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Opinion

Recommendations for Advancing the Resistance Exercise Overtraining Research

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Abstract: Short-term periods of increased resistance exercise training are often used by athletes to enhance performance, and can induce functional overreaching (FOR), resulting in improved physical capabilities. Non-functional overreaching (NFOR) or overtraining syndrome (OTS), occur when training demand is applied for prolonged periods without sufficient recovery. Overtraining (OT) describes the imbalance between training demand and recovery, resulting in diminished performance. While research into the effects of resistance exercise OT has gathered attention from sports scientists in recent years, the current research landscape is heterogeneous, disparate, and underrepresented in the literature. To date, no studies have determined a reliable physiological or psychological marker to assist in the early detection of NFOR or OTS following periods of resistance exercise OT. The purpose of this work is to highlight the conceptual and methodological limitations within some of the current literature, and to propose directions for future research to enhance current understanding.

Keywords: overtraining; overtraining syndrome; overreaching; resistance exercise; strength training; periodisation

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1. Introduction

Overtraining syndrome (OTS) is an accumulation of training and/or non-training stress resulting in a decrement in performance capacity, with or without related physiological and psychological signs and symptoms of maladaptation in which restoration of performance capacity may take several weeks or months [1,2]. Other than long-term performance decrement, there is no single validated identifier of OTS. Diagnosis requires the exclusion of organic disease, infections, dietary caloric restriction, and insufficient carbohydrate or protein intake [2]. As such, a diagnosis of OTS can only be made once confounding factors have been ruled out [2]. Due to its complex and multifactorial nature, a multidisciplinary approach to understanding and diagnosing OTS is essential [3].

The term "overtraining" (OT) describes the imbalance between training demand and recovery that could result in either diminished performance or an improvement above baseline [2,4]. OT is the *process* of undertaking training with an increase in training volume or intensity of effort, whilst OTS would be a possible *outcome* of OT. Our recent scoping review [5], as well as the explorative systematic review published by Grandou et al. [6], reported minimal evidence of OTS in either competitive strength sports or those undertaking periods of resistance exercise, even after purposeful attempts to impair performance. Our research has also reported that high-performance strength coaches are not concerned with the risk of OTS, and rarely consider such the disorder a consequence of resistance exercise [4].

In cases where OT results in performance decrement lasting fewer than several weeks, with no observable performance improvement even after sufficient recovery, the term non-functional overreaching (NFOR) is used [1,2]. There is an implication within expert consensus that while OTS shares similarities to NFOR, these conditions cannot be distinguished by the magnitude or type of symptoms, only by retrospective time course to recovery from impaired athletic performance [2]. Functional overreaching (FOR) is considered to be a desirable training outcome where periods of OT lead to an initial short-term reduction in performance, followed by an improvement or "rebound" above the initial baseline [7,8]. This improvement in performance is only observed after an initial reduction in performance lasting several days [9]. Interestingly, whilst symptoms of increased fatigue, hormonal disruption, and psychological disturbance (e.g., impaired mood, reduced vigor) are associated with NFOR/OTS, these symptoms may also be present in athletes classified as FOR [7]. Consequently, FOR can only be differentiated from NFOR/OTS by resulting change in performance and not the symptoms presented.

Research from the endurance sport domain has indicated that the magnitude of performance improvement following FOR is no greater than the improvements observed following the same training without experiencing an initial performance decline [7,10]. Therefore, intentional attempts to induce a state of FOR through intentional OT might not be required to optimize performance. Nevertheless, high-performance strength coaches regularly use periods of deliberate OT (typically in the weeks preceding competition, referred to as "planned overreaching") to invoke the physiological adaptations necessary to achieve FOR, and consequently, a meaningful standard of performance improvement [11]. However, some coaches choose to avoid intentional resistance exercise OT because of a lack of confidence in their ability to *detect* NFOR, knowledge relating to how OT should be structured to *achieve* FOR, and uncertainty that OT yields greater performance improvement compared to traditional continuous training. Whilst research into resistance exercise OT has gathered attention from sports scientists in recent years, the field has traditionally focused on the endurance athlete [1,2,12]. Consequently, scientific literature regarding the detection of NFOR and OTS caused by prolonged or excessive resistance exercise is underrepresented [5,6].

