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Energy Deficiency and Nutrition in Endurance Sports – Focus on Rowing

Energiemangel und Ernährung im Ausdauersport: Fokus Rudern

REVIEW

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Summary

- **Athletes** and particularly endurance athletes, such as rowers, expend considerably more energy than their sedentary counterparts, which increases their risk of failing to match these elevated requirements through their diet. Contrary to textbook knowledge, the resulting state of energy deficiency does not necessarily lead to weight loss, as metabolic adaptations can conserve energy to return to energy balance at a lower set-point.
- The purpose of this mini-review was to focus on energy deficiency in endurance athletes, with special reference to the sport of rowing. A secondary purpose was to present practical approaches for the detection of energy-deficient athletes and strategies to alleviate some of the effects detrimental to athletic performance.
- **We present an approach** of combining indirect calorimetry and advanced imaging to quantify reductions in resting metabolic rate, which can be reduced by as much as 10% in energy-deficient athletes and has been linked to performance impairments. While dietary treatment should be the first approach in these cases, there are situations in which a negative balance cannot be avoided, such as desired weight loss or sports which emphasize low body weights or leanness.
- **As energy conservation** is linked to the downregulation of key endocrine pathways related to musculoskeletal health, we explore strategies that protect the functional capacity of lean tissues in these states, including targeted exercise and increased dietary protein consumption.

Zusammenfassung

- **Leistungssportler,** insbesondere solche in Ausdauersportarten wie Rudern, haben im Vergleich zur Allgemeinbevölkerung einen erhöhten Energieumsatz. Somit besteht das Risiko, dass dieser erhöhte Umsatz durch die Nahrung nicht gedeckt werden kann. Entgegen den Erwartungen führt das daraus resultierende Energiedefizit jedoch nicht notwendigerweise zu einem Gewichtsverlust. Vielmehr können metabolische Anpassungsreaktionen dazu führen, dass Energie konserviert wird und sich so ein energetisches Gleichgewicht an einem niedrigeren set-point einstellt.
- **Das Ziel des vorliegenden Minireviews war es,** das Thema Energiedefizit im Ausdauersport und spezifisch im Rudern zu beleuchten. Des Weiteren werden praktische Anwendungen für die Erkennung von Sportlern mit einem möglichen Energiedefizit sowie zum Vermeiden negativer Auswirkungen auf die körperliche Leistungsfähigkeit diskutiert.
- **Wir stellen einen Ansatz vor,** mit dem mittels indirekter Kalorimetrie und bildgebender Verfahren die Absenkung des Ruheenergieumsatzes als Folge eines Energiedefizits quantifiziert werden kann. Diese Absenkung kann in bestimmten Risikogruppen bis zu 10% betragen und mit einer Leistungsminderung einhergehen. Während eine Ernährungsintervention das erste Mittel der Wahl sein sollte, gibt es Situation, in denen sich ein Energiedefizit nicht vollständig vermeiden lässt, wie z. B. während beabsichtigter Gewichtsreduktion oder in Sportarten, die ein geringes Körpergewicht oder Schlankheit bevorzugen.
- **Zentrale hormonelle Stoffwechselwege,** die mit der Gesundheit von Knochen- und Muskelgewebe einhergehen, können durch Energiekonservierung beeinträchtigt sein. Daher stellen wir Strategien vor, die die funktionale Kapazität der Magermasse in solchen Situationen aufrechterhalten können, wie zum Beispiel gezieltes Training und eine Erhöhung der Proteinzufuhr.

