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REVIEW

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Recovery redefined: A multidimensional approach to enhancing human performance in the human weapon system

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ABSTRACT

Introduction

Recovery is a foundational but underdefined element of the Human Weapon System (HWS) paradigm, which integrates physical, psychological, cognitive domains, etc. to optimize the tactical professionals. Existing definitions such as "return to duty" or "combat regeneration," are overly simplistic and fail to capture the complexity of recovery within the multidimensional operational demands placed on HWS personnel. This review proposes a comprehensive, operationally relevant definition of recovery tailored to the HWS context.

Materials and Methods

This narrative review synthesizes literature across traditional and non-traditional Human Performance (HP) domains, including physical readiness, cognitive function, fiscal methods, nutrition, sleep, and environmental adaptation. Emphasis was placed on identifying causal (e.g., workload, stress exposure) and resultant (e.g., biomarkers, fatigue indices, psychological metrics) factors that affect recovery processes. The review also examined cross-domain interdependencies that influence performance degradation and restoration.

Results

Recovery within the HWS paradigm is best conceptualized as a multidimensional process involving restoring causal and resultant performance metrics to baseline or optimal functional levels.This review highlights that effective recovery cannot be assessed solely through return-to-duty timelines or physical indicators; it must also incorporate resolution of the causal metrics. By aligning recovery with tangible and measurable outputs across the HWS HP domains, this model enables a more precise quantification of fatigue and restoration, offering a holistic perspective.

Conclusions

This review proposes a refined definition of recovery as "the process of restoring causal and resultant metrics to baseline levels to mitigate fatigue and maximize performance across all HWS HP domains." This conceptual model is a new foundation for developing targeted, evidence-based interventions and monitoring strategies to enhance recovery, resilience, and sustained performance among tactical HWS professionals.

KEY WORDS

Recovery; Human Weapon System (HWS); Fatigue; Performance; Metrics; Human Performance (HP)

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Introduction

Human performance (HP) is essential to Human Weapon System (HWS) populations. Over the past decade, the Department of Defense has stood up HP focused programs to address the specific needs and challenges of service members, including Special Operations Command (SOCOM) Preservation of the Force and Family (POTFF) in 2013 and the US Army Holistic Health and Fitness (H2F) program in 2021. In fiscal year 2021, the US Army budgeted $110 million to resource the Holistic Health and Fitness (H2F) program [1]. The US Armed Forces are developing and adopting different HP programs like H2F and POTFF to meet the needs of the US HWS tactical professionals. A similar framework is employed in these programs which aim to optimize and sustain mission readiness, longevity, and performance through a domain or pillar system addressing a holistic approach [2]. The term, recovery, is disguised with phrases such as "return to duty" or "combat regeneration." In military jargon, these terms explain recovery at the most basic level. However, recovery has undefined broader concepts across the different HWS HP domains, encompassing more than the traditional five-domain athletic human performance model [2].

This paper aims to define recovery through the multi-domain HP lens of the HWS. To accomplish this task,this paper will explain the term HWS, the different types of fatigue, how fatigue affects the different HWS domains, how to qualitatively measure fatigue, and use these elements to define and quantify recovery.

What is the Human Weapon System?

In the early 2000s, human performance programs were applied to US Military Special Operations Forces, particularly in strength and conditioning, modelled after professional and Division 1 NCAA athletic programs. The application of these athletic performance programs led to the term "Tactical Athlete" being applied to the US Military, police, and first responders [2–7].

Typically, a "tactical athlete" is a term often used to describe professionals who must maintain a high level of physical fitness and mental toughness to perform their jobs. These individuals typically engage in specialized training regimens that focus on functional fitness, encompassing a variety of exercises and routines designed to improve their overall physical performance and reduce the risk of injury. An athlete is "a person who is proficient in sports and other forms of physical exercise." Usually, a person envisions a professional or high-performance athlete when discussing

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the traits of an athlete. This image occurs because professional athletes are at the peak of their physical and genetic performance. For this reason, the military and first responder professions began to apply professional and collegiate athletic performance models to improve physical performance. Therefore, first responders and warfighters began to be called "tactical athletes". However, first responders, law enforcement, and tactical populations differ significantly from athletes [2].

Sports and HWS populations are fundamentally different. HWS professionals are exposed to different intensities and sustained levels of stress when compared to athletes. Due to these differences, HWS professionals do not meet the definition of 'tactical athlete'. HWS is defined as "A human being comprised of a complex set of physiological, cognitive, and emotional systems that create a cohesively functioning tool that is professionally trained, maintained, and optimized; capable of learning and adapting; and using various equipment and knowledge for constructive, destructive, and healing purposes, always bounded by societal moral, ethical, and legal standards" [2].

