Physiological and Psychological Stressors Affecting Performance, Health, and Recovery in Special Forces Operators: Challenges and Solutions. A Scoping Review

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Physiological and Psychological Stressors Affecting Performance, Health, and Recovery in Special Forces Operators: Challenges and Solutions

A Scoping Review

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ABSTRACT

Introduction: Special Operations Forces (SOF) Operators (SOs) are exposed to high levels of physiological and cognitive stressors early in their career, starting with the rigors of training, combined with years of recurring deployments. Over time, these stressors may degrade SOs' performance, health, and recovery. **Objectives:** (1) To evaluate sources identifying and describing physiological and psychological stressors affecting performance, health, and recovery in SOs, and (2) to explore interventions and phenomena of interest, such as the biological mechanisms of overtraining syndrome (OTS). **Methods:** This review followed the recommendations and methodology of the Joanna Briggs Institute and the Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) guidelines. A database search from December 1993 to December 2021 was performed in PubMed, the Cochrane Library, and the Defense Technical Information Center (DTIC). Potential articles were identified using search terms from their titles, abstracts, and full texts. Articles effectively addressing the review questions and objectives were eligible. **Results:** After 19 articles were excluded for not meeting established inclusion criteria, a total of 92 full-text articles were assessed for eligibility. After the final analysis, 72 articles were included. **Conclusions:** Allostatic imbalance may occur when supra-maximal demands are prolonged and repeated. Without adequate recovery, health and performance may decline, leading to nonfunctional overreaching (NFO) and OTS, resulting in harmful psychological and hormonal disruptions. The recurring demands placed on SOs may result in a chronically high burden of physical and mental stress known as allostatic overload. Future investigation, especially in the purview of longitudinal implementation, health, and recovery monitoring, is necessary for the health and readiness of the SOF population.

Keywords: *humans; cognition; overtraining syndrome; allostatic load; military personnel; sports*

Introduction

Special Operations Forces Operators (SOs) experience frequent combat deployments and missions that expose them to a plethora of physiological and psychological stressors.[1-3] To meet the mission's unique physical, emotional, and environmental demands, SOs train rigorously and continuously. Ideally, this training process is allostasis, the body's optimal adaptive behavioral and physiological state of readiness to an environmental stressor.

SOs routinely operate in austere environments ranging from dry/arid deserts to subarctic/arctic regions, traverse through varying terrain, and sometimes operate at extreme altitudes. It

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is not uncommon for an SO with ten years or more of operational experience to have had up to fifteen combat deployments, including hundreds of individual direct-action missions.[1-3,9] In fact, SOs may be in direct action every night for days, not returning to the Forward Operating Base for weeks.[12] SOs are also exposed to an array of other mission-related stressors to include 1) extended patrols while wearing heavy gear, 2) routinely lifting and pulling heavy equipment, 3) working in awkward positions for hours, 4) convoy operations that require sitting for prolonged durations while wearing heavy combat gear, and 5) exposure to extreme conditions for prolonged periods that must be endured until the job is completed.[1-3,6]

To mimic the allostatic load of modern warfare, SOs train under very stressful conditions. Nindl et al.[4] studied the physiological consequences of Ranger School on strength, power, and body composition. He found that Ranger School students sleep an average of only 3.6 hrs/day, experience acute caloric deficits, and chronically expend more energy than consumed (e.g., net caloric loss) for the majority of the 8-week course.[4] This type of training and the physiological consequences of such activity are analogous across all special operations commands.[1,4]

The combined training and constant deployment demand on SOs throughout their career result in a chronically high burden of physical and psychological stress.[9, 14] SOs may also experience continual overexposure to internal and external stressors, leading to significant degradations in performance and health. Stress is a "threat, real, or implied to an individual's psychological or physiological integrity."[13[p.2094]] The autonomic nervous system (ANS) and adrenocortical system are the regulators of the stress reaction to which all other systems in the body may react. Both serve as protectors of bodily functions in the short term but can hasten the disease process in the long term if not managed appropriately.[10, 13]

There are essential differences in how acute versus chronic stress can manifest into stress-related diseases. Understanding these differences is necessary when attempting to lessen the impact of stressors on SOs. Stress should be viewed as a conceptual and methodological basis for describing the physiological and behavioral factors and mechanisms which lead to the disruption of standard biological systems, structures, routines, and functions. These factors consist of genotypical, intrinsic traits, or environmental, extrinsic factors, such as life experiences, living and working environments, exercise, interpersonal relationships, sleep habits, diet, education, and other lifestyle factors.[9]

The normal physiological and cognitive load of an SO approaches, and often extends beyond, physiological limits, depending on the environment, type and duration of the mission.[1,4-6] This may lead to an allostatic imbalance known as overtraining syndrome (OTS) that begins to emerge over weeks, months, or years. OTS is a chronic imbalance between recovery and allostatic load, and without adequate periods of respite can manifest into long-term impairments in physiological and psychological functionality. Over time, OTS may manifest in SOs who have deployed many times and engaged in rigorous training but did not receive adequate periods of respite following such intense events.

