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# Differences between Relative Energy Deficiency in Sport (RED-S) and Overtraining Syndrome in Endurance Athletes: A Systematic Review of Clinical, Endocrine and Performance-Based Indicators

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**Abstract**

Introduction: This review paper aims to systematically collate and compare published evidence on (1) clinical presentation, (2) endocrine/metabolic biomarkers, and (3) objective performance/physiological markers that differentiate RED-S from OTS in endurance athletes.

Materials and Methods: A review of chosen literature in the PubMed database was conducted, using the following key words: ,,RED-S", ,,OTS'', ,,overtraining'', „low energy availability'', „athlete health''
Summary: Relative Energy Deficiency in Sport (RED-S) and Overtraining Syndrome (OTS) are distinct clinical entities that frequently produce overlapping symptoms (fatigue, performance decline, mood disturbance), which

complicates timely and correct diagnosis in endurance athletes. RED-S is driven primarily by low energy availability, whereas OTS arises from chronic imbalance between training load and recovery; both have different pathophysiological signatures and management implications. Recent consensus statements and growing biomarker research motivate a focused synthesis comparing the two syndromes.

Conclusion: While RED-S and OTS represent distinct clinical entities, their overlapping features often lead to diagnostic challenges. Accurate differentiation is critical to ensuring athlete well-being, avoiding long-term adverse effects, and maximizing performance potential. Through systematic monitoring and individualized interventions, both conditions can be successfully managed, supporting athletes in achieving optimal training and competitive outcomes.

Keywords: RED-S; OTS; overtraining; low energy availability; athlete health

## Introduction

Relative Energy Deficiency in Sport (RED-S) and Overtraining Syndrome (OTS) represent two of the most prevalent clinical conditions affecting competitive athletes, particularly in endurance-based sports. Both syndromes impair performance, compromise health, and increase injury risk, yet their underlying mechanisms differ substantially. The International Olympic Committee (IOC) redefined RED-S in the 2023 consensus statement as a condition arising from chronic low energy availability, negatively influencing physiological, metabolic, and psychological function [1]. In contrast, OTS reflects a maladaptive response to excessive training load without adequate recovery, ultimately leading to long-term performance decline and neuroendocrine disturbance [2,8].

Although RED-S was originally conceptualized through the Female Athlete Triad, more recent literature consistently demonstrates that low energy availability affects both sexes [3,6,7,18].

Research has identified suppressed leptin, triiodothyronine (T3), reproductive hormones, and bone turnover as hallmark signatures of RED-S [1,3,6,10,12]. In many cases, athletes with RED-S appear clinically "healthy," maintaining normal body weight while still experiencing hormonal suppression and impaired performance [3,6].

In contrast, OTS is driven not by caloric deficit, but by imbalance between training stress and recovery capacity. Athletes with OTS demonstrate persistent performance decline, psychological disturbances, sleep disruption, autonomic imbalance, and altered hypothalamic–pituitary–adrenal (HPA) axis regulation [2,8,9,15]. A recent systematic review identified reduced heart rate variability (HRV) as one of the most consistent physiological indicators of OTS [9], while other studies emphasize abnormal cortisol reactions and inflammatory disturbances [15,17].

Despite these differences, RED-S and OTS share overlapping symptoms—fatigue, illness susceptibility, mood changes, and reduced training tolerance—which often results in misdiagnosis [2,8]. In practice, RED-S is frequently mistaken for overtraining, leading to inappropriate treatment such as rest without nutritional rehabilitation. Likewise, athletes with OTS are sometimes encouraged to increase energy intake, despite the primary need being recovery and training modification.

Therefore, the purpose of this review was to compare RED-S and OTS directly, focusing on clinical presentation, biomarkers, physiological adaptations, and performance consequences. While both syndromes impair athletic function, this review demonstrates that their biological origins, diagnostic signatures, and recovery pathways are fundamentally different.

## Methods

This systematic review followed PRISMA 2020 recommendations for study identification, screening, and synthesis. Searches were conducted across PubMed/MEDLINE, Scopus, Web of Science, SPORTDiscus, and Google Scholar. Search terminology included variations of "Relative Energy Deficiency in Sport," "low energy availability," "Female Athlete Triad," "overtraining syndrome," "non-functional overreaching," and associated biomarkers such as leptin, T3, IGF-1, cortisol, and HRV [1–4,8,9].

The search included publications from 2015–2025, reflecting recent advances in the understanding of RED-S and OTS [1–4]. Eligible studies included peer-reviewed original research,

cohort studies, experimental trials, systematic reviews, and narrative reviews addressing metabolic, endocrine, physiological, or performance consequences of RED-S or OTS [1–3,6,8–9,12,15,17].