KEY WORDS:
Energy Balance, Resting Metabolic Rate, Adaptive Thermogenesis, Bone Health, Endurance Athletes, Performance

SCHLÜSSELWÖRTER:
Energiebilanz, Ruheenergieumsatz, Adaptive Thermogenese, Knochengesundgeheit, Ausdauersportler, Leistungsfähigkeit

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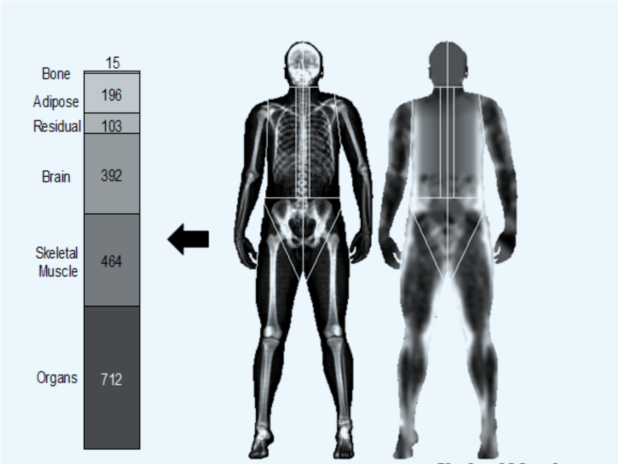
Introduction

One of the features of high-performing athletes are their elevated energy requirements (29). In the normal population, the mean physical activity level (PAL), which describes the ratio of total daily energy expenditure (TDEE) to resting metabolic rate (RMR) is in the range of 1.6-1.7 (43), which translates to average TDEE values between approximately 1500 and 2500 kcal/d. In athletes and particularly endurance athletes, PAL and TDEE levels can be two- to threefold greater. In studies which used gold-standard methodologies to quantify TDEE (doubly-labelled water) and RMR (indirect calorimetry), PAL levels in the ranges of 2.0-2.3, 2.8-3.2 and 3.4-4.0 have been reported in distance runners (6, 34), swimmers (41), and cross-country skiers (36), respectively. So far, the highest sustainable PAL levels of 3.5-5.5



$$RMR_{pred} = \sum_{i=1}^{n} k_i \times T_i$$

Figure 1

Schematic display of our approach combining whole-body imaging with indirect calorimetry to quantify reductions in resting metabolic rate. RMRpred: predicted Resting Metabolic Rate; ki: tissue-specific metabolic rate (in kcal/kg); Ti: size of specific tissue (in kg).

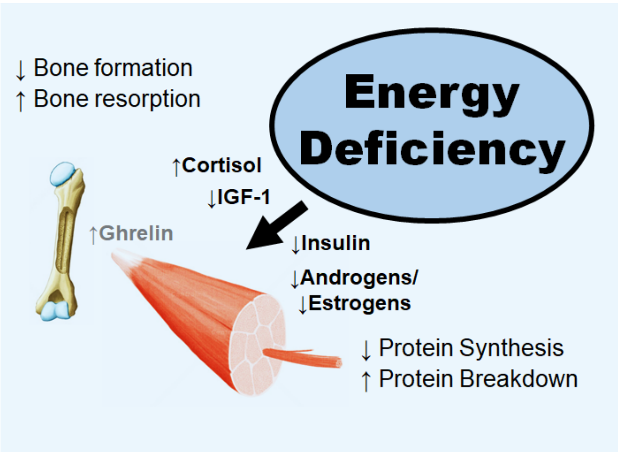


Figure 2

Summary of the proposed mechanisms and consequences of energy deficiency on the musculoskeletal system.

