during the 12-week study ($p < .001$). The NC group displayed a significant increase in kcal, protein, and carbohydrate intake during the 12-week study ($p < .001$) (Table 2).

Table 2. Nutritional intake and intervention adherence at baseline and 6 and 12 weeks of follow-up.

Variable	**Caloric restriction Group**	**Normal diet Group**	***p*-value**
	n = 12	**n = 16**	
Calorie intake (kcal/kg/d)			
Baseline	41.0 (4.0)	41.5 (4.0)	.6258
6 weeks	30.3 (3.7)	46.9 (4.0)	**.0001**
12 weeks	33.4 (4.4)	45.6 (4.3)	**.0001**
Protein intake (g/kg/d)			
Baseline	2.1 (0.3)	2.1 (0.3)	.9254
6 weeks	2.1 (0.3)	2.5 (0.2)	**.0012**
12 weeks	2.3 (0.3)	2.6 (0.2)	**.0001**
Fat intake (g/kg/d)			
Baseline	1.0 (0.1)	1.0 (0.1)	.885
6 weeks	0.8 (0.2)	1.1 (0.1)	**.0003**
12 weeks	1.0 (0.2)	1.1 (0.1)	.0621
Carbohydrate intake (g/kg/d)			
Baseline	6.1 (0.7)	6.0 (0.7)	.608
6 weeks	3.5 (0.5)	6.7 (0.7)	**.0001**
12 weeks	4.0 (0.5)	6.4 (0.8)	**.0001**

Note. Values are presented as mean ± SD (standard deviation). p values in bold are statistically significant at p < .002.

Table 3. The immune response and changes in fatigue in 28 male professional soccer players at baseline and 6 and 12 weeks of follow-up.

Variables	**Caloric restriction Group**	**Normal diet Group**	***p*-value**
	n = 12	**n = 16**	
Immune response			
Leukocytes, # Cells			
Baseline	5298 (1280)	5513 (1316)	.412
Change 6 weeks	579 (2380)	−0.6 (1907)	.48
Change 12 weeks	−8 (2024)	385 (2137)	.681
Lymphocytes, # Cells			
Baseline	2391 (449)	2451 (570)	.774
Change 6 weeks	−94 (662)	−339 (650)	.35
Change 12 weeks	443 (513)	198 (573)	.273
Fatigue			
Creatine kinase, U/L:			
Baseline	290.3 (110.0)	365.6 (263.5)	.926
Change 6 weeks	−45.2 (143.1)	−44.3 (225.3)	.39
Change 12 weeks	56.1 (206.6)	25.4 (250)	.732
Creatine kinase, U/L/kg:			
Baseline	3.8 (1.4)	4.9 (3.4)	.71
Change 6 weeks	−0.59 (1.8)	−0.61 (2.84)	.403
Change 12 weeks	0.72 (2.74)	0.44 (3.37)	.815
Urea, mg/dL:			
Baseline	40.6 (6.9)	38.6 (9.1)	.559
Change 6 weeks	−5.9 (4.7)	−6.3 (7.2)	.849
Change 12 weeks	−1.8 (13.5)	0.5 (6.3)	.591
Testosterone, pg/mL:			
Baseline	6.5 (2.2)	6.8 (1.9)	.458
Change 6 weeks	−1.61 (2.08)	−1.33 (1.58)	.687
Change 12 weeks	2.0 (0.94)	1.18 (1.91)	.202
Cortisol, µg/dL:			
Baseline	12.8 (3.5)	12.9 (2.0)	.902
Change 6 weeks	3.4 (5.0)	4.6 (4.8)	.626
Change 12 weeks	0.3 (6.4)	0.5 (4.4)	.925

Note. Values are presented as mean ± SD (standard deviation). p values in bold are statistically significant at p < .002.

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Immune response

The CR group did not experience significant changes ($p > .5$) in leukocyte and lymphocyte counts at the 6- and 12-week marks. The NC group displayed similar immune blood marker results ($p > .5$). These parameters had comparable values between both groups ($p > .5$) (Table 3).

