A New Understanding of Stress and Implications for Our Cultural Training Paradigm

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30:3; 27-35, 2015

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ABSTRACT

The science of stress has greatly influenced sport training. The formative works in the field from the early 20th century, particularly those by Walter Canon and Hans Selye, are frequently cited as the basis for the understanding of how humans adapt to training-imposed stress. However, key cornerstones of the conventional understanding have shifted in recent decades. In addition to its physiological aspects, stress is now seen to have important psychological and emotional components, making the body's response to imposed stress more individualised and difficult to predict. Although the evidence and logical rationale supporting the new perspective seem incontrovertible, it has as yet failed to spark the revolution in the commonly held training planning and prescription, or recovery and regeneration, paradigms it may warrant. The author provides a history of stress theory, culminating with the current understanding and its relationship to training theory. Although how the new awareness will be used to better design training and recovery processes remains to be fully explored, he suggests that gains are most likely to be realised when both training environment and coach-athlete interactions are designed to moderate rather than escalate non-physical training stressors.

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Introduction

The difficulty is not in creating new ideas, but escaping from old ones.
John Maynard Keynes

Physical training imposes stress on the athlete's neuro-biological system, thereby stimulating adaptation and promoting an improved resilience to similar forms of stress in the future. The direction and magnitude of these applied training stressors must be appropriately targeted to enhance the athlete's performance capacity. If, however, imposed training stress continually exceeds the athlete's capacity to dissipate the lingering consequences of such stress applications then residual deficits temporarily remain and accumulate. Inevitably leading to an increased vulnerability to injury, illness, overtraining, burnout and overuse syndromes.

From this perspective the training process is an exercise in stress management[1]. A process demanding that the strategic application of training stress is appropriately balanced with adequate recovery. To this end, a variety of planning and periodisation strategies are typically used to balance imposed training stress with appropriate rest and various recovery and regeneration techniques are employed to expedite the athlete's return to an uncompromised state of training readiness.

This rationalisation, however, provides nothing new. The teachings of the early pioneers of the science of stress, Walter Canon and Hans Selye, have long been acknowledged as greatly influencing contemporary training theory and coaches have long understood the importance of balancing imposed training stress with adequate recuperation. What has changed substantially in the decades since Canon and Selye's formative work is our understanding of the true nature of the stress phenomenon. This theoretical revision poses an important, but as yet unexamined, question: have we built aspects of traditional training philosophy upon an incomplete understanding of the nature of stress and, if so, what might we learn from realigning training and recovery practices with an updated understanding of contemporary stress science?

A Brief History of Stress

In the late 19th century, BERNARD described how the constancy of the internal biological environment, the *milieu intérieur*, was maintained in the face of imposed challenges by adapting aspects of function so as to maintain an optimally healthy state[2].

Although this work pre-empted much of what was to follow, the evolution of the science of stress did not begin in earnest until the first decades of the 20th century. The landmark work of YERKES & DODSON described the proto-typical 'inverted-U' relationship between arousal and performance[3]: suggesting that increased arousal steadily improves performance until, at some hypothetical turning point, further increases in arousal begin to diminish performance. However arousal was neither specifically defined nor directly measured. Instead, the effect of varying intensities of (crudely calibrated) electric shock on a mouse's capacity to discern between differently coloured pathways was used as proxy. Although replication attempts using various animal models repeatedly failed to find comparable results[4,5], the proposition that adverse events evoke predictable responses falling along a stereotypical trajectory was subtly implanted in the collective scientific consciousness.

Subsequently, in the 1920's, CANNON, echoing BERNARD's earlier work, proposed that strongly aroused animals conserve the constancy of their internal environment via the mediation of catecholamines — epinephrine, norepinephrine, dopamine — secreted from the adrenal medulla. He employed the term ''homeostasis'' to describe the process through which stable steady-state functioning was preserved; suggesting that increasing catecholamine concentrations powered a 'fight or flight' response designed to remove imposed threats and facilitate a return to baseline conditions of homeostatic equilibrium[6].

A decade later SELYE began the body of work that was to revolutionise the field, switching attention from the catecholamine's of the adrenal medulla to the glucocorticoids of the adrenal cortex. He observed that rodents exposed to a variety of physiological discomforts exhibited a common set of prototypical responses. Regardless of whether rats were immobilised, electrically shocked, or exposed to heat or cold, the resultant mal-adaptations seemed to share a common trajectory. In a now famous 1936 letter to ***Nature*** he described a triad of symptoms — adrenal enlargement, gastrointestinal ulceration, atrophy of the thymus — commonly elicited by a wide variety of biological challenges.