have been measured in road cyclists participating in a 3-week simulation of the Tour de France (44), which when converted to TDEE values amounted to a daily expenditure of 7000-8600 kcal. Although only one published study used doubly-labelled water and indirect calorimetry in rowers, the reported PAL of 2.85±0.9 in a sample of light weight rowers (11) strongly suggest that competitive rowers are also located at the upper end of energy expenditure spectrum. These elevated levels of energy expenditure among exercising populations are recognized by the American College of Sports Medicine, which states in their 2009 Position Stand on Nutrition and Athletic Performance that addressing "energy needs is a nutrition priority for athletes" and that "energy balance occurs when energy intake [...] equals energy expenditure [...]" (33). In light of this recommendation, the question remains whether energy balance is really an objective of athletes, and more importantly whether it is an athlete's goal to be in energy balance? Historical evidence suggests that for most athletes, the concept of energy balance is a means to an end, as it is applied primarily to manipulate body weight and body composition (17). Intentional attempts to achieve weight gain via an energy surplus are rare and challenging (7). However, the likelihood of athletes entering a negative energy balance is much higher, whether it is through reducing dietary intake to achieve or maintain a low body weight in sports with weight limitations (e.g. lightweight rowing), endurance sports, or anti-gravity sports, as the result of disordered eating and clinical eating disorders, or the inability to match the increased expenditure as a result of training and competition (18). The etiology as well as the consequences of chronic energy deficiency, i. e. a long-term mismatch between energy intake and expenditure, have been reviewed extensively in the context of the female athlete triad (5), and more recently under the term relative energy deficiency in sports (RED-S), a more encompassing approach to include a broader athletic population and numerous health-related outcomes aside from bone and menstrual health (22, 23). In contrast, the purpose of the present mini-review, which resulted from an invited presentation at the 2018 World Rowing Conference held in Berlin, Germany, was to highlight issues specific to endurance sports and more specifically rowing, with a special emphasis on practical approaches for the detection of energy-deficient athletes and strategies to alleviate some of the effects detrimental to athletic performance.

Consequences of Energy Deficiency in Athletes

Textbook knowledge suggests that a negative energy balance results in weight loss via the mobilization of energy stores from fat and lean tissues in efforts to balance the imposed energy deficit (9). In addition to providing energy, the loss of metabolically active body tissue also results in a reduction in energy expenditure, thereby reducing the initial energy deficit (10). However, this reduction is typically not sufficient to balance the imposed deficit completely and therefore requires additional reductions in TDEE to return to a physiologically preferential state of equilibrium at a lower set-point. In fact, it is well documented that almost any induction of an energy deficit leads the downregulation of energy-expending processes to conserve energy in efforts to further minimize the energy gap between intake and expenditure, a phenomenon referred to as adaptive thermogenesis (24).

The component of TDEE which has the greatest potential for energy conservation is RMR, as an athlete's training and competition is typically very regimented and non-exercise physical activity is primarily driven by environmental factors. While adaptive reductions in RMR in response to energy restriction have been documented in numerous longitudinal studies in various populations (1, 12, 13, 25), cross-sectional approaches to identify athletes whose RMR is chronically suppressed are much more challenging, as RMR is highly variable between individuals (26). One particular problem is the lack of suitable prediction equations for athletic populations, as prominent equations (e.g. Harris-Benedict, Cunningham, Mifflin-St.Jeor) fail to account for the unique body composition of athletes (21, 37), thereby potentially under- or overestimating their RMR substantially. To overcome this issue, we have implemented a novel approach (Figure 1) which combines advanced whole-body imaging with indirect calorimetry (15). In short, we compare RMR measured via indirect calorimetry with RMR predicted from the size of the primary tissues and organs contributing to whole-body energy expenditure (inner organs, brain, skeletal muscle, adipose tissue, bone) using established tissue-coefficients (26). We have validated this approach in a group of female athletes with exercise-associated amenorreha, a well-established model of chronic energy deficiency (3), whose measured RMR was ~9% (~100 kcal/d) lower than that predicted based on tissue and organ expenditure (15). While amenorrhea represents a clear clinical sign which has been linked to energy deficiency for many years (20), its diagnosis in female athletes involves the exclusion of other causes (4). Further, subclinical menstrual disturbances which may go unnoticed by the athletes, have also been linked to energy status (3). As such, the confirmation of RMR suppression can provide additional evidence for the role of energy deficiency in the etiology of menstrual disturbances, especially since it involves tools commonly available to sports nutrition practitioners. Further, energy deficiency is more likely to go unnoticed in male athletes, whose reproductive function appears to be less vulnerable by energy status (32), as well as female athletes using hormonal contraception. In these cases, RMR measurements may be a first step in the detection of energy deficiency. In fact, unpublished data from various athlete and non-athlete groups suggests that other at-risk groups, such as male athletes involved in leanness sports (8), exhibit similar reductions in RMR. Confirmation of energy deficiency may complement available screening tools and make it easier for athletes and their support staff to adopt appropriate dietary treatment approaches (5, 22, 23).