Fatigue and inflammatory response

After 6 weeks, the CR and NC groups showed a decrease in CPK, urea, and testosterone ($p < .05$). After 12 weeks, only CPK and testosterone returned to baseline values ($p > .05$), whereas urea continued to decrease ($p < .05$). Fatigue biomarkers showed no significant differences between both groups ($p > 0.1$) and remained consistent during the study (Table 3). Both groups showed similar alterations in LDH values ($p > .4$), increasing at 6 weeks and decreasing at 12 weeks ($p = .443$).

Physical performance

CR and NC groups exhibited similar changes in SJ and CMJ performance. RPE decreased at 6 weeks but maintained low results only in the CR group ($p = .001$) (Table 4).

Table 4. The changes in physical performance and exertion in 28 male professional soccer players at baseline and 6 and 12 weeks of follow-up.

	Caloric restriction Group	**Normal diet Group**	***p*-value**
	n = 12	**n = 16**	
SJ, cm			
Baseline	38.4 (4.4)	37.0 (3.1)	.327
Change 6 weeks	1.4 (2.2)	1.9 (2.9)	.485
Change 12 weeks	0.3 (2.7)	−0.5 (2.5)	.296
CMJ, cm			
Baseline	41.5 (4.6)	41.4 (4.1)	.946
Change 6 weeks	1.9 (1.5)	1.3 (3.4)	.574
Change 12 weeks	−0.8 (1.5)	0.9 (2.5)	.072
PEr, points			
Baseline	7.9 (0.6)	7.2 (0.6)	.006
Change 6 weeks	−0.51 (0.45)	−0.52 (0.75)	.962
Change 12 weeks	0.01 (0.43)	0.62 (0.41)	**.001**

Note. Values are presented as mean ± SD (standard deviation). p values in bold are statistically significant at p < 0.002. SJ: Squat jump; CMJ: Countermovement jump; PEr: Perceived exertion rating.

DISCUSSION

Because athletes strive to improve performance, incorporating dietary interventions can be highly beneficial. We found that implementing CR can have a positive impact on professional soccer players. Our findings suggest that CR reduced perceived exertion and maintained normal immunity, fatigue, and inflammation.

Immunity and inflammatory response

During exercise, post-training, and resting, high-intensity physical exercise or competition triggered a proinflammatory response (Contrepois et al., 2020; Scheffer & Latini, 2020). However, the inflammatory response is a defence mechanism to protect athletes against infection or injury by localizing and eliminating the harmful agent and removing damaged tissue components to facilitate healing (Scheffer & Latini, 2020; Wang et al., 2020). Regular exercise had an anti-inflammatory effect, because leukocyte and lymphocyte counts decreased during exercise (Wang et al., 2020). Our study highlights that both groups had similar findings. However, CR regulated the immune response and improved the performance of immune cells (Lee & Dixit, 2020; Okawa et al., 2021). Thus, our findings show that CR does not alter the immune response.

The impact of CR on the immune response in athletes remains unclear. Studies have evaluated CR in non-athletes, where sustained −25% of CR for 2 years induced a notable reduction in white blood cells (Meydani et al., 2016). Other studies using energy restriction in amateur athletes for 20 weeks found a reduction of lymphocytes and an increase of white blood cells (Sarin et al., 2019). However, our investigation yields novel insights, underscoring that short-term CR regimens do not significantly affect white blood cell count, suggesting that immune parameters remain relatively unaffected in the context of brief CR episodes. These findings advance our understanding of the nuanced relationship between CR and immune function. Particularly, 6 weeks of CR could be a promising intervention to enhance the immune response in male professional soccer players and should be further investigated.