The HWS framework is more precise in defining and addressing the unique demands for understanding the physical, cognitive, emotional, policy, and fiscal demands placed on tactical, law enforcement, and first responder populations. The tactical athlete paradigm emerged from adapting sports performance training models to tactical populations. While the tactical athlete framework acknowledges the physical demands of these professions, it fails to account for the broader and more complex challenges these professionals face, such as life-and-death decision-making, high-stress environments, and multifaceted roles beyond physical performance. Labeling these populations as athletes oversimplifies their realities and neglects the holistic approach required to optimize their performance.

The HWS paradigm defines tactical professionals as integrated systems comprising physiological, cognitive, and emotional subsystems capable of constructive, destructive, and healing actions within moral, ethical, and legal boundaries. This approach emphasizes adaptability, resilience, and specialized skills essential for operating in unpredictable, high-stakes environments qualities that traditional athletic training models do not address. By viewing tactical professionals as weapon systems, human performance programs can expand beyond the conventional domains like physical performance, sports medicine, and nutrition to include additional areas such as education, spirituality, fiscal, and policy (Figure 1). This holistic approach acknowledges the complex and interconnected nature of the HWS and aims to tailor human performance optimization to meet their unique demands, ensuring they are better equipped to fulfill their mission-critical roles.

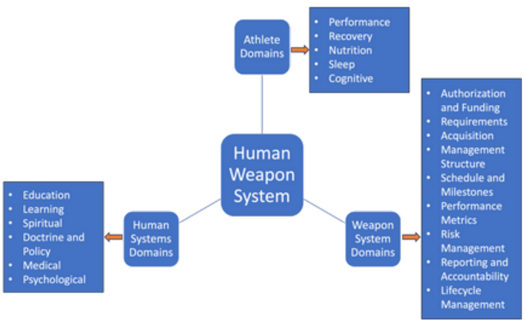

Figure 1. The human performance (HP) domains of the Human Weapon System (HWS). The HWS domains consist of domains from the athlete HP model, weapon system program of record, and human systems [2]. These listed domains are not an exhaustive list.

What is Fatigue?

Understanding and defining the different types of fatigue is a precursor to defining recovery. Fatigue is defined the inability to maintain a particular activity's intensity and duration. This definition includes acute and chronic causes that cause decrements in exertion, endurance, and resilience. Two types of fatigue exist: central (chronic causes) and peripheral (acute and chronic causes) fatigue. These types of fatigue are very different but have some similar underlying causes. This section defines and discusses these two types of fatigue.

Central fatigue

As its name suggests, central fatigue relates to the central nervous system (CNS) and its ability to communicate with the peripheral nervous system (PNS) due to a failure at the level of the central command center [8-11] (Figure 2). Central fatigue is a complex phenomenon characterized by a progressive failure of the CNS to adequately activate muscles, leading to reduced physical performance and endurance [10–12]. It is influenced by various physiological and biochemical factors, which different types of exercise and conditions can trigger. The causes of central fatigue can be broadly categorized into neural, biochemical, psychological, and systemic factors [10,13–18].

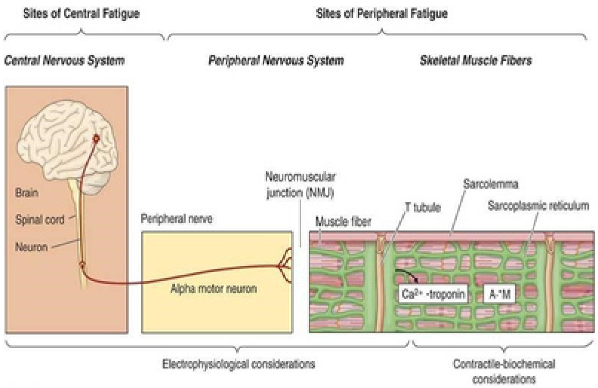

Figure 2. This figure depicts the different sites where central and peripheral fatigue occurs.

The neural factors of central fatigue appear to be caused by the CNS's inability to generate sufficient motor commands, which is influenced by neural feedback from working muscles. This feedback involves small-diameter group III and IV nerve fibers that affect CNS processes [10,13]. Long-duration hyperoxic exposures and high-intensity activity can reduce nerve impulses and decrease neuronal excitability, contributing to central fatigue [16,19,20]. The biochemical factors, particularly the accumulation of hydrogen ions (H+) (muscle acidosis), are shown to contribute to central fatigue by affecting group III/IV muscle afferents, which relay fatigue signals to the CNS [14,15]. Additionally, mitochondrial dysfunction and oxidative stress, characterized by decreased ATP and increased reactive oxygen species (ROS) levels, are implicated in central fatigue, affecting the hippocampus and skeletal muscle tissues [16–18]. Psychological factors, such as emotional stress, play a pivotal role, as evidenced by animal models replicating human symptoms of depression and anxiety [16]. Finally, the systemic factors are exacerbated by systemic conditions such as chronic diseases, including multiple sclerosis, chronic obstructive pulmonary disease (COPD), and cardiovascular disorders, which affect muscle perfusion and oxygen delivery [13].

While central fatigue is often associated with physical exertion, psychological and systemic health play a more prominent role in its development. Understanding these

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diverse causes can aid in developing interventions to mitigate central fatigue and better define recovery.