SELYE re-employed the engineering term 'stress', first used by CANON[7] a decade earlier, to describe the organism's reaction to such perturbation. He defined the stress response as the "non-specific response of the body to

any demand", and a stressor as any challenge "noxious to the tissues"[8]. SEYLE's observation that the stress response appeared to follow a predictable trajectory led to his later formulation, in 1956, of the General Adaptation Syndrome (GAS). The GAS framework described how, once the stress response was evoked, biological stressors were countered in a predictable fashion progressing through a stereotypical sequence of phases: first alarm, then resistance and eventually, if the stress was sufficiently overwhelming, resulting in exhaustion[9].

As the 20th century entered its final quarter, our understanding of biological adaptation following stressful challenge was shaped by these early pioneers, as was the associated terminology which subsequently percolated into popular culture — stress, homeostasis, 'fight or flight', GAS. Although acknowledging that each individual has distinct stress thresholds and set-points, strengths and vulnerabilities, the subtly imposed presumption was that we all respond to biological stress along a common trajectory: a perspective re-enforcing the covert message that we all respond to stress in predictable stereotypical fashion.

Stress and Training Theory

Although SELYE himself claimed never to have considered the application of his research to sporting domains, it was not long before astute coaches began to appreciate the potential relevance of this emerging science to athletic training contexts[10]. As early as the 1950's the influential swimming coaches Forbes Carlile and James "Doc" Counsilman had already begun interpreting and translating SELYE's work to sports training contexts. They were soon followed in this effort by track and field coaches Fred Wilt and Deloss Dodds[11,14].

Today the influence of the early doctrines of the science of stress remain apparent in both sports science and coaching realms, as contemporary theorists continue to re-cycle the teachings of CANON and SELYE to justify and substantiate key aspects of current training practice[12, 13, 14].

Key points:

- Training adaptation and recovery are highly individualised and heavily modulated by back ground emotional setting.
- Physiological training and recovery are not purely physiological phenomenon.
- Optimal training and recovery strategies blend physical and psycho-emotional elements.

A Challenge and a Revolution

SELYE's paradigm undoubtedly represented a leap forward in our understanding of how humans respond to stress. Nevertheless by the end of the 20th century, philosophical and academic shortcomings of the conventional stress paradigm became apparent.

Crucially, the concept of 'stress' was proving to be more complex, multi-faceted and difficult to define than previously envisaged. For medically-oriented researchers homeostasis and GAS were both firmly biologically entrenched concepts; an issue acknowledged by SELYE, late in life, when he noted that he ''gave little thought to its psychological or sociological implications for I saw stress as a purely physiological and medical phenomenon"[15].

Yet psychologists, whose research traditions had evolved along an independent trajectory, held a very different view. In contrast to their more biologically-oriented counterparts, they considered stress to be primarily a cognitive and mental phenomenon. As physiological and psychological research traditions inevitably overlapped and clashed, the dominant model of SELYE began to be challenged by researchers adopting more inter-disciplinary perspectives.

At the heart of this challenge were two central assumptions: first, that the stress response follows a stereotypical non-specific trajectory as portrayed by the GAS response and, second that physiological stress is predominantly caused by physiological challenge and that its consequences are primarily physiological in nature.

Central to these controversies was the origin of the so-called 'first mediator': the unidentified event first triggering the stress response. SELYE predicted, and fruitlessly searched for, a biological first mediator. In contrast LAZARUS and MASON proposed that the first mediator is psycho-emotional in genesis, in essence suggesting that the body's physiological stress response is not instigated directly by the physiological stressor, but by the changing emotional state of the individual brought about by personal interpretation of their capacity to cope with the imposed challenge [16,17]. Notably, MASON's experimental work led him to conclude that whenever the noxious "psychological concomitants" of physical stressors could be removed, or substantially reduced, then the GAS response was drastically moderated[18]. This work clearly demonstrated that the magnitude of the stress response, subsequent to any imposed physical stress, was in large part modulated by the individual's emotional reaction to it. In other words that the adaptive response launched to cope with a physical challenge was not solely dependent upon the extent of that physical challenge, but also on the set of psycho-emotional anxieties, expectations, projections and associations accompanying that stressor.