LDH is a blood biomarker of the inflammatory response and its concentration depends on the relative equilibrium between glycolytic rate, O_2, mitochondria muscle density, pyruvate metabolism, and NADH (Glancy et al., 2021). This correlation explains the peaks of LDH concentration after high-intensity exercise (Glancy et al., 2021) and maintenance of high concentration after exercise for a few days in the resting stage, as observed in soccer players without dietary intervention (Mohr et al., 2016; Silva et al., 2018; Souglis et al., 2015; Xin & Eshaghi, 2021). Our findings show a similarity in LDH concentrations between both groups, highlighting that LDH concentrations remain unchanged by CR.

Fatigue

Testosterone is an anabolic–androgenic steroid hormone that has multiple functions in regulating muscle mass, bone mass, and nervous system (Gharahdaghi et al., 2021). At the onset of physical activity, testosterone levels surge and then stabilize to baseline levels. Actual evidence indicates that testosterone levels remain largely unaffected by exercise (Gharahdaghi et al., 2021). Consistently, our findings indicate that testosterone homeostasis remains unchanged by CR. This has been corroborated in other studies with different dietary interventions and sport disciplines (Huovinen et al., 2015; J. J. Peos, Helms, Fournier, Ong, et al., 2021; Vidić et al., 2021).

Blood cortisol is conditioned by the intensity and duration of physical exercise (Scheffer & Latini, 2020). Cortisol increases during exercise and returns to baseline levels in the recovery period, corresponding to the bioenergetics process (Contrepois et al., 2020; Souglis et al., 2015). After long-term exercise, cortisol regulates the immune response (Scheffer & Latini, 2020; Wang et al., 2020). These metabolic changes could explain the uniformity of immune response in both groups in this study. Uniformity of cortisol balance was similar to other studies in jumpers, sprinters (Huovinen et al., 2015), and soccer players (Souglis et al., 2015). However, cortisol results differ from studies in Judo (Abedelmalek et al., 2015) and male weightlifter (Longland et al., 2016). These discrepancies are due to the direct relationship between cortisol level, body composition, and muscle mass (Calbet et al., 2017; Longland et al., 2016).

Studies in male soccer players without nutritional intervention (Field et al., 2023; Marqués-Jiménez et al., 2022; Peres et al., 2022; Souglis et al., 2015) found that urea plasma concentrations increased immediately after exercise due to decreased urea urinary excretion, increased muscle catabolism, and protein turnover. After 24–72 h, plasma urea values recover to baseline values of pre-match or pre-exercise (Field et al., 2023; Marqués-Jiménez et al., 2022; Souglis et al., 2015). Our findings signal a decrease in urea levels in CR and NC groups. These variations between studies could be due to differences in training session and inter-day, inter-week, season, position, and inter- and intra-individual variability of biomarkers (Alshuwaier et al., 2022; Becker et al., 2020; Nowakowska et al., 2019). In addition, urea recovery values can be a manifestation of protein metabolism adaptation and an indicator of recovery from fatigue (Marqués-Jiménez et al., 2022;

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Nowakowska et al., 2019; Skorski et al., 2022). Therefore, our results reflect optimal recuperation of participants and preservation of physiological mechanism during recovery.

CPK is responsible for generating ATP, creatine for muscle contraction, and other energy-demanding processes (Silva et al., 2018). After exercise, the total serum activity of CPK increased and peaked at the end of exercise, and then decreased in the following 72 h (Silva et al., 2018). In this study, CPK decreased at 6 weeks and recovered to baseline values at 12 weeks. This was also observed in male volleyball athletes and football players after official matches (Barros et al., 2017; Berriel et al., 2020; Khaitin et al., 2021).

Physical performance

CMJ and SJ are reliable measures for power, strength, and speed in soccer (Nuñez et al., 2021; Rodríguez-Rosell et al., 2017). Our results indicated that CR, like NC, improved physical performance due to CR-induced physiological adaptations. *In vivo* studies have shown that CR can increase the quality and number of mitochondria in skeletal muscle, resulting in improved energy efficiency and physical performance (Chen et al., 2015; Kitaoka et al., 2016; Shirai et al., 2021). Other studies have demonstrated that CR can increase energy efficiency and physical performance after just 1 month of taekwondo and athletics (Capó et al., 2020; Pons et al., 2018). Overall, our results suggest that CR has a positive effect on physical performance through biological adaptations induced by CR.

