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Musculoskeletal overuse injuries and heart rate variability: Is there a link?

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ABSTRACT

Accurate detection and prevention of overuse musculoskeletal injuries is limited by the nature of somatic tissue injury. In the pathogenesis of overuse injuries, it is well recognized that an abnormal inflammatory response occurs within somatic tissue before pain is perceived which can disrupt the normal remodeling process and lead to subsequent degeneration. Current overuse injury prevention methods focused on biomechanical faults or performance standards lack the sensitivity needed to identify the status of tissue injury or repair. Recent evidence has revealed an apparent increase in the prevalence and impact of overuse musculoskeletal injuries in athletics. When compared to acute injuries, overuse injuries have a potentially greater negative impact on athletes' overall health burden. Further, return to sport rehabilitation following overuse injury is complicated by the fact that the absence of pain does not equate to complete physiological healing of the injured tissue. Together, this highlights the need for exercise monitoring and injury prevention methods which incorporate assessment of somatic tissue response to loading. One system primarily involved in the activation of pathways and neuromediators responsible for somatic tissue repair is the autonomic nervous system (ANS). Although not completely understood, emerging research supports the critical importance of peripheral ANS activity in the health and repair of somatic tissue injury. Due to its significant contributions to cardiac function, ANS activity can be measured indirectly with heart rate monitoring. Heart rate variability (HRV) is one index of ANS activity that has been used to investigate the relationship between athletes' physiological response to accumulating training load. Research findings indicated that HRV may provide a reflection of ANS homeostasis, or the body's stress-recovery status. This noninvasive marker of the body's primary driver of recovery has the potential to incorporate important and as yet unmonitored physiological mechanisms involved in overuse injury development. We hypothesize that abnormal somatic tissue response to accumulating microtrauma may modulate ANS activity at the level of HRV. Exploring the link between HRV modulation and somatic tissue injury has the potential to reveal the putative role of ANS homeostasis on overuse musculoskeletal injury development.

Introduction

Musculoskeletal overuse injuries are of concern and significance in athletics, particularly in endurance sports where the balance between exercise loading and recovery is often compromised for maximal performance outcomes [1–4]. Although prevalence differs due to a variety of factors, reported overuse injury prevalence estimates range from 20.9% among youth and adult track and field athletes [5], to 56% in iron-distance triathletes [6], and 68% in high school runners [2]. Even amongst elite athletes, where access to advanced training technologies is common, the burden of overuse injuries is great: a recent prospective study on 142 Olympic and Paralympic candidates during a 40-week training period demonstrated a significantly greater proportion of reported overuse injuries versus acute injuries (70.1% and 20.8%, respectively, of all injuries reported) [4]. When compared to injury severity and time lost due to acute injuries or illness, overuse injuries were responsible for 49% of the summed cumulative severity score, thus representing the greatest overall health burden on athletes [4].

The prevalence and negative impact of overuse injuries supports the need for an effective monitoring system that can accurately reflect athletes' evolving adaptations to training stimuli.

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Although the current approach for exercise monitoring and injury prevention using physical performance measures (PPMs) is advancing, the measures readily employed in sport lack adequate sensitivity to predict injury in recreational or elite athletes [7–12]. PPMs are limited in their ability to predict injury in several important respects. First, PPMs address athletes' absolute values of strength, functional motion, agility, or speed, and do not capture a pattern of change of these indices over time [13]. Second, PPMs are often based on an assumed common linear approach from interaction of multiple risk factors to resultant injury. This type of monitoring paradigm does not account for the evolving influence of intrinsic and extrinsic risk factors as an athlete is repeatedly exposed to training and sport participation [13]. It has been proposed that a dynamic recursive model of etiology in sport injury, as opposed to the common linear approach, may be more successful at depicting shifting markers of injury risk [13]. Finally, the most commonly employed musculoskeletal screening measures, including the Functional Movement Screen™ (FMS™), are focused on biomechanics and do not establish a baseline measure of the athlete's physiological readiness to perform in sport or accept training load. Therefore, predicting overuse injury risk based upon biomechanical assessment alone excludes the influence of systems involved in somatic tissue remodeling and repair, such as the autonomic nervous system (ANS), on an athlete's physiological readiness to perform.

Previously, heart rate (HR) has been used to monitor the impact of exercise load, or stress, on the body [14–19]. When examined closely, the beat-to-beat fluctuation of resting HR, known as heart rate variability (HRV), is an indirect measure of ANS modulation during stress and recovery [20–22]. Measured and averaged over time, HRV is believed to reflect the interplay of the two branches of the ANS, the parasympathetic and sympathetic nervous systems (PNS and SNS, respectively), and their activity as it relates to HR control [20,21].