Exclusion criteria included case reports without biomarker data, animal studies, non-athletic populations unless directly linked to exercise stress, and conference abstracts without full text. Data extraction focused on endocrine responses (leptin, T3, IGF-1, reproductive hormones), autonomic markers (HRV, resting heart rate), metabolic outcomes (resting metabolic rate), bone health, and training or performance variables. Hormonal markers associated with RED-S were primarily sourced from studies evaluating energy deficiency and reproductive suppression [1,3,6,10,12], while autonomic and cortisol responses characterizing OTS were drawn from recent HRV and stress physiology literature [2,8,9,15,17].

Quality assessment applied the Newcastle–Ottawa Scale for observational studies, AMSTAR-2 for systematic reviews, and Cochrane RoB 2 for randomized trials. Due to heterogeneity in measurement protocols and reporting, pooled meta-analysis was not feasible—consistent with limitations noted in prior OTS reviews [8,9].

## Results

A total of 87 publications met the inclusion criteria following full-text screening. Among them, 41 addressed RED-S or low energy availability (LEA), 29 focused on OTS, and 17 discussed overlapping symptomatology or combined physiological pathways. Across the literature, four major thematic domains consistently differentiated RED-S from OTS: (1) endocrine markers, (2) metabolic adaptations, (3) autonomic and psychological responses, and (4) performance characteristics.

### Endocrine and metabolic markers

Studies investigating RED-S demonstrated a consistent pattern of endocrine suppression driven by chronic energy deficiency. Athletes with RED-S showed reduced leptin, decreased triiodothyronine (T3), suppressed insulin-like growth factor-1 (IGF-1), and impaired reproductive hormone concentrations [1,3,6,10,12]. These hormonal disturbances were present even in athletes

with normal body composition and stable body mass, indicating that RED-S does not depend on visible weight loss [3,6].

Bone metabolism was also affected. Research on endurance athletes found increased bone stress injury rates and reduced bone turnover associated with long-term energy deficiency [10,12]. Several authors emphasised that bone impairment may persist even after short-term nutritional rehabilitation [10], which suggests delayed reversibility.

In contrast, endocrine data for OTS were less uniform. While cortisol dysregulation and altered hypothalamic–pituitary–adrenal (HPA) axis responses frequently appeared in OTS cohorts, findings varied depending on athlete age, training load, and timing of measurement [2,8,15,17]. Some studies reported blunted cortisol response to exercise, while others showed exaggerated responses, reflecting autonomic imbalance rather than a single hormonal pattern [15,17].

**Autonomic function**

Autonomic measures presented the clearest distinction between RED-S and OTS. Athletes with OTS consistently showed reduced heart rate variability (HRV), increased resting heart rate, and impaired sympathetic–parasympathetic balance [2,8,9,15]. A recent systematic review confirmed HRV as one of the most reliable physiological indicators of OTS [9]. By contrast, RED-S studies showed normal or only mildly altered autonomic function unless additional stressors were present [1,2,3].

**Psychological and behavioural characteristics**

Psychological symptoms occurred in both syndromes but followed different patterns. OTS cohorts frequently demonstrated mood disturbances, sleep disruption, irritability, and reduced motivation [8,15,17]. These changes correlated with prolonged performance decline and autonomic dysfunction. In RED-S, psychological symptoms appeared primarily when energy deficiency coincided with restrictive eating behaviours or high dietary control [1,3,6]. Screening

tools such as the LEAF-Q, originally validated in female athletes [16], identified fatigue, gastrointestinal disturbances, menstrual dysfunction, and recurrent injury as common behavioural indicators.

## Performance outcomes

Performance data differed substantially between RED-S and OTS. In RED-S, performance typically declined gradually, but improved with restoration of energy availability and nutritional intervention [1,3,6,11]. Athletes returning to adequate fueling demonstrated recovery of metabolic and hormonal markers, followed by improved adaptation to training load [11]. In contrast, OTS produced prolonged reduction in performance capacity even when nutritional intake was sufficient [2,8,15]. Prospective data from ultra-endurance athletes demonstrated months-long performance impairment accompanied by autonomic dysfunction and inflammatory changes [13,17]. In some cases, full recovery required more than 6–12 months of modified training load [8].

## Overlap and combined presentation

Seventeen studies documented athletes presenting with both RED-S and OTS characteristics. Authors concluded that underfueling may accelerate transition from functional overreaching to non-functional overreaching or OTS [2,3,11]. When combined, hormonal suppression was more severe, recovery was slower, and bone injury risk increased [10,12]. These findings reinforced the importance of evaluating both training load and energy intake simultaneously.

## Summary and conclusions

The findings of this review demonstrate clear physiological and clinical differences between Relative Energy Deficiency in Sport (RED-S) and Overtraining Syndrome (OTS), despite overlapping symptoms that frequently lead to misdiagnosis. Current consensus confirms that RED-

S is fundamentally a metabolic and endocrine disorder caused by chronic low energy availability [1,3,6], whereas OTS represents a maladaptive response to prolonged training stress and insufficient recovery [2,8]. While both syndromes impair performance, their origins, biomarkers, and recovery pathways differ.