While quantifying RMR reduction may be an important tool to detect chronically energy-deprived athletes, the RMR reduction is nothing but the product of underlying metabolic adaptations, i.e. a symptom. Therefore, other metabolic, endocrine or clinical markers are required to determine causal and mechanistic factors contributing to RMR suppression. In amenorrheic athletes, the RMR suppression was not only associated with the suppression of the reproductive hormones estrogen and progesterone, it also correlated with reductions in key metabolic hormones, such as leptin and T3 (15). These findings provide real-life evidence of previous seminal studies by Anne Loucks and colleagues who established a direct and dose-dependent relationship between energy availability and alterations in hormones related to energy status (e.g. leptin, thyroid hormones), the growth hormone/IGF-1 axis, stress hormones and reproductive function (19).

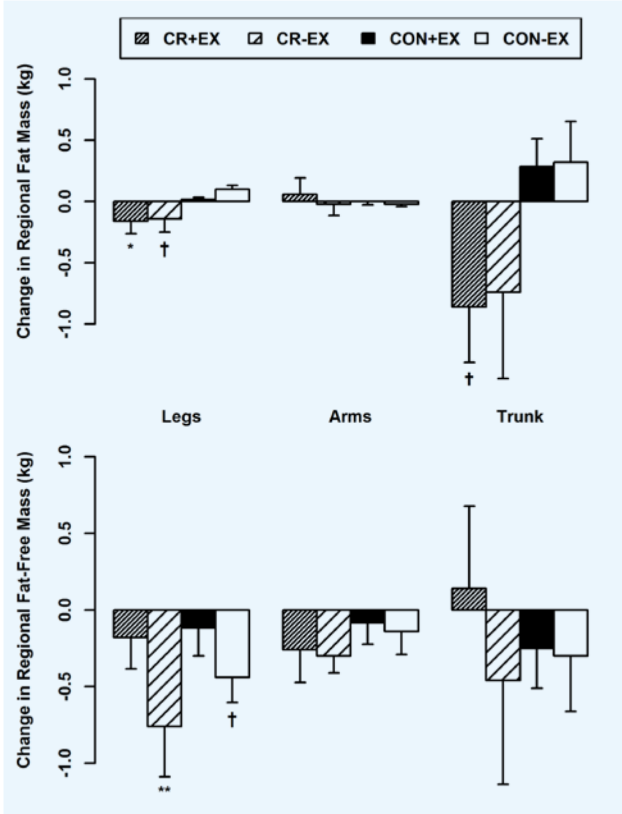


Figure 3

Changes in regional body composition (top: fat mass; bottom: fat-free mass) in response to caloric restriction with exercise (CR+EX), caloric restriction without exercise (CR-EX) as well as energy-balanced control conditions with (CON+EX) and without exercise (CON-EX). Caloric restriction amounted to a reduction in energy availability to 15 kcal per kg fat-free mass per day. †=p<0.1; *=p<0.05; **=p<0.01.

Impact of Energy Deficiency on Athletic Performance

By directly impacting bone health via suppressed bone formation and elevated bone resorption (16, 35) and possibly muscle protein turnover via reduced protein synthesis and elevated protein breakdown (2, 30), these metabolic and endocrine consequences of energy deficiency (Figure 2) can compromise an athlete's health by increasing the likelihood of musculoskeletal injuries such as bone stress injuries and fractures (39).