Peripheral fatigue

As its name suggests, peripheral fatigue relates to the PNS' ability to activate skeletal muscle. This type of fatigue is defined as the reduced ability of skeletal muscle to produce force despite unit activation of the CNS [21,22]. Peripheral fatigue is a complex phenomenon resulting from various biochemical and mechanical processes within the muscle cells and the muscle-tendon complex, which is characterized by a decline in muscle function due to non-central nervous system mechanisms, often exacerbated by intense or prolonged physical activity (Figure 3). The primary causes of peripheral fatigue include the accumulation of inorganic phosphates (Pi) and hydrogen ions (H+), alterations in cross-bridge formation, changes in muscle-tendon unit stiffness, and reduction in ATP production due to free radical and inflammation accumulation [9,12,17,18,23–26]. These factors collectively contribute to the reduced ability of muscles to produce and sustain forceful contractions over time.

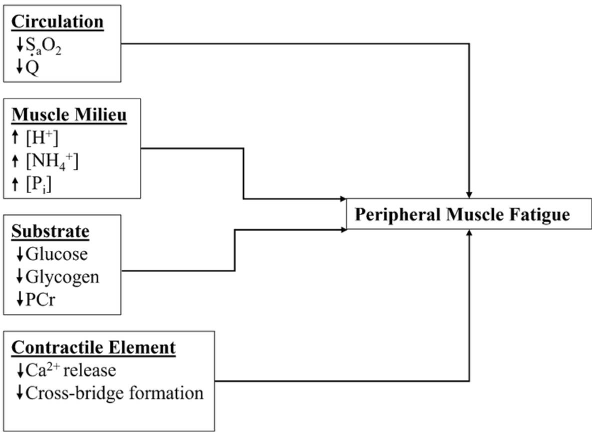

Figure 3. This figure depicts the causes of peripheral fatigue [27]. Used with permission.

While local muscle factors primarily drive peripheral fatigue, the role of systemic conditions, such as chronic stress, exposure to austere conditions, and low physical fitness, will exacerbate fatigue. These conditions limit physical, social, emotional, and spiritual functioning, highlighting the need for a comprehensive approach to managing peripheral fatigue in HWS professionals.

Quantifying Recovery in the HWS HP Paradigm

Central and peripheral fatigue have tangible and quantifiable effects on HWS professionals. Figure 1 details 19 possible HP domains; however, the figure is not exhaustive. HP and medical professionals can measure resultant and causal effects of central and peripheral fatigue. Recovery is defined by understanding and applying resultant and causal metrics.

A resultant metric refers to a composite or combined measurement derived from multiple individual metrics or components. In other words, it is a metric that represents the outcome or effect of several contributing factors. This type of metric is often used in complex performance evaluations where no single factor can fully capture the desired outcome. A few common HP resultant metrics are force production, speed and power, composite score (i.e. the Army Combat Fitness Test or the Air Force Special Warfare Operator Fitness Test). The goal of a resultant metric is to simplify a complex performance evaluation into a more digestible or actionable measure by integrating multiple variables.

A causal metric refers to a measurement or metric that is directly influenced by or results from a specific cause or factor. In other words, it reflects the outcome or impact of a particular action, event, or condition, and is used to understand how changes in one variable leads to changes in another. An HP metric example is an increase in sprint times (the resultant metric) due to improved lower body power (causal) due to specialized training (acute stressor/stimulus). Another example is a decrease in lower limb force production (resultant) due to decreased quadriceps size (resultant) with increased TNF-α, IL-6 blood concentrations (resultant) after a six-week field training exercise (acute stressor/stimulus).

When identifying the effects of fatigue, the resultant metric is the first tangible observation (i.e. decreased force production, mood alteration, increased nocturnal resting heart rate, etc). This is how HP and medical professionals can begin to identify the negative effects of stress. The causal metrics help the HP and medical professionals understand how the effects of fatigue are causing the observed resultant metric. In many cases, increases in inflammatory-mediated cytokines and oxidative stress are the causal metrics, but this is not always the case. No matter the cause metric, once identified, the path to understanding how fatigue is causing the negative outcome. The rest of this section examines how recovery from fatigue is quantified and thus defined via three independent HWS multi-modal HP paradigm domains.

Musculoskeletal (MSK) domain

Under the HWS HP construct, the performance domain in the Athletic HP model (Figure 1) is referred to as the Musculoskeletal (MSK) domain. Recovery, in particular to the MSK Domain (Figure 1), involves the processes and strategies used to restore energy, repair tissues, cardiovascular function, and regain force production and velocity after exertion. Many of these factors are biochemical and exertion based. This section details these factors and how fatigue and recovery are quantified.