When the body experiences an unmanageable level of chronic internal (e.g., anxiety), external (e.g., austere conditions), and lifestyle (e.g., poor nutrition) stressors it can lead to a state of allostatic overload where an SOs' performance and mission readiness is degraded over time. Allostatic overload often manifests as chronic health problems that significantly impede SOs' ability to sustain peak performance.[5-9]

While some levels of anxiety may be considered good for maximizing performance, an unmanageable level of chronic anxiety may worsen performance in SOs over time. High allostatic load may lead to over activation of the sympathetic nervous system, which constantly oscillates until the stressful situation abates.[10] When the stress persists and becomes chronic, neuronal excitability becomes variable or elevated and catabolic hormones are released into the blood. Chronic stress may also lead to unhealthy lifestyle behavioral changes such as poor nutrition/diet, decreased physical activity, tobacco and alcohol use, disruptions in circadian rhythm, and insufficient sleep duration and quality.[11]

The acute effects of training and deployment on SOs are well described in the literature.[2-9] However, there is a lack of reviews describing the long-term effects of stressors on SOs and the types of performance recovery monitoring that may elucidate the harmful effects of these stressors. Thus, this scoping review focuses on factors that affect performance, health, and recovery in SOs. It provides postulates as to the biological mechanisms for OTS and allostatic overload in the SO population and insights on a multidimensional performance recovery tracking (MDRT) model.

The primary objectives of this review were (1) to identify and expound the various types of physiological and cognitive stressors affecting SO performance and health, and (2) to investigate the potential benefits of a MDRT model, including performance physiology, psychological function, biomarkers, and functional movement.

Our primary question for this scoping review was (1) what types of physiological and psychological stressors affect long-term performance and health in SOs? In addition, a subquestion was (2) what recovery tracking approaches deserve further exploration in ameliorating chronic physical and cognitive overload in SOs?

Methods

This scoping review fulfilled the PRISMA-ScR.[15] For this scoping review, we followed the JBI guidance for the conduct of scoping reviews published in the JBI *Manual for Evidence Synthesis*.[16] This review is not registered in the JBI database for reviews and implementation. However, this review can be acquired on request from the corresponding author.[1]

Inclusion Criteria

Primary, secondary, and tertiary articles were eligible for inclusion and had to be written in English. Peer-reviewed and non–peer-reviewed articles were eligible for inclusion and had to address the scoping review's primary and secondary questions and objectives. Articles that focused on "interventions," such as performance and recovery monitoring, and "phenomena of interest" as to the biochemical mechanism of OTS, were eligible for inclusion. Finally, articles that adequately described OTS and allostatic load in athletes or US Military Special Forces were eligible for analysis.

Search Strategy and Screening

The authors (RBO, LS) performed a three-step search strategy recommended by the JBI for all scoping reviews.[15,16] An initial limited database search was conducted using the Cochrane Library, PubMed, and the DTIC for studies related to the topic, questions, and objectives of this scoping review. For the second database search, we used the index terms and keywords from the articles we located for inclusion during the initial search. Finally, we reviewed additional relevant reference lists of the eligible full-text articles.

For our initial search in PubMed, we included the following article types: books and documents, case reports, clinical studies, evaluation studies, historical articles, introductory journal articles, meta-analyses, observational studies, randomized controlled trials, original reviews, systematic reviews, and Department of Defense technical reports published between 31 December 1993 to 31 December 2021.

The first search terms entered into PubMed pertinent to this scoping topic were "physiological, psychological, stress in Special Forces," which produced four articles; three were retrieved for further analysis of the text words used in the title and the index terms that described the articles. For the second search in PubMed, we entered "Performance, health, recovery, Special Forces," which generated 35 articles related to the scoping topic; 4 were retrieved for further analysis of text terms and index terms. Our third search in PubMed was related to the review question, which was entered as "Factors, health, physical, performance, Special Forces," which produced 21 articles related to the primary scoping question; two were retrieved for further analysis of text words and index terms. Our final search in PubMed was related to "interventions" and "allostatic load." For "interventions," we entered the search terms "performance, recovery, monitoring," which generated 363 articles; 13 were retrieved for further analysis. Finally, the search term "allostatic load" produced 291 articles; 40 were retrieved for further analysis.

We performed an advanced title, abstract, and keyword search in the Cochrane Library for articles published from 31 December 1993 to 31 December 2021. Search limits consisted of Cochrane Reviews, Cochrane protocols, Clinical Answers, and Special Collections using the word variations (physiological OR psychological OR stress OR Special Forces) AND (performance OR health OR recovery OR Special Forces) AND (factors OR health OR performance OR Special Forces) AND (interventions OR performance OR recovery OR monitoring) AND (allostatic load OR overload OR stress) which generated 22,108 potential articles. We followed a similar search strategy sequence in the DTIC database under the Department of Defense Science and Technology reports icon and selected the Department of Defense technical report PDF documents, which resulted in 13,210 technical reports.