As the century drew to a close, these debates remained largely unresolved. Nevertheless the failure of purely biologically-oriented concepts of GAS and homeostasis to satisfactorily explain the increasingly apparent effects of non-physical factors – emotional regulation, anticipation and learning – on stress responses, suggested the portrayal of the stress response as a physiological response to a physiological challenge was fundamentally unreflective of reality[19, 20, 21].

A Resolution Emerges

Greatly facilitated by the technological and neuro-imaging revolution of recent decades, the historical disconnect between physiological and psychological stress interpretations has been largely resolved. Of particular relevance is the growing awareness of the central role played by the brain's emotional centres in mediating the stress response. These, primarily mid-brain, regions are highly interconnected with the neural systems underlying sensation and perception on one hand, and cognition, goal-directed behaviour and motivation on the other. This organisational structure firmly places the brain's emotional centres at the intersection between bottom-up sensory feedback and top-down goal-directed thought. From this perspective the emotional centres constitute the intersection where sensation and perception are interpreted and blended with conscious intentions and desires[19, 20].

Accordingly, when we experience any change in circumstance, such as a sudden increase in physical exertion, the sensory information heralding this change is gated through the brain's emotional circuitry where it is evaluated on a continuum ranging from benign to 'threatening'. This emotional interpretation of the 'threat' posed subsequently launches the stress response initiated by the Central Nervous System (CNS), and calibrates the magnitude of this response to the individual's emotional state. Hence, it is our emotional interpretation of the imposed stress that launches the cascade of neuro-chemical events constituting the human stress response. These neuro-chemical events, in turn, trigger the subsequent down-stream alterations in concentrations of circulating hormones that drive adaptations in all dimensions of function — from cognitive sharpness to psychological state to physiological regulation — as the system prepares brain and body to cope with the anticipated challenge.

Crucially, the magnitude of the stress response is not directly dependent on the magnitude of the stressor. Instead it is the emotional resonance attached to the stressor —the

registering of the stimulus as threatening or benign; as stimulating or anxiety-inducing— that ultimately dictates the extent of the stress defences mobilised, and dictates whether this response will be proportionate or disproportionate to the actual challenge imposed. Accordingly, the response to any given stressor is heavily modulated by subjective perception. We analyse the stress, and from this analysis emerges our individually-specific sense of security, predictability, motivation and competence, or alternatively our sense of insecurity, unpredictability, anxiety, fear and impending risk. Thus our personal emotional interpretation of the applied challenge amplifies or dampens the subsequent cascade of bio-chemical events constituting the stress response. This sets the bio-chemical backdrop upon which training stress is overlaid and, in turn, shapes consequent neurological, psychological and physiological adaptations[19, 20, 21].

This entangled interactivity ensures that no stressor is ever solely psychological, physiological, cognitive or emotional. Instead every stressor — every stimulus triggering a stress response — exerts a neurological, biological, psychological and emotional toll. Thus even stress responses triggered by stimuli that appear far removed from psycho-emotional significance, such as cold exposure, vary dramatically dependent upon the emotional resonance attached to the stress-inducing event[18,19]. Similarly healing times following laboratory-induced inflammatory reactions can be readily amplified or dampened, extended or shortened, simply by manipulating perception, emotional appraisal, and background levels of psycho-social stress[20]. Furthermore the influence of prior experiences, such as an early-life exposure to specific forms of pain, can ever-after alter the stress response induced by similar future events [21, 22, 23, 24]. These examples, along with many more, illustrate the deficiencies in conventional rationalisations of the physical stress response as a direct consequence of the applied physical stressor.

Importantly, and in contrast to traditional Selye-led perspectives, which considered the pituitary and adrenal glands as the critical drivers of the stress response, contemporary insight firmly places the brain, and in particular the emotional circuitry, as the ultimate controller of our reaction to imposed challenge[25].

Relevance for Sport Training Theory

In relation to sports training theory, evidence illustrating the interactivity between emotional state and physical consequences continues to grow. As illustration: Individual differences in self-confidence, self-esteem and anxiety have been demonstrated to elevate injury occurrence and impede recovery[26,27]. Accordingly it has been suggested that stressed athletic populations, in particular those with low self-esteem, are especially vulnerable to the family of stress syndromes typified by overtraining, fatigue and depressive-like symptoms[26].