MSK domain resultant metrics

MSK performance testing metrics

A few highly used MSK performance testing techniques provide resultant metrics. These techniques include one and three-repetition maximum lifts, force production measured by force plates and isokinetic dynamometers, vertical jump, broad jump, etc. [2,28,29]. These techniques produce valuable metrics such as peak force, rate of force production, impulse, peak velocity, power output, time to exhaustion, and eccentric rate of development [29–31]. These metrics, which are not all-inclusive, provide valuable insights into neuromuscular function and MSK characteristics of strength, power, and muscular endurance performance [28,29,31]. MSK performance depends on an individual's rest and fatigue levels [12]. However, MSK performance metrics prove the quantitative and tangible data on how fatigue effects MSK performance. To identify and understand the root causes of how fatigue is causing the MSK performance changes, more information is generally needed.

MSK domain resultant metrics

Pre-hypertrophic hormones and growth factors

Insulin-like growth factor 1 (IGF-1) is a peptide hormone that plays a crucial role in growth development, metabolizes as a primary mediator of human growth hormone, and is involved in several cellular processes, such as proliferation, differentiation, and apoptosis [32,33]. Some research shows that chronic

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fatigue, especially in chronic fatigue syndrome, can cause decreases in measurable IGF-1 production. Also, long periods of caloric restriction and large amounts of energy expenditure will cause reductions in IGF-1 production and concentrations [34]. Strong evidence suggests that chronic fatigue causes decreases in IGF-1 production; however, caution must be exercised. Little to no research exists that investigates the effects of fatigue on IGF-1 in HWS populations.

Myostatin and activin A are part of the TGFβ superfamily that downregulates muscle protein synthesis [33,35,36]. The effects of these two hormones are blocked by follistatin [33,35,36]. Research suggests these hormones are not directly affected by fatigue but rather through the increased concentration of cytokines and free radicals [33,36–38].

Changes in androgen production and concentrations correlate to acute and chronic fatigue. For example, changes in cortisol levels are well-documented. Acute stress causes heightened cortisol production, whereas chronic stress causes decreased cortisol production and sensitivity. Increases in inflammation-mediated cytokines such as TNF-α, IL-,1 and IL-6 and oxidative stress influence the secretion of cortisol [39,40]. Testosterone (free and bound) levels react similarly to acute and chronic stress as demonstrated with cortisol [37,41–44]. Conversely, the changes in DHEA in response to stress are unclear [37,43,44].

Several other associated growth factors are involved with MSK growth and repair. Several factors such as fibroblast growth factors, vascular endothelial growth factor, and hepatocyte growth factor are crucial elements of satellite cell activation and proliferation. The increase in cytokines and oxidative stress reactive oxygen species (ROS) due to chronic stress upregulates myostatin and downregulates as fibroblast growth factors, vascular endothelial growth factor, hepatocyte growth factor, and other regulatory proteins [45,46]. Combining this downregulation of these associated growth factors and regulatory proteins and upregulation in myostatin due to inflammatory cytokines and oxidative stress causes significant decrements to MSK regeneration and adaptation.

Structural, protection and energy production proteins

This grouping of MSK proteins is highly extensive. However, only a small number of these proteins are detectable. Skeletal muscle creatine kinase (CK-MM) is highly associated with MSK damage [35,47–52]. Furthermore, CK-MM is highly detectable via blood serum and urine [53,54]. This protein is an excellent marker of MSK damage is due to its location on the myomesin bridges within the M-band of the myofibril. CK-MM is the enzyme responsible for adenosine triphosphate synthesis via the phosphagen pathway within MSK [12,35]. MSK microtrauma causes breaks in the myomesin bridges which release CK-MM in the bloodstream. CK-MM recovery reference ranges exist to measure MSK repair after intense exercise [55,56].

Creatinine is another excellent marker of MSK damage [57]. This protein is a byproduct of the “spontaneous, nonenzymatic, irreversible cyclization of creatine” [58]. Similar to CK-MM, creatinine is released into the bloodstream during MSK breakdown and microtrauma. Additionally, reference ranges exist to measure MSK repair and are measured via blood serum and urine [58–60]. Similar to CK-MM blood serum and urine concentrations, reductions in urine creatinine concentrations are a measure of MSK repair.

Titin, a structural protein that is considered the “third myofilament”, provides elasticity and mechanical stability to the sarcomere [35,61–65]. As MSK microtrauma and damage occur, urine titin concentration increases, making this protein an excellent marker for measuring MSK damage [66,67]. After intensive eccentric exercise, urinary N-titin increases and is correlated to other markers of MSK damage [68]. Titin concentrations are highly correlated to CK-MM concentrations as a marker of MSK damage after intense exercise [68–71]. As with CK-MM and creatinine, reduction in titin concentrations after intensive exercise is correlated with MSK repair.

Heat Shock Proteins (HSP) are proteins that play critical roles in cellular protection against inflammation and oxidative stress [10,72]. Eccentric MSK contractions, HSPs 72 and 25 are excellent markers on the severity of MSK damage [73,74]. This class of protective proteins are only detectable in blood serum. As with CK-MM, creatinine, and titin, increases in HSP blood serum concentrations are highly correlated to MSK damage, and the return to normal concentrations after intensive exercise is correlated to MSK repair [74,75].