2. Issues with Identifying Overtraining

Previous research has indicated that in endurance sports, OTS might affect 20–60% of athletes at some point in their careers [1,2]. However, Weakley and colleagues [13] have cast doubt over those figures, proposing that there are no studies providing objective evidence of performance suppression lasting ≥4 weeks. The current diagnostic tool presented in expert consensus [2] suggests that for a diagnosis of OTS to be considered, long-term performance suppression and "persistent fatigue or exhaustion" lasting ≥4 weeks are key factors. Whilst performance suppression for <4 weeks might be indicative of NFOR rather than OTS, it might also be reflective of the transient fatigue experienced by athletes in the weeks following OT that might result in FOR given sufficient recovery [11,14]. Symptoms of OTS can mimic other diseases, therefore only when confounding factors have been ruled out can a diagnosis be made [15]. If a diagnosis of OTS is made without the exclusion of confounding factors, misdiagnosis is more likely, and performance decrement experienced by the athlete could be caused by other factors such as illness, insufficient fueling, or detraining. OTS affects multiple physiological systems and the symptoms presented by athletes vary, suggesting that OTS is a heterogeneous disorder [8,16]. Existing research has not (and likely will not) yet identified a single reliable physiological or psychological marker to assist in the early detection of OTS [13]. Moreover, because OTS can only be differentiated from NFOR by retrospective time-course to performance restoration, the NFOR to OTS threshold is practically indistinguishable.

In our recent review [5] we highlighted two cases where resistance exercise OT resulted in a duration of performance decrement potentially indicative of OTS [17,18]. However, in both cases, methodological considerations need to be addressed. In the study by Cadegiani and colleagues [17], OTS was diagnosed due to prolonged underperformance (classified as ≥10% decrease from previous sport-specific performance), persistent fatigue lasting >2 weeks, and a self-reported increase in sense of effort when undertaking resistance exercise. Whilst this goes some way to indicate an attenuation in performance, the duration of performance impairment was not reported, making a diagnosis of the OTS difficult.

Further, compared to healthy participants, those classified as OTS-affected reported lower carbohydrate intake (3 times lower than in participants not classified as OTS-affected) and overall lower energy intake. The authors suggested that OTS could be triggered by the combined effects of high training demand and excessive calorie restriction, stating that "the most remarkable trigger of OTS among high-intensity functional training was the long-term low carbohydrate and calorie intake". However, expert consensus states that diagnosis of OTS requires excluding factors such as calorie restriction and insufficient carbohydrate intake [2]. Secondly, due to shared pathways, etiology and symptoms, OTS shares several similarities with relative energy deficiency in sport (RED-S); a maladaptive disorder characterized by negative health and performance outcomes triggered by low energy availability [3]. Severe or prolonged low energy availability can perpetuate symptoms of performance decline that are indicative of NFOR and low energy availability might blunt training adaptation [19], therefore decreasing the potential for FOR. It is plausible that participants of this research were suffering from a disruption of physiological processes and compromised performance caused by insufficient fueling, and not OTS [20]. However, because energy availability was not reported, this cannot be confirmed.

Fry and colleagues [18], investigated if high-intensity OT would result in OTS. The authors defined OT as an increase in training volume or intensity that results in long-term performance decrement i.e., $\geq$2 wks. A state of OT was determined based on an observed 5% decrease in training-specific criterion (1-repetition maximum squat machine strength assessment). It is worth noting that the performance assessment took place only one week after the completion of the 2-week OT intervention and therefore alterations in performance might simply have been reflective of short-term transient fatigue indicative of the acute adaptive response. In this sense, a lack of follow-up testing did not permit for analysis of individual participant response to OT. Further, the use of a negative 5% performance marker is somewhat redundant considering that the current consensus recommends diagnosis be made on duration ("several weeks to months") and not just the magnitude of performance decrement. The diagnostic tool presented in expert consensus literature [2] suggests that a >10% decrement in performance would (in part) be necessary to indicate a state of OTS. It is worth noting that arbitrary cut-offs do not determine if the response to training is clinically or practically relevant [21]. Again, it is completely plausible that given sufficient recovery, participants might have improved performance relative to baseline and therefore experienced FOR. Follow-up interviews indicated that participants required 2–8 weeks of recovery before they were able to resume "normal" weight training, which the author used to assume the presence of OT. Of course, diagnosis of a complex disorder as severe as OTS based on subjective self-reported reduction in training ability should be taken with caution due to response and recency bias, as well as the potential for athletes to over- or under-estimate the demands of training [21]. Moreover, if training demand is reduced prematurely based on the perception of fatigue alone (without corroboration from physiological/performance data), detraining could occur due to early termination of training/insufficient training stimulus [22]. Our previous research has indicated that when high-performance coaches prescribe periods of OT, they are not concerned about NFOR/OTS. Instead, they often question whether a miscalculation of training could result in "undershooting" the training stimulus or that they are "not putting enough risk in the program to get the desired reward" [11].