Furthermore, there is increasing evidence that physical performance is also impacted by energy deficiency. However, as prospective experiments are challenging if not prohibitive in competitive athletes, most of the knowledge on the potentially detrimental effects of energy deficiency on performance is derived from observational studies. For example, Van Heest et al. followed a group of young elite female swimmers during a 12-week training period. In light of the connection between energy status and menstrual health, swimmers were retrospectively divided into groups based on their menstrual status. Confirming the presumed energy deficient state, swimmers with menstrual disturbances exhibited a 30% lower dietary energy intake when compared to swimmers with regular menses. Further, swimmers with menstrual disturbances demonstrated endocrine evidence of low energy availability, including reduced concentrations of thyroid hormones and IGF-1. More importantly, they exhibited a ~10% decrease in their 400-m swim performance over the course of the 12-week training period, whereas regularly menstruating swimmers improved their performance by 8% (42). A similar study was recently published by Woods et al., who monitored athletes of the Australian National Rowing Team participating in a 4-week intensified training program. While the training resulted in a 20-50% increase in training volume, the athletes failed to increase their dietary energy intake. As a result, athletes lost weight (-1.6 kg, 2%) and specifically fat mass (-2.2 kg, -18%), providing strong evidence that they were in a negative energy balance over the course of the training period, an assumption that was further corroborated by a 5% reduction in RMR (-111 kcal/d). Analysis of 5-km time trial data demonstrated a 3.5% reduction in rowing performance, which was particularly evident during later stages of the time trial (~7%) (45).

Possible Counterstrategies

Despite the above mentioned negative effects on health and performance of athletes, acute or chronic states of energy deficiency remain a part of competitive sports. Reasons for this continued problem include seasonal variations in training volume, the need to lose weight or improve body › composition, and regulations or traditions in specific sports, including light weight rowing. Given this conundrum, it is instrumental to develop diet and exercise strategies which minimize possible harmful effects for an athlete's health or performance. For example, shifting weight loss away from functional tissues, such as skeletal muscle and bone, towards the loss of adipose tissue has the potential to maintain functional capacity (28). This can be achieved using exercise as a stimulus to preserve muscle mass, as data from our lab demonstrates. Young, healthy and endurance-trained men underwent repeated periods of severe energy deficiency, once with incorporation of exercise and once without exercise. To maintain equicaloric conditions, participants were compensated for the additional energy cost of the prescribed exercise (14). Despite similar reductions in body weight and fat mass, the incorporation of exercise preserved lean mass (Figure 3) and prevented declines in submaximal performance indices and indices of well-being (31). A recent follow-up study suggest that these beneficial effects can be expanded by combining exercise with elevated protein intake (1.7 g/kg) of the energy-restrictive diet (27). Although it may be challenging to incorporate more exercise into the training schedule of most athletes, these data highlight the importance of maintaining an effective exercise regimen. The fact that the preventative effects of exercise on lean mass occurred predominantly in the exercised extremities suggest that exercise can be targeted exercise to protect specific muscle sites. Further, recent reports on sedentary behavior among elite level rowers (38) suggest that at least some targeted exercise can be incorporated into the lifestyle of competitive rowers, given that this does not interfere with their recovery.

Conclusion and Outlook

The importance of adequate energy intake in athletes is reflected by the most recent position stand of the American College of Sports Medicine, which states that an "[...] appropriate energy intake is the cornerstone of the athlete's diet because it supports optimal body function [...]" (40), as well as other literature pertaining to RED-S (22, 23). Given the significance of adaptive reductions in energy expenditure, changes in body weight alone are insufficient measures of energy status. Instead, a careful evaluation of an athlete's metabolic state, including an assessment of their RMR and body composition, may help identify energy-deficient athletes and can, especially when coupled with other clinical, metabolic and endocrine indicators, help steer appropriate dietary treatment strategies. When states of energy deficiency cannot be avoided at all costs, for example in sports that continue to emphasize low a low weight and/or leanness, some of the negative effects on the musculoskeletal system and performance may be alleviated through functional exercise and increased dietary protein. However, additional strategies may be needed to address other components of the RED-S framework which might be negatively impacted by energy deficiency.

Conflict of Interest

The authors have no conflict of interest.

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