Inflammatory cytokines and oxidative stress

Up to this point, the aforementioned biomarkers investigate the MSK's structural integrity since this MSK aspect produces the MSK mechanical action. However, these markers may not fully explain the causal changes in MSK performance metrics. MSK markers, and other domain biomarkers, are influenced by inflammatory cytokines and oxidative stress.

TNF-α, IL-1 and IL-6 and free radicals play significant roles in many physiological processes. When cytokine and free radical concentrations exceed redox balances, they cause physiological dysfunction by interfering with key protein and enzymatic reactions [76–81]. TNF-α, IL-1 and IL-6 and free radicals, particularly reactive oxygen species, are detectable in blood serum. As the overall stress load increases due to stressors such as physical exertion and sleep deprivation, the body's response includes elevated cytokine levels and increased oxidative stress, characterized by higher concentrations of ROS [10,17,18,72,82]. As the stress response is alleviated, the cytokine and ROS concentrations decrease [10,72,82]. The detection in changes in these biochemicals provide tangible insights into the causal effects of fatigue and quantifiable recovery metrics.

Cognitive, psychological, and spiritual domains

Traditionally, these three domains are separate. However, the holistic integration of these four domains is essential for HWS performance optimization. These domains share significant context of the Human Weapon System as this paradigm integrates elements of the cognitive, psychological, spiritual, and learning domains, forming a central hub for mental resilience and performance. HWS professionals must have the ability to acquire, process, and apply knowledge while maintaining psychological resilience and emotional regulation under stress. For example, the cognitive domain relies on the psychological well-being, as factors like stress, anxiety, and emotional dysregulation to maintain and improve decision-making, focus, and adaptability under fatiguing conditions. The cognitive domain draws from the learning domain by leveraging memory, recall, and metacognition to adapt to new challenges continuously. Furthermore, the Spiritual domain provides a deeper sense of purpose, values, and inner resilience, allowing HWS professionals to be grounded, motivated, and aligned with their values, enabling them to

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sustain peak performance and ethical conduct in the most demanding operational environments. Synergy across these four domains is crucial; optimization is measured through resilience. Resilience is one's ability to "prepare, absorb, recovery from, and adapt to disruptions". This term refers to one's capacity to withstand and bounce back from challenges [2]. Cognitive, psychological, learning, and spiritual domain professionals use a myriad of tools to measure the effects of fatigue and gauge resilience.

Cognitive, psychological, learning and spiritual domains resultant metrics

Cognitive, psychological, learning and spiritual domains testing metrics

Measuring resilience is critical for cognitive psychologists, psychologists, and chaplains who work with HWS professionals to promote mental health, well-being, and spiritual growth. Two primary avenues to measure resilience are through self-assessments and heart rate variability (HRV). The following section discusses commonly used self-assessment tests to measure resilience, highlighting their strengths, limitations, and applications in various settings [2].

Self-Assessments and questionnaires

The cognitive, psychological, learning, and spiritual domains utilize self-assessments and questionnaires to ascertain certain metrics. Many of these tests measure the interconnected metrics of resilience, stress management, decision-making, and adaptability [2,83,84]. Although each domain may have different tests for these four resultant areas, the metric is measurable, tangible, and shared across all domains. This overlap highlights the interconnected nature of these domains, emphasizing the importance of a holistic approach to understanding and enhancing human performance. By leveraging these shared metrics, HP and medical professionals can gain deeper insights into an individual's overall well-being and capacity to thrive, providing targeted interventions that address multiple facets of their development simultaneously. Three of the most used self-assessment tests are discussed below.

The Conner-Davidson Resilience Scale is a self-assessment tool used to measure psychological resilience. This 25-question, self-report questionnaire uses six domains: personal strength, social support, family support, emotional regulation, coping, and spiritual belief to measure and quantify psychological resilience [85]. This self-assessment has high test-retest and internal consistency rates [86]. The Connor-Davidson test does have limitations. This test originated to test the resiliency of trauma survivors and individuals with severe and chronic medical conditions [87]. The lack of introspect into different demographics or cultural groups may lead to cross-cultural validity [88]. Besides its limitations, the Connor-Davidson Resilience Scale continues to be one the most widely used self-assessments in academia and in the field [85-88].

The Resilience Scale for Adults is a six-question resilience self-assessment widely used in clinical research and military populations [88-91]. The test is used to evaluate the impact military service and combat experience for active-duty service members and veterans [92]. This assessment is widely used due to brevity, scoring simplicity, and its reliability [88-91]. The Resilience Scale for adults is seen to have two specific limitations. The primary limitation is how the test was designed around the traditional definition of resilience. The assessment does not use a theoretical framework which can cause limitations in the assessment's ability to fully encapsulate the complexity of resilience [88-91]. The secondary limitation, which stems from the test's rigid interpretation of resilience, is the narrow range of constructs the test uses. The six-questions are limited to personal strength and social and family support. This narrow view lacks insight into other aspects of resilience such as emotional regulation and spiritual well-being. Despite these limitations, its brevity and ease of use is a make it an easy tool used by HP and medical professionals in a field setting.