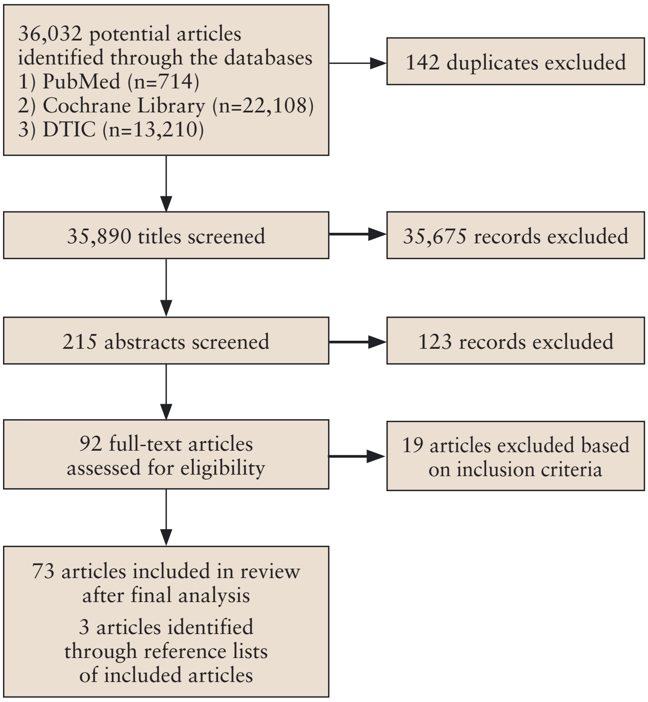
Source Selection and Data Analysis

The authors (RBO, LS) independently reviewed titles and abstracts that were included from the initial database search against inclusion criteria, then searched and selected full-text articles meeting the inclusion criteria. Articles were then independently appraised by both authors (RBO, LS) using the JBI Critical Appraisal *Checklist for Systematic Reviews and Research Syntheses.*[17] When there were disagreements regarding the overall appraisal process, both reviewers met to discuss the issue until they agreed. Both authors (RBO, LS) developed a data extraction form, which was pilot tested before the database search and then revised after each reviewer appraised a minimum of three articles. The final list of research data characteristics extracted and evaluated from all articles included (1) author(s) and year, (2) article type, (3) primary aim, (4) method, and (5) key outcomes.

Results

Figure 1 shows the scoping review flowchart for selecting sources. Articles were screened for eligibility, based on the established inclusion criteria. Seventy-three articles were included for extensive review. Articles selected for inclusion consisted of the following: primary research articles (n = 23), reviews (n = 25), DTIC reports (n = 3), observational studies (n = 1), perspective articles (n = 1), systematic reviews (n = 6), book chapters (n = 2), dialogue articles (n = 2), meta-analyses (n = 2), manuals (n = 1), consensus articles (n = 3), hypothesis/theory articles (n = 1), abstracts (n = 1), white papers (n = 1), and opinion articles (n = 1).

FIGURE 1 *Scoping review flowchart.*



DTIC, Defense Technical Information Center.

Discussion

Allostasis

Allostasis occurs when the body, to counteract acute threats, alters physiologic parameters via the output of stress hormones that allow the organism to achieve stability through change.[11,18] For example, the heart maintains its rate in a stressful environment at levels not typically held in a non-stressful environment. This response comes with an added energy cost through anticipation of the challenge/threat known as "brain-pull." Brain-pull is a condition in which the brain actively demands energy from the body to meet the acute threat.[19] When exposure to stress is chronic, the brain-pull response is prolonged. Repeated or prolonged activation of these brain-pull mechanisms during chronic stress may lead to the accumulation of visceral fat (i.e., internal fat storage) and loss of subcutaneous fat, as well as a host of other related health disorders (e.g., endocrine dysfunction, chronic pain, poor sleep).[9,19]

Allostatic Load

Allostatic load/overload accumulates as one is repeatedly exposed to chronic stressors, causing wear and tear on the body; in other words, it is the "the price the body pays when exposed to chronic stressors resulting in repeated overactivation of the neuroendocrine and immune systems."[10] The normal physiological response of an individual to a given stressor occurs for a short interval and is then turned off once the stressor has abated. However, when an individual's ability to cope with environmental challenges is exceeded, allostatic overload develops as a transition to an extreme state in which the neuroendocrine and immune systems are repeatedly activated and buffering protective factors are inadequate.[10,13]

Four primary biomarkers measure allostatic load/overload. These consist of 12-hour integrated measures of the hypothalamic-pituitary-adrenal (HPA) axis activity and sympathetic nervous system activity: (1) cortisol, (2) adrenaline, (3) noradrenaline, and (4) dehydroepiandrosterone (DHEA). These biomarkers accurately measure HPA neuroendocrine responses to stress.[10,20] The secondary biomarkers that indicate allostatic load/overload include (1) systolic blood pressure measurement, (2) diastolic blood pressure measurement, (3) waist-hip ratio, (4) total cholesterol level, (5) high-density lipoprotein cholesterol level, and (6) blood sugar levels.[10] Interestingly, the four primary markers of allostatic load are considered equally influential in predicting mortality over 4 years compared with the secondary outcomes of allostatic load.[10,19]

According to Guidi et al.[11] and Davies,[18] allostatic load/overload is not an actual physiological principle but repeated or lengthy deviations from homeostasis. Chronic negative health consequences may result from prolonged allostatic load/overload caused by overexposure to stressors (e.g., repeated deployments, work, family, social), leading to hypertrophy of the adrenals and hyperemia, hemorrhagic erosive gastritis/ulcers, and atrophy of the thymus and lymph nodes, collectively referred to as the "stress triad."[21] Over time, chronic stress can slowly degrade the physical and mental attributes of SOs while increasing their vulnerability to overuse injuries.[4,5,22-24,25-26] The health and efficiency of what is referred to as the "human motor" are markedly impacted by the brain's increased energy demands and chronic physiological and psychological stress.[13,27]

Given the unique training and deployment burdens and resulting chronic stress, a unified understanding of the consequences of SO life is beginning to emerge. A recent observational study by Frueh et al.[9] found a distinctive pattern of physiological and psychological conditions in the Special Forces population. Over 6 years, clinicians in this study observed that SOs suffer from unusually high allostatic loads. High allostatic load and overexposure to endocrine, neural, and immune stress mediators can adversely affect various organ systems, manifesting into disease.[9,13] Frueh et al.[9] concluded that, because of continuous, long-term exposure to extreme environmental conditions and training, traditional medical models of care are frequently not effective in treating the interrelated functional performance and health deficiencies of SOs. Thus, to ensure the health and performance readiness of SOs, future researchers should focus their efforts on early detection through the use of wearable technology and by adopting an interdisciplinary model of care that can adequately address these interrelated health and performance deficiencies.[5,9]