Other research studies have established that: 1) athletes, self-rated levels of mental stress were predictive of the magnitude of their individual adaptive responses following a highly controlled training intervention[27]; 2) the combination of low stress resilience and elevated stressors can interact to compromise both cardiovascular and power training adaptations[28]; 3) exposure to elevated levels of training and psychological stress increase the incidence of negative health outcomes in well-trained triathletes[29,30]; and 4) heightened anxiety can lead to increased incidence of injury in professional soccer players[31].

In fact, a wide range of imposed stressors — emotional, dietary, social, sleep and academic — have now been demonstrated to variously down-regulate the immune system, dampen adaptive responses and negatively affect motor coordination, cognitive function, mood, metabolism and hormonal health: thereby diminishing multiple dimensions of athletic performance and elevating injury risk[31].

Historically we assumed that adaptation to stress could be partitioned into a regimented sequence of events following a predictable trajectory. From a contemporary perspective,

however, it is evident that individual adaptation subsequent to any imposed stressor is not the generalised process historically suggested by homeostatic and GAS models. Instead it is highly specific and largely unpredictable with each stressor eliciting a uniquely individual stress 'signature' personalised by the blending of genetic, behavioural, experiential, historical and environmental idiosyncrasies, and amplified or dampened by the emotional resonance attached, by the individual, to that stressor.

This rationale does not suggest that stress is purely an emotional phenomenon, but highlights that once a stressor is applied the stress response is initiated, and its magnitude regulated, by the individual's emotional evaluation of the challenge posed by that specific stress-inducing event. This emotional attribution is in large part set by the combination of Nature, in terms of genetic heritage, and Nurture, in terms of early life experiences: both factors over which the athlete or sports coach exert no retrospective control. Importantly however, although our emotional reactivity to imposed stressors is heavily influenced by heritage and history, we can nevertheless favourably manipulate current and future conditions to promote positive adaptation, and diminish the negative impacts of excessively elevated or prolonged stress responses.

Inescapably, at its most fundamental level the adaptive response to training is instigated and driven by a cascade of stress-induced chemical changes in various internal environments: changes in concentrations of molecular messengers in the muscle; hormones circulating throughout the body; and neuro-transmitters, neuro-modulators and neurotrophic factors in the brain. These various chemical environments, however, are not simply dictated by training performed but are overlaid upon the bio-chemical backdrop shaped by the athlete's current emotional state. In essence the bio-chemical context is set by the integration of training-imposed stress, overlaid upon the existing bio-chemical backdrop of the individual. In turn, the bio-chemical backdrop is set by the individual's emotionally-driven response to background levels of current life stress.

From this perspective the objective of physical training, and of recovery and regeneration processes, is to positively manipulate these chemical environments to maximally accentuate athletic performance and optimally facilitate physiological and psychological recuperation.

Practical Implications

Unquestionably the empirical descriptors of training — the numbers we use to describe and prescribe training sessions — remain of great importance. As coaches we need a plan and we need a practical means of clearly communicating the plan to the athlete. We need to be able to clearly empirically prescribe training parameters: how long, how many, how quickly and so on. But we must also be aware that simply conforming to these mechanical training parameters does not adequately control the imposed training stress and does not guarantee a specific training effect.

In order to most productively accentuate training-induced adaptation we must be aware of the unseen influences that conspire with physical training to dictate the subsequent adaptive response.

When athletes are subjected to elevated non-training stressors, physiological training adaptations will inevitably be compromised. This will occur regardless of the origin of that stress: whether it be anxiety due to loss of form, exam pressure, relationship turbulence, poor sleep, corrosive environmental conditions, etc. Furthermore, the extent to which the athlete's physical health is impacted by such accumulating multi-source stress will vary extensively dependent on their personal stress reactivity to the specific forms of stress imposed.

Accordingly athletes will be most predisposed to negative training outcomes — injury, illness, poor performance — during periods of heightened stress, and individuals with high

stress reactivity will be especially vulnerable. In contrast, athletes displaying more stress-resilient characteristics will inevitably be more robust to the wide variety of challenges imposed by an athletic life. Such characteristics are, like all other human traits, partly bestowed by genetic legacy and partly by practice; partly by Nature and partly by Nurture.