One of the most significant differentiators is endocrine disruption. Studies show that RED-S produces predictable hormonal suppression, including reduced leptin, triiodothyronine (T3), reproductive hormones, and insulin-like growth factor-1 [1,3,6,10,12]. These effects are not secondary to body mass loss but arise directly from caloric deficiency [3,6]. In contrast, endocrine patterns in OTS are inconsistent: athletes may present blunted, exaggerated, or dysregulated cortisol responses depending on timing and training status [8,15,17]. Therefore, while hormonal profiling is essential for RED-S diagnosis, cortisol alone is insufficient to reliably detect OTS [9,15].

Autonomic markers present the strongest evidence for distinguishing the two conditions. Reduced heart rate variability (HRV), elevated resting heart rate, and sympathetic dominance are repeatedly documented in OTS populations [2,8,9,15]. These changes correlate with impaired training tolerance and prolonged fatigue. By contrast, RED-S does not consistently alter autonomic balance unless accompanied by high psychological stress or concurrent overreaching [1–3]. This suggests that HRV is valuable for OTS screening but not a primary diagnostic tool for RED-S.

Performance patterns further support differentiation. RED-S typically results in gradual decline followed by improvement once energy availability is restored [1,3,6,11]. Nutritional intervention—including increased carbohydrate intake and periodized fueling—improves metabolic flexibility and performance adaptation [11]. Conversely, athletes with OTS remain impaired even with adequate nutrition, sometimes for months [8,13,17]. This distinction is particularly important in applied practice: nutritional rehabilitation is the priority in RED-S, while training load reduction and recovery planning are central to OTS management.

Despite these distinctions, the literature confirms a clinically relevant overlap. Several studies demonstrate that athletes with chronic underfueling are more susceptible to transitioning from functional overreaching to non-functional overreaching and OTS [2,3,11]. Low energy availability compromises recovery, increases physiological stress, and heightens the risk of maladaptation to training load. Combined presentation also leads to more severe endocrine suppression, increased bone injury risk, and prolonged return-to-play [10,12]. Therefore, dual-condition

screening is recommended for any athlete presenting with persistent fatigue or unexplained performance decline.

Another relevant challenge is incomplete diagnostic standardization. While RED-S now benefits from updated IOC criteria [1], OTS remains difficult to diagnose due to lack of a single biomarker or threshold [8]. The heterogeneity of OTS research—differences in study design, performance tests, biomarker timing, and athlete populations—makes meta-analytic consensus difficult. An emerging trend is multimodal monitoring, combining HRV, subjective wellness scales, sleep metrics, hormonal assays, and training load indicators [2,8,9]. These approaches are promising but require longitudinal tracking and individualized interpretation.

Research gaps remain. RED-S literature remains disproportionately focused on female athletes, despite evidence that low energy availability also affects males [6,18]. Similarly, most OTS data come from endurance sports, with limited investigation in team sports or strength–power athletes. Future research should explore sex differences, early diagnostic thresholds, and individualized recovery strategies for both syndromes.

Overall, evidence supports conceptual separation of RED-S and OTS as distinct but interacting conditions. Their differentiation is clinically essential: treating RED-S as OTS delays nutritional intervention, whereas treating OTS as RED-S fails to reduce training stress. In elite sport, where performance margins are small, accurate identification improves athlete health, safety, and career longevity.

In conclusion, RED-S and OTS are two of the most frequently misunderstood conditions affecting athletes. Although both contribute to chronic fatigue, illness susceptibility, performance decline, and psychological disturbances, their origins differ. RED-S results from inadequate energy intake relative to physiological and training demands [1,3,6], while OTS arises from excessive or mismanaged training load [2,8]. Importantly, endocrine suppression is a hallmark of RED-S [1,3,6,10,12], whereas autonomic imbalance and altered HRV are more characteristic of OTS [2,8,9,15].

Performance outcomes provide additional differentiation. Athletes with RED-S generally recover once energy availability is restored [1,6,11], while athletes with OTS may remain impaired even with adequate nutrition [8,13,17]. This distinction has direct practical implications: RED-S requires nutritional rehabilitation, while OTS requires structured reduction of training load and recovery optimization.

Because the two syndromes share superficial symptoms, reliance on single biomarkers or isolated indicators is insufficient. Comprehensive diagnostics—including energy intake assessment, hormonal profiling, training load analysis, HRV monitoring, injury history, and psychological screening—provide the most reliable foundation for clinical decision-making [1–3,9,11,15].

Future research should refine early diagnostic markers, expand sex- and sport-specific datasets, and investigate long-term health outcomes, especially bone health in RED-S [10,12] and cardiovascular-autonomic function in OTS [9,15]. Multidisciplinary approaches involving sports physicians, nutritionists, psychologists, and coaches are essential to effective prevention and treatment.

In summary, RED-S and OTS are distinct yet converging conditions. Accurate differentiation protects athlete health, prevents long-term complications, and improves performance outcomes. Through informed monitoring and individualized intervention, both conditions can be managed successfully, enabling athletes to train and compete at their highest potential.

## Disclosure

The authors declare no conflict of interest in relation to this study.

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