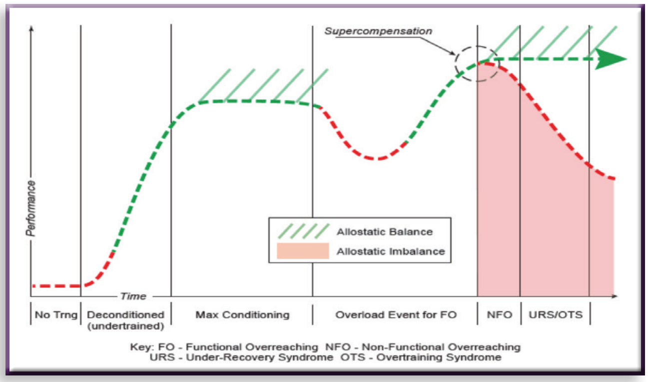
Allostatic Imbalance

At the most basic level, when there is low demand, the body becomes deconditioned, and performance is decreased. With maximum, optimal demand and physical training (i.e., balanced), maximum performance will be reached, requiring normal rest periods and recovery to be sustained. These training levels can be exceeded for short periods, leading to a temporary decline in performance but ultimately resulting in improved performance. This state is known as functional overreaching and is a positive adaptation used by athletes who must perform at supra-maximal levels. To maintain performance and prevent injury, these supramaximal training and performance episodes must be followed by complete recovery (approximately 2 weeks).[6,28-31] When supramaximal demands are prolonged and repeated without adequate recovery, performance will decline, and the body will show signs of increased wear and tear.[6] This is known as NFO,[6,28-32] defined as a training-specific condition in which there are negative psychological and hormonal disruptions (e.g., low testosterone/high cortisol levels) and decreased performance, leading to overtraining syndrome."[32] In this state, the body requires a more prolonged recovery period to restore maximal performance and lessen the risk of injury. NFO commonly occurs in SOs, when mission demands make it impossible to gain recovery during deployments. When NFO persists over longer periods, OTS will develop. OTS is a chronic condition in which health and performance decline further.[6,28,33] The symptoms of OTS may include diminished performance, increased morning resting heart rate (HR), alterations in hormonal status, marked weight reduction, lack of improved training status, increased vulnerability to injuries, diminished appetite, restlessness, disruption in circadian rhythm, general lethargy, decreased self-esteem, emotional insecurity, and depressed mood.[34]

Finally, a more non–training-specific concept known as under-recovery syndrome (URS) is a broader condition of insufficient recovery. URS develops when there is an imbalance between daily life demands (e.g., work, family, social life) and restoration.[28,31,32] In other words, the imbalance occurs when continuous, excessive psychological or physiological demands, whether perceived or real, exceed those of recovery, leading to psychological, neurophysiological, and physiological degradation.[9,28,32]

We posit that progressive, ongoing fatigue can result in long-term under-recovery and underperformance, further placing SOs at increased risk of acute and chronic decrements in physical, psychological, neuroendocrine, and immunological systems. Therefore, we propose a theoretical continuum model synthesizing the incremental stages leading to these progressive degradations (Figure 2). This model displays the steps leading to URS/OTS and elucidates the importance of recovery/restoration following an overload event (e.g., deployment, rigorous training cycles), leading to super-compensation, whereby the individual has a higher performance capacity than they did before the overload event. Inadequate recovery may result in allostatic imbalance, requiring a recovery period of days, weeks, months, or years to regain peak performance.[11,30,31,35] This theoretical continuum model has yet to be substantiated within the SO community and thus deserves extensive exploration.

FIGURE 2 *Theoretical model for allostatic imbalance continuum.*



FO, functional overreaching; Max, maximum; NFO, nonfunctional overreaching; OTS, overtrained syndrome; Trng, training; URS, under-recovery syndrome

There are conflicting estimates of the incidence and prevalence of OTS, likely because of the wide-ranging definitions, small study cohorts, contradictory diagnostic criteria, and varied definitions of what truly qualifies as NFO.[34] Presently, there is no agreed-upon theory of how NFO or OTS develops, especially in SOs. However, it is accepted that in certain occupations, such as those of SOs, where the body is under stress for prolonged periods, the risk of entering a state of NFO markedly increases.[1,2,6,36,37] Furthermore, researchers have proposed various hypotheses but have not yet agreed about the pathophysiology of OTS.[37] For SOs, a common risk factor for NFO is the improper ratio of recovery to ongoing physiological and psychological stress, especially following a rigorous training or deployment cycle.[1,6] However, according to the Joint Consensus Statement of the European College of Sport Science and the American College of Sports Medicine,[38] there is currently no simple yet sensitive test for diagnosing OTS. Hence, there is a definite need for a system to diagnose OTS.

OTS is a chronic imbalance between allostatic load and recovery, associated with fatigue and other physiological and psychological symptoms. Over weeks or months, the related symptoms of OTS may result in significant decrements in overall physical and mental performance. Restoration and recovery from OTS take even longer than from NFO, and although full recovery is possible, there may be permanent performance deficits if major chronic musculoskeletal injuries have occurred. We posit that OTS is more likely to occur in SOs who have deployed many times and have undergone a prolonged, intense training schedule with inadequate recovery interventions during their career.