The Spiritual Resilience Scale is a multi-dimensional questionnaire that assesses spiritual resilience. The 20-question self-assessment test investigates a few areas such as sense of meaning and purpose, faith and trust, spiritual connection, sense of awareness, and community [93]. The strengths of this test assist professionals to evaluate the relationship of spiritual reliance and mental health outcomes [94]. The spiritual approach creates limitations to this assessment. The Spiritual Readiness Scale places a significant emphasis on the positive aspects of spirituality. This aspect make skew the outcomes by avoiding exploring the negative aspects of spirituality. The hyperfocus nature on spirituality of the test skips over cultural and socioeconomic factors [93,95]. These factors play a significant influence spiritual resilience such as support systems and resources [93,95]. Despite these limitations, the Spiritual Resilience Scale is one of the most widely used self-assessments to measure spiritual resilience.

Relying only on self-assessments limits a professional's ability understand the other impacts of fatigue on resilience. This aspect is especially true for the physiological responses to fatigue. An emerging concept is a mixed-method approach to include heart rate variability (HRV) metrics to further understand resilience.

Heart Rate Variability (HRV)

A crucial shared resultant test is heart rate variability. This metric is significant for the cognitive, psychological, spiritual, and learning domains because it is a marker for stress response and recovery [96-100]. At its core, HRV is the "variation in inter-beat intervals of the heart and reflects the level of activation of the autonomic nervous system, which is indicative of physiological and psychological stress levels" [101]. The interplay of the sympathetic and parasympathetic nervous systems determines an individual's heart rate. The greater the activation of the sympathetic nervous system, the smaller the variations in HRV; the greater the parasympathetic nervous system, the greater the variations. Under stressed and fatigued conditions, HRV decreases signaling greater sympathetic nervous system activation. The use of HRV as a tool for monitoring stress and recovery in austere settings highlights the importance of understanding the balance between stress exposure and recovery several HWS HP domains.

Building on the concept of HRV as a marker for stress response and recovery, combining HRV and self-assessments create a more complete picture to measure and quantify resilience. HRV assists individuals to gain insight into their physiological and psychological responses to fatigue and stress, enabling them to identify areas where they may need to focus on stress management and recovery strategies [100,102–104]. These self-assessments provide insight to identify patterns, thoughts, and emotions that may be contributing decreased HRV, allowing individuals to develop targeted strategies to improve their resilience. Furthermore, by regularly monitoring

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HRV and completing self-assessments, individuals can quantify their progress over time, adjusting their stress management and recovery techniques as needed [100,102–104]. This mix-method approach can provide a powerful tool for building resilience, enabling individuals to better navigate challenging situations and maintain optimal performance across various domains, including cognitive, psychological, spiritual, and learning [100,102–104].

Cognitive, psychological, learning and spiritual domains causal metrics

The effects of hormonal imbalances, inflammation, oxidative stress, androgen imbalance, and mitochondrial dysfunction on psychological, cognitive, and spiritual resilience are complex and multifaceted. Hormonal imbalances, such as elevated cortisol levels, can disrupt the body's natural rhythms and contribute to fatigue, leading to increased anxiety and stress levels, decreased mood, and impaired emotional regulation [105]. Additionally, chronic inflammation can promote fatigue by activating the immune system and releasing pro-inflammatory chemicals, which can lead to decreased motivation, decreased sense of purpose and meaning, and increased risk of mental health disorders [106–109]. Oxidative stress, which occurs when the body's antioxidant defenses are overwhelmed by free radicals, can also erode psychological, cognitive, and spiritual resilience by damaging cellular structures, disrupting the body's natural rhythms, and increasing the risk of chronic diseases [110,111].

Androgen imbalance, which can contribute to fatigue, undermining psychological, cognitive, and spiritual resilience [112]. Decreased motivation and increased symptoms of depression and anxiety are all potential consequences of androgen imbalance, which can lead to a decrease in overall well-being and an increased risk of burnout [105,113,114]. Mitochondrial dysfunction, which can lead to fatigue due to decreased energy production, can also erode psychological, cognitive, and spiritual resilience by disrupting the body's natural rhythms, such as sleep, and increasing the risk of chronic diseases [109,113,114]. Furthermore, mitochondrial dysfunction can impair memory and concentration, decrease attention and focus, and increase the risk of cognitive decline and dementia [111,112].

The impact of these factors on spiritual resilience is also significant, as they can lead to decreased sense of purpose and meaning, increased feelings of disconnection and isolation, and decreased ability to practice mindfulness and meditation [105]. Additionally, these factors can increase the risk of spiritual crisis or existential distress, which can have a profound impact on an individual's overall well-being [105]. Addressing these underlying factors through lifestyle changes, nutrition, and stress management techniques can help to promote psychological, cognitive, and spiritual resilience [109]. For example, practicing mindfulness and meditation can help to reduce stress and anxiety, while engaging in regular exercise and eating a balanced diet can help to improve mood and reduce the risk of chronic diseases [111]. By taking a comprehensive approach to addressing these factors, individuals can help to promote their overall well-being and resilience.