Both HR and HRV have been widely researched in elite and well-trained athletes in order to understand the body's response via ANS to intensified training loads [14,16,20–24]. Due to the unique nature of HRV for each individual in addition to methodological inconsistencies across studies, conflicting results have been reported on which patterns of HRV modulation accurately reflect an athlete's negative or positive adaptation to training load. In some cases, increased parasympathetic tone, represented by increased day-to-day variability of HRV and/or relative increases of other HRV indices representing parasympathetic influence, were associated with improved performance [15,23–27]. Alternatively, HR monitoring of highly trained athletes has revealed variable results with negative correlation between increased HRV and performance improvements [28,29] or no correlation [30,31]. HRV has also been used as an index to objectify the physiological consequences of ANS distress observed in athletes who demonstrate prolonged abnormal adaptations to training, also known as non-functional overreaching (NFOR) and overtraining syndrome (OTS) [20,28,32–34]. Similar to studies investigating HRV and intensified load, this area has revealed some consistent patterns with athletes in NFOR or OTS showing a decrease in the day-to-day variability of HRV indices, indicative of reduced parasympathetic activity [18,33–35]. However, a definitive conclusion on how HRV indices change in athletes who respond negatively to training remains unclear due to studies that have reported contradictory results [28,29,36] or no correlation between HRV and overtrained athletes [14,37]. It is believed these inconsistencies occur due to lack of uniform data collection, testing protocols, and analysis [14,22,32]. Despite such discrepancies, routine monitoring of HR indices remains an attractive option for a non-invasive, convenient measure to track athletes' health and performance adaptations over time [22–24].

Hypothesis

An area of HR monitoring that has not been researched is the relationship between HRV indices and musculoskeletal overuse injury. With the advancement of personal health tracking devices, HRV has emerged as a time-efficient, inexpensive tool to guide training. Although claims have been made that HRV-adjusted training can prevent overuse injuries, to date, no research has been published to validate this statement. It is well accepted that multiple factors contribute to the development of overuse injuries and that the injured tissue demonstrates failure of the tissue remodeling process [38–40]. The exact pathophysiology of overuse injury remains debated but a theme observed among common injuries such as tendinopathy, bone stress injury, and hamstring strains, is an abnormal physiological response to the stress of tissue loading and unloading [1,39–41]. Similarly, for athletes presenting with tendinopathy, optimal tissue loading appears to hold a crucial role in the healing process of injured tissues [39,42]. Research seeking to understand tendon healing has revealed the dynamic role of the ANS via neuromediators that regulate pain, inflammation, and tissue repair [38,43,44]. The neuronal signaling between the peripheral and central nervous system is intricately involved in the tissue repair process [38]. Considering this dynamic communication pathway between the central and peripheral nervous system during an inflammatory response to somatic tissue dysfunction, monitoring the body's response to stress and recovery at the ANS level may have the potential to reveal early signs of somatic tissue distress (see Fig. 1) [45].

This paper hypothesizes how HRV, an indirect measure of ANS homeostasis, may be able to indicate early signs of somatic tissue overload prior to the onset of pain or fully developed injury. If HR indices of ANS monitoring are modulated by accumulating micro-trauma and resultant neuromediators at the peripheral tissues, these measures, used in combination with psychological and biomechanical markers of stress, may improve our ability to interpret an athlete's response to training. Since HRV measures offer a unique profile for each athlete, information collected from this index may also contribute to our knowledge of the relationships that exist between training workload, sport performance, injury, and illness. With an improved understanding of physiological response to training stress, athletic programming can be appropriately adjusted to achieve positive performance outcomes and avoid the negative consequences of overtraining (OT) such as overuse injury or OTS. Accurate interpretation of ANS monitoring also has the potential to shift our focus from pain as the primary indicator of somatic tissue dysfunction and injury, to physiological indices that reflect the body's evolving balance between stress and recovery, remodeling and degradation.

The autonomic nervous system and injury of the somatic tissues

In order to explore the proposed relationship between HRV indices and musculoskeletal overuse injury, an overview of the pathophysiology of somatic tissue injury is needed. This section will briefly describe the physiological response of a tendon under excessive load in which the normal healing process fails, as is observed in painful human tendinopathy. Although the exact physiological response to injury differs between somatic tissue types, for the purpose of this paper the concepts presented can be applied to other soft tissue areas that are frequently susceptible to repetitive strain injury.

Tendons are comprised primarily of type I collagen imbedded in dense, regular connective tissue. Due to their unique position