Given the consequence of NFO/OTS, the resulting musculoskeletal injuries sustained by SOs, and the negative impact of these injuries on force readiness, research is needed to determine how to achieve effective recovery.[1-3,5,6] Fatigue and under-recovery can be resolved, and organismic allostatic balance regained, through the use of proven physiological and psychological recovery strategies and rest periods.[28] However, NFO requires a more extended, continuous recovery period.[28,32] According to Kellmann and Kölling,[28] recovery is defined as a multilayered (e.g., physiological, psychological) restorative process over time. Additionally, Kellmann[34] emphasizes the need for personalized recovery strategies and monitoring and defines recovery as "an inter-individual and intra-individual multi-level (e.g., psychological, physiological, social) process in time for the re-establishment of performance abilities. Recovery includes an action-oriented component, and those self-initiated activities (proactive recovery) can be systematically used to optimize situational conditions and to build up and refill personal resources and buffers."[34] Top operational performance cannot be accomplished through optimal training intensity and volume only; adequate rest and recovery periods between training cycles and deployments are also necessary.[1,5,39]

Researchers and practitioners should consider future human performance recovery initiatives for SOs to sustain peak performance and improve career longevity through (1) the timing of appropriate recovery interventions following deployments and advanced training courses, (2) training to manage other life stressors, and (3) the use of appropriate recovery tracking technology to encourage behavioral changes as well as to track key physiological warning signs of NFO and OTS. Accurately diagnosing either NFO or OTS has historically been difficult because of the complexity in diagnostic testing[37,40] and lack of longitudinal research in the SO community.[6,37,39] Therefore, as a first step, we propose the use of multidimensional recovery tracking (MDRT), using wearable physiological monitoring devices to warn of an impending state of NFO or URS/OTS.

Biological Mechanisms for NFO/OTS

As reviewed previously, the initial and sustained training of SOs is physiologically demanding, resulting in reductions in testosterone (−6%), lean body mass (−5%), and muscular strength (−12%), all of which are connected to sleep deprivation (3 h/day) and caloric deficits (−3,351 cal).[2] Ultimately, the stressors of the job may exceed the capacity of SOs for physiological adaptation. Simply put, SOs may fail to adapt to recurring stimuli (i.e., stressors), leading to a state of physiological depletion. Hence, we postulate that such overexposure may result in significant disruptions in the neuroendocrine system, which is one of the most responsive of physiological systems (e.g., nervous, immune, endocrine) and serves as a pivotal regulator of physiological homeostasis.[41] Repeated disruptions in the HPA axis, overactivation of the ANS, and suppression of the hypothalamus-pituitary-gonadal axis may lead to longstanding decrements in the health and performance of SOs.[42-47]

We postulate that the biological mechanisms for NFO/OTS in SOs are explained by the principles of homeostatic regulation and the general adaptation syndrome (GAS) model. First, the GAS model serves as a robust theoretical framework that describes any organism's ability to adapt to disruptions in the physiological milieu. Hackney[41] states that "it is unclear as to what is the physiological mechanism that induces overtraining syndrome." However, "the most prevailing theory suggests that clinically overt overtraining syndrome may reflect the exhaustive stage of Selye's GAS."[41] An organism's perceptual response to a stimulus will regulate the degree of its neurophysiological response to it. For example, all mammals perceive stress differently; therefore, their response will vary individually across time. For instance, an organism's response to an acute stressor will likely abate faster depending on its perceived intensity of the stressor and the recovery time afforded between stress exposures. However, if the acute stressor does not fully abate, then these repeated acute stress exposures, coupled with inadequate recovery, can lead to chronic overactivation of the HPA axis and ANS. The combination of a SO response to repeated acute stressors, lack of adequate recovery between stress exposures, and their reaction to the perception of these stressors may lead to NFO/OTS.[44]

Our second postulate as to the biological mechanisms for NFO/OTS is explained by the basic principle of homeostasis, which is an organism's ability to maintain nearly constant internal conditions in response to external stimuli through self-regulatory processes. Hence, any biological factor (e.g., HR, blood pressure level, core temperature, blood glucose level) will continually oscillate around an organism's minimum and maximum normal homeostatic range.[44,48] Homeostasis is not constant; rather, it continually expands in response to internal or external agitation, extending its normal homeostatic range. Thus, the normal adaptive homeostatic range expands into a positive or negative adaptive range. Adaptive homeostasis is "the transient expansion or contraction of the homeostatic range for any given physiological parameter (e.g., heart rate, blood pressure, core temperature) in response to exposure to sub-toxic, non-damaging, signaling molecules or events, or the removal or cessation of such molecules or events."[48] Thus, adaptive homeostasis infers that there is no constant homeostatic set point but rather continual fluxes in an organism's response to internal and external stimuli. Therefore, based on the adaptive homeostatic theory, we postulate that the excessive and repetitive exposures to stimuli (stressors) encountered by SOs throughout their careers may result in chronic overactivation of these positive and negative adaptive homeostatic pathways, leading to limited or reduced capacity of the SO to regulate their transient adaptive responses to stimuli.

For example, according to Pomatto and Davies,[48] "an aged organism, which has faced a lifetime of chronic or excessively repetitive adaptive stimuli, relies upon constant activation of stress responses, with little or no ability to modulate adaptive homeostasis."[48] Therefore, we extend this theory to describe how NFO/OTS may develop in SOs. Simply put, continual overactivation by SOs of these adaptive pathways may limit their ability to extend their functional adaptive homeostatic range, ultimately leading to severely compressed adaptive ranges, resulting in chronic low-grade stress. Finally, lack of recovery between repeated acute stress exposures over time may manifest into chronic, long-term impairment in SO health and performance.