3. Developing Resistance Exercise Overtraining Protocols Is a Challenging Task

Studies designed to investigate potential diagnostic markers of NFOR/OTS have incorporated well-controlled but varied resistance exercise OT protocols. Such studies have included both high-volume [23–25] and high-intensity training [18,26–33] that have utilized either single exercise protocols (typically a variation on a squat) [18,26–31,33] or multiple exercise training programs [23,24,32,34–37]. To explore the mechanisms that underpin the response to OT, several of these training protocols have not been designed to *improve* physical performance (i.e., achieve FOR), but to *induce* a state of OT for the purpose of elucidating diagnostic and mechanistic information. Interestingly, whilst some (at times extremely challenging) protocols have been developed to induce OT, the incidence of NFOR/OTS is still low. Studies that have failed to report a state of NFOR/OTS are more likely to reflect normal strength training practices [6].

The diverse range of training protocols used in OT research assists in the overall understanding of the response to demanding resistance exercise in a controlled environment, and aids in identifying potential mechanisms and markers that underpin OT due to the high level of control associated with laboratory research. Very few studies have used the same protocol across multiple research studies, therefore substantial methodological heterogeneity makes it difficult to compare results between studies where there is a lack of standardized training factors (i.e., frequency, duration, volume, exercise selection, and intensity of effort). Highly controlled training protocols provide a model on which to study the physiological mechanisms that may contribute to OTS. However, "real world" observational research conducted in environments where there is a risk of OT (i.e., training camps, planned overreaching) has the potential advantage of assessing training outcomes using resistance exercise training designed to induce FOR. The current landscape of protocols used in resistance training OT studies is representative of the many ways in which coaches and practitioners prescribe periods of resistance exercise, therefore should not be perceived negatively. High-performance strength coaches typically approach the prescription of such training intuitively, using an individualized approach [11]. Therefore, the development of a single best practice protocol used across a diverse range of sports, athlete types and complex-chaotic training settings is challenging and would eliminate the flexibility in which intentional resistance exercise OT is prescribed.

Providing objective evidence of performance decrement following prolonged periods of resistance exercise OT is difficult [13]. As such, there is a lack of longitudinal research reporting follow-up performance tests, making it difficult to accurately determine if OTS has occurred. It is critical that future studies determine if performance suppression following periods of resistance exercise OT is due to acute fatigue, FOR/NFOR or OTS (or other disorders such as RED-S). With a heterogeneous and diverse range of associated symptoms and only a minimal understanding of the underlying mechanisms that dictate the response to OT, the time course to performance restoration and performance change is currently the only way to differentiate FOR from NFOR/OTS. Performance testing follow-up should be conducted at ≥4 weeks post-intervention to accurately determine NFOR from OTS. However, it is acknowledged that follow-up testing to verify diagnosis might be difficult considering the associated duration and frequency required for data collection.

4. Could an Analysis of Inter-Individual Response Variability Be the Next Step to Understanding Resistance Exercise Overtraining?

The concept of individual response variation to a given dose of exercise training is not a new concept [38]. It is well established that when a group of individuals undertake the same resistance exercise program, their response to that program will vary, even in groups comprising small sample sizes [39]. Some individuals will present meaningful improvements in performance, whereas others will present an adverse response [40,41]. Such variation is largely controlled by genetic and epigenetic factors [42–45] and modulated by genotype [46,47], muscle fibre typology [48,49], age, and biological maturation [50]. Additional factors such as the level of competition/training status [51] and the individual's "stress capacity" [52,53] will also affect performance outcomes. For example, men and women undertaking 12 weeks of resistance exercise reported one-repetition maximum strength changes ranging from 0 to 250% and skeletal muscle hypertrophy of −2 to 59%, suggesting some participants experienced performance changes indicative of FOR, whilst others did not [47].