The effects of hormonal imbalances, inflammation, oxidative stress, androgen imbalance, and mitochondrial dysfunction on psychological, cognitive, and spiritual resilience are complex and multifaceted. By understanding the impact of these factors on overall well-being, individuals can take steps to promote their resilience and reduce the risk of mental health disorders [110,112,114]. As stated by McEwen, "the brain is a highly dynamic and plastic organ that is shaped by experience and environment," and by addressing these underlying factors, individuals can help to promote their overall well-being and resilience [105]. Furthermore, as highlighted by Dantzer et al., "inflammation is a key component of the stress response," and by reducing inflammation, individuals can help to promote their psychological, cognitive, and spiritual resilience [108].

Fiscal domain

Fiscal domain resultant and causal metrics

Domains outside of the traditional five-domain athletic performance model, such as the fiscal domain, are often overlooked in traditional athletic modeled HP programs. The HWS HP paradigm considers the effects of these types of domains, such as the fiscal domain, and how they influence HWS professionals' performance. Since these non-traditional domains lack standardized assessment protocols within the performance model, practitioners frequently adapt tests and metrics from well-established domains from the five-domain athletic model or from other analogues found within industry. While borrowing from these methodologies provide valuable insights, this process may not fully capture the complexity and interdependence of these non-traditional domains within the broader performance context. As a result, there is a growing need to develop specialized, validated assessments that better reflect the unique demands and challenges of these emerging performance areas. However, using the borrowed metrics provides practitioners with a starting point to quantify the effects of fatigue and recovery.

The fiscal domain plays a pivotal role in HP by addressing the financial resources required to support HWS professionals. This domain includes programmatic budgeting for essential components such as training programs, specialized equipment, health services, and continuing education to ensure sustained performance and readiness. Understanding the fiscal aspects at the programmatic and individual levels involves assessing cost-effective strategies for optimizing performance while balancing long-term sustainability and return on investment. Factors such as access to funding resources and constraints, political factors, and the allocation of personalized support services all play a crucial role in shaping an HWS professional's ability to achieve and maintain peak operational effectiveness. Focusing on and analyzing the programmatic and individual needs, HWS HP programs measure the effects of fatigue on the program and find ways to improve fiscally.

Programmatically, an HWS HP program can leverage best practices from various industries, such as corporate financial management, healthcare, and government budgetary frameworks. Effective fiscal management within HWS programs requires comprehensive assessments to ensure resources are allocated efficiently, costs are controlled, and return on investment ROI is maximized while maintaining maximum performance and recovery. These resultant metrics give strategic insight into how well the program works and its sustainability. The following are some possible metrics used:

Cost-Benefit Analysis (CBA)

The CBA is a systematic financial evaluation tool used to assess the strengths and weaknesses of alternatives to determine the best approach to achieve benefits while minimizing costs. For the Fiscal Domain, the CBA can be used to evaluate the cost per service member for implementing an HP program versus the estimated benefits of reduced injury rates and improved operational efficiency [115–117]. As recovery rates improve, the cost per HWS professional will decrease.

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Return on Investment (ROI)

Like the CBA, ROI is a financial performance metric used to evaluate the efficiency or profitability of an investment. It measures the gain or loss generated relative to the cost of the investment, providing a straightforward way to assess how well an investment has performed. In an HWS HP, the comparison of specialized equipment to measurable performance outcomes, such as changes (positive or negative) in physical fitness scores, is an ROI metric [2,28,118–120].

Key Performance Indicators (KPIs)

In Human Performance, KPIs are a set of carefully selected metrics crucial to assessing the performance and outcomes of individual athletes or teams. The primary goal of KPIs is to identify the most relevant tests and measurable factors that directly impact the human performance of the HWS [28]. These indicators enable practitioners to track progress, establish goals, and refine training strategies to enhance efficiency and achieve optimal results. KPIs are used to evaluate essential aspects of an organization, such as strategic, operational, and functional components, by comparing them against predefined objectives or desired outcomes [121].

Applying these industry-proven methodologies and metrics, HWS measures and continuously improving their effectiveness. Typically, at the programmatic level, the Fiscal Domain resultant tests do not dive into the causes. The causes come from other domains and rely on these domains' causal metrics to fully understand the outcomes. However, the Fiscal Domain applies to the individual HWS professional as well.

Fiscal imbalances are a source of stress. Stress caused by fiscal imbalances impact the social, professional, and personal aspects of HWS professionals. Fiscal stress is a significant cause in increases mental health issues, job performance, career decisions, and family implications [122–126]. Just like training stress from exercise or emotional stress, long term exposure to stress causes fatigue. This fatigue will exhibit as peripheral and, possibly, central fatigue.