Recovery Monitoring

Individualized recovery strategies and commercial technologies for objective monitoring may be the first step in addressing the recurring problem of chronic stress burden, overtraining, and under-recovery in the SO community.[1,2,6,9] Considering the biological uniqueness of each individuals' NFO/OTS, recovery monitoring should begin in the early phases of the initial training of SOs. The baseline measures used for comparison are essential for detecting early signs of overtraining to preserve the performance and health of SOs. The importance of establishing standardized testing, combined with structured data aggregation in the SO community, is also essential. For example, according to Vrijkotte et al.,[6] elite military personnel, such as SOs, experience high operational turnover, and the recovery component of performance is often abandoned to tactical training priorities. Therefore, they conclude, "to be able to determine whether a soldier is at risk to develop NFO/OTS, health and performance status of military personnel concerning NFO/OTS should be checked at entry into service with a yearly follow-up," and "there is a need for regular standardized check-ups" on an individual basis.[6]

Multidimensional Recovery Tracking

We propose the concept of multidimensional recovery tracking (MDRT) to address NFO/OTS. Based on our findings, both objective (quantitative) and subjective (qualitative) monitoring should be considered in evaluating an individual's adaptation to acute and chronic physiological and psychological stressors.[1,6,40] For example, collecting objective measures using wearable physiological monitoring devices and biomarkers, and qualitative measures such as validated and reliable short response questionnaires, allow one to assess the whole person's response to both acute and chronic stimuli. MDRT should include the following dimensions: (1) performance physiology, (2) psychological function assessment, (3) biological markers, and (4) functional movement assessment.

Numerous researchers[49-53] have reported that the diagnostic assessments and types of wearable devices chosen for tracking physiological measures should offer some degree of validity and reliability, provide telling data, and be easy to administer. However, further exploration of the domains of MDRT is essential to understand the unique conditions and challenges of the SO community.

The Performance Physiology Dimension

Measuring performance capability is an ecologically valid measure of recovery but is not always practical.[6] Decrements in physical performance measures are considered the primary marker for diagnosing OTS in athletes. However, investigators highlight the difficulty in supporting and administering performance tests in sports, especially in large groups of athletes.[30] Nonetheless, sports and exercise medicine practitioners can leverage the real-time data provided by wearable devices to tailor treatment and recovery to SOs individually. Furthermore, and perhaps more importantly, by sharing this physiological data with the SO, they will be able to directly see the performance-enhancing effects of recovery technology and other treatments provided, which provides a strong incentive for adopting recovery techniques. We have seen this "buy-in" phenomenon happen in Special Operations Performance and Recovery, a performance enhancement and recovery program at the Center for the Intrepid, when such data are shared with SO participants.[54] It is hypothesized that such knowledge will facilitate adoption by the SO of essential self-management tools as well as help create a cultural shift toward recognizing the importance of recovery and treatment in the SO community. Nonetheless, published research on the early detection and amelioration of NFO and URS/OTS is presently lacking in the SO community; therefore, this area of research warrants extensive exploration.[6]

Commercially available wearable devices can track important, measurable factors affected by the training and operational demands to which SOs are exposed. For example, heart rate variability (HRV) is an essential physiological variable that can indicate how an athlete responds to training stressors and subsequent recovery strategies over time.[55,56] HRV is the variation in the time between heartbeats and measures ANS health, which refers to the balance between the sympathetic (fight/flight) nervous system and parasympathetic (rest/digest) branches.[56,57] The noninvasive measure of HRV using a wearable device is considered a valuable tool to effectively monitor an individual's response and adaptation to training demands, overall strain levels, and recovery interventions. Thus, to ensure accuracy, long-term (24 h) or short-term (5 min) HRV recordings are recommended by the Society of Cardiology and the North American Society of Pacing and Electrophysiology Task Force.[57]

Hinde et al.[57] recently reviewed a variety of physiological monitors. They evaluated 32 wearable devices based on each device's ability to provide continuous, reliable, and accurate standard HRV parameters in a field setting.[57] They used the following criteria in evaluating the wearable devices: the ability to record HRV data continuously, the range of HRV parameters measured, the validity of HRV measures, battery life, raw data accessibility, the robustness of the device, and its suitability for use in a military field setting.[57] They found that the Polar H10 Heart Rate Sensor delivered better signal quality (99.6%) and had a higher correlation ($r = 0.997$) compared with a three-lead electrocardiogram (ECG) Holter monitor. More importantly, the Polar H10 outperformed the ECG Holter during high-intensity exercise, detecting 74 R-R interval errors (99.4% signal quality) compared with R-R interval errors (89.9% signal quality) from the ECG Holter. Hence, the authors identified the Polar H10 as the most accurate, reliable, and durable wearable device for monitoring continuous HRV in a military field setting.[57]

Omegawave is a noninvasive technology that can be used to assess the internal stress level of a SO, overall readiness to perform, and brain function by employing direct current potential and HRV.[58,59] This device consists of a Bluetooth sensor, HR sensor, electrocardiography chest strap, and electrodes that measure cardiac system readiness, ANS readiness, and central nervous system readiness within 5 minutes.[58,59] The device shows robust agreement with a quality-controlled Holter electrocardiogram, with deviations not exceeding 25ms between beat intervals in 95% of the cases. Hence, this technology is within manageable ranges for clinical practice and sports physiology.[60] Omegwave could prove useful for evaluating the immediate readiness of a SO to perform based on recovery status from the previous day's events.