Whilst it is likely that the physiological response to the same program of training will differ between a group of athletes, current understanding of inter- and intra-individual variation in response to resistance exercise remains limited [54], especially in studies designed to induce FOR. Much of the previous research in this area has focused on group-based analysis, where the mean pre-to-post change in an intervention group (typically referred to as an "overtraining" group) is compared to the mean pre-to-post change in a control group (a "normal" training group) [40,55]. Therefore, there is a strong rationale for exploring the individual response to periods of resistance exercise OT. Similar recommendations have been made by Bellinger [7], who suggested that future research exploring FOR should focus on the inter-individual response to exercise training and the variable development of performance outcomes following periods of high training demand.

Previous research has reported that trained individuals undertaking periods of either single or multiple sets of high-intensity resistance exercise (including a challenging protocol of 8 sets of back squats at 80% of repetition maximum to volitional exhaustion twice per week) can be classified as "high responders" (>20%) or "low responders" (<10%) based on changes in strength [56]. Interestingly, whilst some participants reported improved performance (which could be considered FOR) and others reported a decline in performance, there was no change in energy intake between responder groups either prior to or during the study, suggesting variation in response could not have been attributed to energy intake. A second point to note was that the "peaking phase" of the training protocol (a 4-week high-intensity, low-volume phase designed to reduce the risk of NFOR) was only effective for high responders. Whilst the authors were unsure as to why this was the case, they proposed that the training that preceded the peaking phase was sufficient to evoke the "realization" of strength development. This poses an additional but interesting question relating to the importance of individualizing the tapering phase as well as the organization of increased resistance exercise training demand. This is an area of research that has received minimal attention [14,57] but should be considered in future experimental studies.

It is anticipated that by adopting an individualized approach to resistance exercise, sports scientists and practitioners might optimize resistance exercise OT to achieve FOR and mitigate the negative effects of NFOR or OTS.

5. Recommendations for Future Research

- Clinicians and practitioners should cease to refer to short-term (<4 weeks) attenuation in performance as OTS. Instead, a pragmatic approach to the probable causes of a short-term reduction in performance after periods of resistance exercise OT should be taken. Such an approach must consider the multiple factors that might lead to suppressed performance, including changes in training demand, sleep characteristics, insufficient recovery, and non-training stressors such as work-life balance and motivation.
- To determine OTS, it is critical that performance testing should be conducted at ≥4 weeks post-intervention. It is acknowledged that follow-up testing to verify diagnosis might be difficult considering the associated duration and frequency required for data collection, however, longitudinal research studies monitoring performance during a follow-up period is underrepresented in the literature.
- Future research should explore the similarities between OTS and other disorders that lead to physiological impairment and performance decrement (e.g., RED-S) to better understand overlaps in etiology and pathology. It is our view that enhancing understanding of such conditions will strengthen differential diagnosis and subsequent treatment for recovery.
- Well-controlled training protocols designed to induce a state of OT provide a model for determining contributing mechanisms of NFOR/OTS. Studies designed to provide mechanistic information for the early detection of NFOR or diagnosis of OTS should include a control training period prior to an increase in training load and should also demonstrate adequate control for confounding variables of energy availability and carbohydrate intake to improve the confidence of a true diagnosis of NFOR/OTS.
- Observational data collected during training periods where athletes might be at risk of NFOR/OTS provides an opportunity for sports scientists to conduct "real world"

assessment. In environments such as training camps or during periods of planned overreaching, it is important to collect training data to determine performance changes, but also to collect data from uncontrollable factors that might influence the response to training (recovery status, readiness, sleep characteristics, dietary intake, and life stress). However, it is acknowledged that it might be difficult to conduct follow-up testing to verify diagnosis in an observational setting.

- Future research should explore factors that underpin the possible inter-individual response to resistance exercise OT. It is completely plausible that the same period of OT might result in different training outcomes (i.e., FOR or NFOR). Currently, little is known about the factors that influence response heterogeneity following periods of resistance exercise OT.

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