Perceived exertion

Perceived exertion is a surrogate indicator to monitoring training load (Djaoui et al., 2017). The effect of dietary interventions on RPE in athletes has been scarcely studied. Our results agree with a study in which 10 competitive cyclists who completed a protocol of 3 weeks of CR (−40%) had significantly lower RPE after CR (Ferguson et al., 2009).

Final considerations

Despite the benefits of CR on physical performance, fatigue, inflammation, and immunity we recognized key aspects of implementing CR. Moderate and severe CR could decline cognitive behaviour and memory due to decreased blood glucose (Cherif et al., 2016; Zouhal et al., 2020). In players undergoing CR, short intervals to stop intervention or “*diet breaks*” are advisable. This strategy will allow for increased mental focus, decreased irritability, and increased sensation of fullness (J. J. Peos, Helms, Fournier, Krieger, et al., 2021).

Unplanned or severe CR can cause deficiency of essential nutrients, such as vitamins, minerals, amino acids, and fatty acids (Pons et al., 2018), which can negatively impact the physical performance and health of athletes (Pons et al., 2018). Moderate or severe CR (>30% with respect to REI) can negatively impact the metabolic, endocrine, cardiovascular, and muscular systems (Antonio Paoli et al., 2021; Ito et al., 2023; Thomas et al., 2016; Turocy et al., 2011). Therefore, CR should always be slightly limited (20%–30% of REI) and carefully planned to maximize its positive effects and avoid undesirable consequences (Pons et al., 2018; Thomas et al., 2016). In this study, a structured dietary plan was implemented to control for these aspects. We encourage researchers to monitor potential alterations.

Limitations and strengths

The principal strength of this study was that it investigated the effects of CR (−25% of REI) on elite male professional soccer players. This study has three limitations. First, sports performance in elite athletes could be influenced by other dietary factors that were not considered, for example, gut microbiota and caffeine intake (Guest et al., 2021; Marttinen et al., 2020). Second, our results were obtained during a CR of −25% REI; therefore, other degrees of CR could obtain different results. Third, although all players were encouraged to maintain their regular training program, physical activity was not controlled, making it difficult to compare the exercise level in future studies.

CONCLUSIONS

Our research has shown that implementing CR, 25% less than the REI, can be a suitable intervention for male professional soccer players to reduce perceived exertion. This intervention did not change biochemical parameters, such as cortisol, testosterone, urea, immune, or inflammatory response. To avoid cognitive decline, physical damage, and nutritional deficiencies, it is advisable to implement CR through a structured diet, diet breaks, and supervision. Studies should evaluate the combined effect of mild and moderate CR with other dietary factors.

AUTHOR CONTRIBUTIONS

Conceptualization, G. G., A. N., J. D .C., and C. T. G.; Data curation, G. G.; Formal analysis, G. D., and G. G.; Funding acquisition, G. G. Investigation, G. G., and A. N.; Methodology, G. G., J. D. C., and C. T. G. Project administration, G. G., and A. N. Resources, G. G.; Supervision, G. G., J. D. C., and C. T. G.; Validation, G. G.; Analysis, G. D., and G. G. Visualization, G. D. Writing – original draft, G. G. and G. D.; Writing – review & editing, all authors.

SUPPORTING AGENCIES

No funding agencies were reported by the authors.

DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

ETHICS APPROVAL

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. The study followed ethical research practices and received approval from the research ethics committee at the Universidad Autónoma de Madrid (Autonomous University of Madrid) (CEI 100-1873) on June 21, 2019.

CONSENT TO PARTICIPATE

Informed consent was obtained from all individual participants included in the study.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author, [GG], upon reasonable request.

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