Commercial sleep monitoring devices can help track the sleep and recovery states of SOs, especially during and after high operational tempo training events and while deployed. However, sports and exercise medicine practitioners should exercise caution when relying solely on these wearable sleep devices to accurately track sleep stages. For example, Stone et al.[51] evaluated the accuracy of eight popular sleep devices, including the Apple Watch Series 3, Beddit Sleep Monitor 3.0, Fatigue Science Readiband, Fitbit Ionic, Garmin Vivosmart, second-generation Oura Smart Ring, Polar A370, and the Whoop Strap 2.0. These sleep-monitoring devices were tested on five study participants for 98 consecutive nights and directly compared with an in-home, previously validated, FDA-approved electroencephalogram device known as the Sleep Profiler (Advanced Brain Monitoring). They evaluated each device's accuracy for measuring total sleep time, total wake time, and sleep efficiency. They observed that a consistent trend for all devices was their inability to quantify the amount of time the user was awake compared with when they were sleeping. The authors' final analysis ranked each device's mean absolute percent error for its total sleep time, total wake time, and sleep efficiency. For this study, they confirmed that the Fitbit Ionic and Oura Smart Ring's sum rank scores were the highest, followed by the Fatigue Science Readiband, Whoop strap, and Polar, Beddit, and Garmin devices.[51]

Kinnunen et al.[53] also highlighted the accuracy of the Oura Smart Ring in measuring HR and HRV. They examined the accuracy of nocturnal (nighttime) HR and HRV in 54 healthy volunteer subjects for 49 whole nights. Enhanced nocturnal HRV was previously associated with improved sleep quality in healthy and clinical patients.[53] This study focused on the importance of standardizing measurements by collecting HR and HRV measures at night because both actions can be affected by prior activities, time of day, and external stressors such as noise, outside temperature, and the presence of people. The authors suggested that to reduce the effects of these compounding factors, nighttime measurement of HR and HRV is appropriate. They found a very high level of agreement between the Oura Smart Ring and the gold standard ECG measurements for nocturnal mean HR ($r^2 = 0.996$) and HRV ($r^2 = 0.980$). Finally, the authors stressed the use of such wearable devices for individualized recovery, sleep, and health-related monitoring: "At present, they (wearables) have enabled highly motivated individual users to adjust their lifestyle and training volumes and pay attention to stress factors by following their ANS responses via changes in their resting HR and HRV."[53]

Performance tests are the gold standard for assessing NFO/OTS because significant decrements in physical performance over time are critical indicators in the early detection of NFO/OTS. To ensure validity, the physical performance test chosen should closely resemble the types of activities the SO routinely engages in and should be recurring (e.g., post-deployment, yearly). Furthermore, establishing baseline performance measures early in the career of a SO may serve as comparatives for distinguishing marked changes in individual performance status. Several maximal performance tests can help distinguish between NFO and OTS.

Other performance tests that are beneficial in the early detection of NFO/OTS are the two-bout exercise protocol, which requires the individual to perform two consecutive maximal exercise bouts to volitional fatigue separated by 48 hours of recovery between tests.[38] The 1.5-mile run test is also helpful because it simulates a maximal test while reducing overall strain on operators, is easy to administer, and may even be used for predicting injury risk and training outcomes. Standard tests used in the military focus on agility, speed, muscular strength, and endurance. However, tests in these domains are less suitable because of inconsistent outcomes associated with NFO/OTS.[6] Unfortunately, according to Vrijkotte et al.,[6] "the ideal set of tests for early detection of NFO/OTS that can easily be conducted regularly does not yet exist." Hence, extensive investigation is essential within this performance dimension.

The Psychological Dimension

Although many of the recovery stress scales described below require further validation within a SO population, they are validated within elite competitive athletic populations and deserve consideration when monitoring recovery status of a SO. Additionally, Nässi et al.[61] recommend that human performance practitioners should first "consider the appropriateness of each psychological tool in the context of their particular group, and regardless of which methods are employed, care should be taken to employ measurement systematically, provide timely feedback, and consider frequency."[61] Psychological recovery monitoring in a SO population may be essential following critical deployments, sustained military operations, and rigorous training courses.

Qualitative questionnaires and measures that can be used to assess recovery in sports neglect the multidimensional facet of assessing overall individual recovery (e.g., internal/external stress). For instance, the visual analog scale pain scale has high test-retest reliability for assessing delayed-onset muscle soreness; however, it provides only a unidimensional measurement of muscular pain perception, not accounting for internal physiological stress. The Profile of Mood States (POMS), although often used in sport-specific recovery research and practice, primarily focuses on stress-related behavior. Assessing an individual's mood-state change in response to training loads is not considered a sport-specific instrument, and the dimensions assessed within the POMS do not adequately gauge the recovery portions of sport extensively.[62,63]

The Subjective Ratings of Perceived Exertion (RPE) Scale is another method routinely used in combination with recovery questionnaires in detecting symptoms of NFO or URS/OTS. However, Urhausen and Kindermann[64] found that overtrained athletes reported only minor changes in their RPE scale ratings, revealing that the RPE scale does not adequately address athletes' multidimensional recovery stress status.[65]

Researchers and practitioners routinely administer the Acute Recovery and Stress Scale (ARSS) and Short Recovery and Stress Scale (SRSS) within the elite competitive athletic arena. These questionnaires provide weekly performance and health information regarding the current recovery-stress status of an individual. The ARSS and SRSS measure the emotional, mental, physical, and overall aspects of acute recovery-stress states. The instrument uses a 7-point Likert Scale. Both questionnaires have acceptable reliability and have been validated in athletes aged 16 and older.[32]