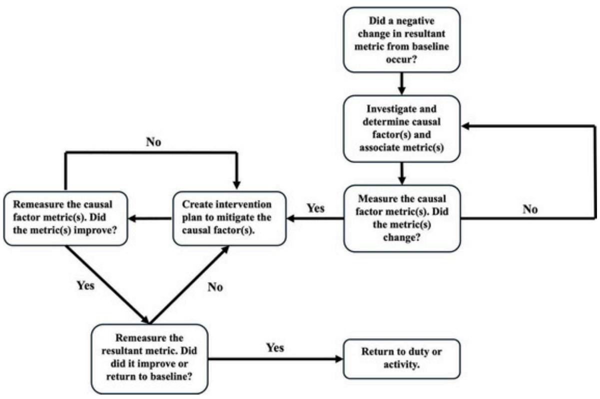
The resultant effects of fiscal stress can be similar to those discussed in the previous two sections. Stress, including fiscal stress, can cause decrements to neuromuscular strength and endurance [127–129]. Additionally, fiscal stress will affect resilience, stress management, decision-making, and adaptability (along with other consequences not discussed) in HWS professionals [125,126]. The tests that determine these resultant metrics physical performance, resilience, stress management, decision-making, and adaptability are tangible and quantifiable. Some of the tests used are, or if not similar to, MSK force production tests, the Connor-Davidson Resilience Scale, and HRV. These metrics allow HP and medical professionals the ability to understand the effects of fiscal imbalances. From here, the HP team can investigate the possible systematic causes, such as chronic increases in cortisol, cytokines, and oxidative (and others not discussed) that are leading to the changes in behavior or physical performance.

The consequences of fatigue induced by acute and chronic stressors are far-reaching and multifaceted, extending beyond the scope of this paper. A crucial takeaway is that stressors can originate from domains outside the traditional five-domain athletic performance model, yet still exert a profound impact on an athlete's performance. The effects of these stressors can manifest as decrements in any of the five athletic performance domains, such as a decline in musculoskeletal (MSK) performance. However, it is essential to recognize that the root cause of these effects may lie in a different domain, one that is often overlooked in traditional athletic performance models. By acknowledging the complexity of stressors and their potential to influence the HWS, HP and medical professionals can adopt a more holistic approach to managing fatigue and optimizing performance.

How Does This Information Help Define Recovery?

This review paper discusses only 3 of 19 domains listed in Figure 1. Even the 19 domains listed in Figure 1 are not an exhaustive list. Other domains must be analyzed and considered in the context of recovery. However, a constant theme emerges from the literature presented thus far. No matter the domain, two different types of metrics exist: resultant and causal metrics.

Knowing the differences between the resultant and cause metrics help HP and medical professionals quantify the fatigue effects. This path provides the way to measure and define recovery. When a negative resultant effect is observed, the desired outcome is to mitigate the negative effect as much as possible or have a complete return to the baseline (Figure 5). As a hypothetical example, we will look at the decrement in lower limb force production (resultant) due to decreased quadriceps size (resultant) with increased TNF-α, IL-6 blood concentrations (resultant) after a six-week field training exercise (acute stressor/stimulus). Immediately after the six-week field training exercise, the subject saw a 6% drop in lower limb power via force plate testing. The HP team discovered the subjected had elevated TNF-α, IL-6 blood concentrations when compared to the subject's HWS population. The HP team identified the fatigue from the field training exercise caused an increase in cytokine concentrations which was causing the drop in lower-limb force production. Based on this information, the HP team created an intervention protocol. The protocol lasted two weeks and followed with post-intervention testing. After the two weeks, the subject had a 5% increase in lower limb power when compared to the post six-week field training exercise. However, the lower limb power was 1% lower when compared to pre-six-week field training exercise. The TNF-α, IL-6 blood concentrations were within normal population averages for the subject. Based on this information, the subject "recovered" from the fatigue of the field training exercise. To reiterate, we define recovery as "the process of returning both the causal and resultant metrics to their baseline levels."



Conclusions

Recovery, as view through the HWS HP paradigm, characterizes a multifaceted process that must be define for optimizing HWS professionals. Recovery is not simply "return to duty" or "combat regeneration," instead, it is as the comprehensive

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process of restoring both causal and resultant metrics across a wide range of interconnected domains to baseline levels.

This review explores the interconnected intricacies of recovery across many domains beyond traditional athletic performance domains. The HWS HP domains include but are not limited to cognitive, emotional, spiritual, and fiscal elements. The process for quantifying fatigue and measuring recovery are the same no matter the domain. The identification of the effects via the resultant metric, and the cause of the effect via the causal metrics, can be applied universally. The process laid out in Figure 4 provides a path to understand the root causes and a way to quantify and determine if recovery is achieved. The ability to quantify recovery through measurable metrics, such as biochemical markers, physical performance tests, and psychological assessments, provides a structured and evidence-based approach to human performance optimization. Future research must aim to refine these metrics and further integrate them into HWS HP programs.

Disclosure Statement

No potential conflict of interest was reported by the authors.

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