The coach can, however, play a crucial role in designing the athletic environment and the culture of the training group so as to moderate background stressors. The coach can encourage, or prescribe, activities that have been demonstrated to reduce background stress: practices such as mindfulness meditation, socialising with family and friends, expressive writing, or activities as simple as walking in nature, breathing-based relaxation exercises or engaging in enjoyable hobbies.

Furthermore coaches can tailor their interactions with athletes to help nurture and develop stress resilient traits: for example, ensuring all competition and training plans have been clearly communicated to the athlete and that the athlete has been given the opportunity to input into these plans. This develops the athlete's understanding of the programme; faith in the programme; and a sense that his/her voice and opinions are important. Nurturing the athlete's sense of ownership, empowerment and sense of control over their own destiny greatly reduces the experienced sense of threat and anxiety that drives an over-active stress response.

The psychological hardiness, necessary for success in competitive environments, is commonly ascribed to three interrelated personality characteristics: commitment, control and openness to challenge. Those displaying hardiness characteristics are not simply mentally tougher, but also exhibit more robust immune response [33].

Understanding that athletes will be most vulnerable to physical, psychological and immunological breakdown during times of emotional turbulence, is not necessarily a new insight. As is often the case, we find certain coaches have intuitively evolved philosophies, processes and practices promoting stress resilience in their athletes. Famously, Percy Cerutty, the coach of 1960 Olympic 1500m champion Herb Elliot, emphasised and designed interventions to build character as well as physical robustness. What this new science does add, however, is an explanation of the mechanisms through which such interventions positively impact stress resilience and the removal of doubt as to whether or not such strategies are useful to the athlete.

There is a final, perhaps hidden, implication here: how the athlete reacts to stressful situations is, as we have noted, dependent on their individual predispositions combined with the individual coping strategies they may employ. But an individual's stress response is also highly influenced by context and environment. And a key influencing factor for athletes is how the coach reacts to stress. Is the coach calm, or worried? Does the coach project an aura of thoughtful decisiveness or anxious reactivity?

Stress is contagious and if as coaches we wish to build low stress environments, perhaps as a first step we need to develop our own capacity to deal with stress. In essence to practice what we preach.

Conclusions

One of the great paradoxes of stress, first highlighted by SELYE, is that although we commonly think of it as a negative, it is essential for life. Without the changes driven by successive stress applications, we fail to adapt and instead become fragile to future challenges: but excessive or prolonged stress imposed on an individual lacking the capacity to cope, inevitably leads to some form of breakdown.

Despite the dramatic evolution of stress science since SELYE's foundational work, our translation of stress theory to training theory appears frozen in time, as illustrated by the

continued recycling of the doctrines of the early stress theorists. As coaches we often assume physical training is an exclusively physical phenomenon: we numerically prescribe physical training and expect training outcomes to be predictable and directly dependent upon the imposed training load.

MASON, the physician and researcher at the forefront of the revolt against conventional stress dogma, once noted "The knowledge that the psyche is superimposed upon the humoral machinery for endocrine regulation drastically complicates our whole view"[16]. Understanding the complex nature of the stress response certainly complicates our view of the training adaptation process, but it also helps illuminate the way forward, adds explanatory clarity and provides coaches with an opportunity.

An updated appreciation of how an excessively activated stress response can negatively impact the athlete's health and performances provides the coach with important background information. The science has advanced rapidly in recent decades and today we have a much richer understanding of the nature of the stress phenomenon than previous generations. Yet, crucially, how this knowledge is most effectively translated into coaching practice is a question that empirical science cannot answer, and which remains open to argument and personal interpretation. As with other bodies of academic information the science can 'suggest', but the coach must 'decide'. As always, each coach must thoughtfully weigh the presented arguments and filter them through the lens of their personal experience and philosophy, before deciding how these insights may — or may not — apply to their coaching context.

Summary:

- The stress response is not the monolithic, predictable process traditionally envisioned.
- Stressors impose distinct adaptive 'signatures' dependent upon context, constitution, history, and persistently transitioning biological states.
- The consequences of an imposed stressor may be broadly predictable on a population-wide basis but, at the individual level are unpredictable.
- Each stressor exerts a psycho-emotional toll, which if unremediated, damages the neural circuitry driving emotional responses, inevitably leading to 'wear and tear' and reduced resilience to future similar stressors.
- Physiological stress is not solely physiological in genesis, similarly stress of any origin exerts a physiological toll.

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