The Recovery-Stress Questionnaire (RESTQ) is a 36-item inventory comprised of six sport-specific scales and six general scales that requires the individual to rank each item on a Likert scale from 0 to 6 (0, does not apply at all, to 6, fully applies). The RESTQ identifies individual imbalances in recovery stress status, which correlates with performance factors and biomarkers of stress, such as testosterone, cortisol, and creatine kinase (CK).[30,34] The RESTQ is especially useful for gauging the physiological consequences of potentially stressful events while also helping to show disparities in the individual's recovery-stress state. Ultimately, the information gleaned from the RESTQ can aid in the early detection of an individual's risk for NFO/OTS.[34]

The Biomarker Dimension

According to the Joint Consensus Statement of the European College of Sport Science and the American College of Sports Medicine,[40] the scientific literature concurs that NFO/OTS should be observed on a continuum with a disturbance, an adaptation, and lastly, a maladaptation of the HPA axis.[38] Although biomarker reference ranges are proper for generalized populations, clinicians and human performance experts should consider establishing individualized mean reference ranges for SOs. For instance, these individualized "normal' values can be appropriately set upon operators' entry into their initial training pipeline and tracked over time to detect the early symptoms of NFO/OTS.[40]

In this dimension, there are several effective enzyme indicators of OTS. The testosterone (anabolic hormone)/cortisol (catabolic hormone) (T/C) ratio can be used with a difference of >30% between the hormones (T/C), serving as a critical indicator that the participant is in a state of OTS.[30] Additionally, enzyme markers such as lactate dehydrogenase and CK should also serve as reliable markers in diagnosing OTS. Researchers have reported that an increase in CK in the blood of 500 U/L is associated with a skeletal muscle injury. However, CK can be difficult to measure, and the measure can be variable.[39] Although the critical indicators suggested are not all-inclusive, multiple inflammatory markers allow for a more precise and accurate indication of long-term dysregulation of the endocrine system because of their pleiotropic nature.[30] Critical hormones released in response to stress include corticotrophin-releasing hormone, adrenocorticotropic hormone (ACTH), cortisol, growth hormone (GH), and insulin-like growth factor-1. ACTH and GH can distinguish between NFO/OTS. The critical weakness in using the indicators within this dimension is the need for routine blood samples. Besides the inconvenience, blood sampling is also sensitive to sampling conditions and time, diurnal variations of hormones, poor reproducibility, and varying methods and techniques used to assess hormonal variations.[30,38]

The Functional Movement Dimension

Over the years, SOs can develop upper and lower body lateral functional asymmetries.[67] Such alterations in muscular activation patterns can be measured noninvasively during real-world situational training using wearable technology.[67-69] For example, Athos is a promising and validated technology consisting of compression apparel that individuals wear directly against the skin during "real-time" training exercises to detect movement deficiencies. After each physical training session, Athos artificial intelligence evaluates the participant's physical performance on nine key injury-prevention markers and assigns them to an injury risk category. Athos assigns the individual lower body supplemental exercises supporting their injury risk category to help the participant progress toward healthier movement patterns. The results from three experiments showed that the output from Athos wearable surface-electromyography sensor technology is valid and reliable and that the measures are repeatable and predictable.[67-72]

<1>Conclusions and Implications

This review highlights knowledge gaps that deserve exploration, especially in the domain of longitudinal implementation, health, and recovery monitoring in the special operations population. Our findings indicate that contributing factors leading to dysregulation of the neuroendocrine system and ANS likely stem from the combined rigors of training and continuous deployment demands on SOs throughout their careers. These recurring demands can result in a chronically high burden of physical and psychological stress known as allostatic overload. We identified four central biomarkers in the literature that are associated with allostatic overload: cortisol, adrenaline, noradrenaline, and DHEA. These biomarkers accurately measure HPA neuroendocrine responses to stress.

Our review found that allostatic imbalance in SOs may occur when supramaximal demands are prolonged and repeated; without adequate recovery, performance will decline, and the body will show signs of increased wear and tear, known as NFO. NFO can result in harmful psychological and hormonal disruptions and decreased performance, leading to OTS. NFO commonly occurs in SOs when mission demands exceed recovery, during both training and deployments, and can persist even after returning to the home station. If NFO continues over more extended periods, OTS will develop. OTS can lead to a chronic condition in which performance and health decline further in SOs.

We propose a theoretical continuum model, which describes incremental stages leading to increased risk of acute and chronic decrements in physical, mental, neuroendocrine, and immunological systems. Further, we postulate that the biochemical conditions for NFO/OTS arise from SO exposure to repeated acute stressors, lack of adequate recovery time between stress exposures, and SO perceptive/cognitive/emotional reaction to these stressors. Finally, we found that continual overactivation of the homeostatic adaptive pathways will likely limit the ability of SOs to extend their homeostatic range, ultimately leading to compressed adaptive spectra, manifesting into chronic low-grade stress.

Our findings illustrate the importance for health practitioners to consider the biological uniqueness of individuals. Thus, a recommended first step for investigating NFO/OTS in elite populations would be to avoid the usual population-based approach. Recovery monitoring should begin in the early phases of the initial training of a SO. The baseline measures obtained during the initial training phase should be used as a comparator throughout an operator's career to detect early signs of NFO/OTS. Establishing standardized testing combined with structured data aggregation in the SO community is also essential. Finally, our findings illustrate the importance of implementing MDRT as well as effective recovery strategies and technologies for SOs to reduce their attrition rates, enhance their readiness, and prevent the chronic overuse injuries so often reported in this community.

Disclaimer

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Author Contributions

RBO performed the first literature review search and transcribed the initial review draft. RBO and LS performed the three-step search strategy and independently reviewed and appraised articles. BK assisted in revising the introduction and the psychological section of this review. JT provided critical review and recommended revisions for each section of this review. RS provided extensive re-organization of the Introduction section of this review.

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