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Masterclass

Innovations and pitfalls in the use of wearable devices in the prevention and rehabilitation of running related injuries

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A B S T R A C T

Running-related injuries are common and are associated with a high rate of reoccurrence. Biomechanics and errors in applied training loads are often cited as causes of running-related injuries. Clinicians and runners are beginning to utilize wearable technologies to quantify biomechanics and training loads with the hope of reducing the incidence of running-related injuries. Wearable devices can objectively assess biomechanics and training loads in runners, yet guidelines for their use by clinicians and runners are not currently available. This article outlines several applications for the use of wearable devices in the prevention and rehabilitation of running-related injuries. Applications for monitoring of training loads, running biomechanics, running epidemiology, return to running programs and gait retraining are discussed. Best-practices for choosing and use of wearables are described to provide guidelines for clinicians and runners. Finally, future applications are outlined for this rapidly developing field.

1. Introduction

Running-related injuries (RRI) have a complex and multifactorial etiology. Of potential factors, aberrant biomechanics and training load errors have long been considered to play a role in the development of RRI (Novacheck, 1998). To date, endurance running biomechanics have largely been studied in laboratory settings with the use of expensive and complicated instrumentation, most notably 3-dimensional motion capture. Recently, wearable technologies have improved substantially in quality and cost, providing the means of moving instrumented running analysis into the clinic. Even more intriguing, wearable devices enable analysis of running biomechanics in the field ("in-field") in a runner's normal training environment. In-field assessments permit the evaluation of a runner's biomechanics under various conditions, such as different surfaces, across shoe types, gradients and environmental conditions. Furthermore, running biomechanics can now be evaluated during different training and racing scenarios. For instance, 3-dimensional biomechanics in 3 runners were recently sampled during a competitive marathon using an array of inertial measurement unit (IMU's) sensors attached to the trunk, pelvis and lower extremities (Reenalda, Maartens, Homan, & Buurke, 2016). Compared with the first 8km of the marathon, the runners altered their strike pattern, demonstrated less peak knee flexion and increased vertical acceleration of their centers of mass in the last 6km of the event (Reenalda et al., 2016).

Wearable technologies are commonplace in many team sports, notably rugby, cricket, soccer, and Australian rules football, to guide the prescription of training loads in an attempt to maximize athlete performance and reduce injury risk (Cummins, Orr, O'Connor, & West, 2013; Gabbett, 2016; Murray, Gabbett, Townshend, Hulin, & McLellan, 2017). Aside from analyzing running accelerations, velocities and distance, the quantification of in-field joint biomechanics e.g., knee kinematics, is challenging due to the highly variable and random movement patterns inherent to team sports. Comparatively, endurance running is characterized by a highly repetitive and predictable movement pattern with low inter-stride variability. Thus, the development of algorithms to recognize movement patterns and quantify joint and tissue loads in runners is potentially less challenging for wearable manufacturers. For a host of reasons though, adoption of wearable devices to evaluate biomechanics and training loads in endurance runners is not yet as widespread as in team sports. For instance, interpretation of wearable data can be time and skill intensive. Furthermore, adoption of wearable devices has largely been driven by coaching staff and strength and conditioning personnel, neither of which are available to most endurance runners. Recent advances in wearable

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devices and analytics can now provide metrics that are informative to runners and clinicians at an affordable price point. Thus, it is expected that wearable devices will rapidly become a valuable tool in the clinic and in the field.

While wearable devices are often thought to be a recent phenomenon, wireless heart rate monitors have been commercially available and used by runners since 1982 with the advent of the POLAR Sport Tester PE2000 (Polar, 2017). Inexpensive, high quality accelerometers, IMU's, instrumented insoles and global positioning systems are now readily available to the clinician seeking to add instrumented running analysis or load monitoring to RRI prevention and rehabilitation programs (Shull, Jirattigalachote, Hunt, Cutkosky, & Delp, 2014) (Cummins et al., 2013; Gabbett, 2016). With an ever-increasing number of products entering the market, the array of choices of wearable devices can be daunting for clinicians and runners alike. This Master Class will provide a basic overview of the need to quantify biomechanical loading in runners and the technology, best practices, clinical applications and potential pitfalls related to using wearable devices in the evaluation and treatment of runners.

2. Why the need to quantify biomechanics and loading patterns in runners?

Across sports, there is a growing body of evidence to suggest that poor management of training loads is a major risk factor for injury (Soligard et al., 2016). While training load errors are often cited as the leading factor in the development of RRI, an evidence-based definition of "training error" has yet to be established for endurance runners (Nielsen, Buist, Sorensen, Lind, & Rasmussen, 2012). Available guidelines e.g., the so-called "10% rule", focus on running volume, defined as distance or time duration of a run. (Nielsen et al., 2012). In fact, running volume is just one construct of training load, and does not take into account a runner's biomechanics, training frequency, intensity, non-running physical activity, recovery, sleep quality or psychosocial factors (Soligard et al., 2016). Furthermore, preliminary evidence suggests that certain RRI may be more susceptible to either high running volume or running speed. For instance, patellofemoral pain appears to be more related to rapid increases in total running volume whereas Achilles tendinopathy may be more susceptible to excessive progression of speedwork/track sessions (Nielsen, Nohr, Rasmussen, & Sorensen, 2013). Thus, more comprehensive metrics to quantify training loads, likely with the use of wearable devices, must be developed to better understand the role "training errors" may play in the etiology and treatment of RRI.

Interestingly, undertraining may inadequately prepare a runner for spikes in training loads that invariably happen (Gabbett et al., 2016). For instance, inconsistent or low overall training loads during the high school cross country preseason were reported to be predictive of elevated RRI risk during higher demand, in-season training sessions (Rauh, 2014). Interestingly, the incidence of RRI's peaked 3–6 weeks after the start of in-season cross country training sessions suggestive of a time lag between training spikes and the increased risk of RRI (Rauh, 2014). The phenomenon of a delayed injury response to training load spikes has been reported in other sports (Hulin et al., 2014; Hulin, Gabbett, Lawson, Caputi, & Sampson, 2016; Soligard et al., 2016). This relatively large time interval between when a runner commits a training load error and the onset of pain may lead the runner to inadequately appreciate the influence of load on development of their RRI. As such, runners may blame relatively inert factors, such as running shoes or not stretching enough (Saragiotto et al., 2014) for their injury rather a recent error in training load. With objective data provided by wearable devices, patient-specific guidelines for best training practices can be developed based on a runner's injury history and biomechanics (Bertelsen et al., 2017).

KEY POINTS: Need for Assessing Training Loads

- Training loads are complex, multifaceted
- RRI's have load-specific risk factors
- The time gap between spikes in training load & onset of an RRI demonstrate a clear need to objectively assess training history

When biomechanics have been implicated in the development of an RRI, treatment should target specific factors identified via a thorough running analysis. In the past, clinical running analysis has largely been limited to the assessment of kinematics (Souza, 2016). The use of wearables can provide important insight into the kinetics that may be responsible for injurious tissue loads. The effectiveness of an intervention aimed to alter identified biomechanical loads can then be objectively assessed to determine if it is appropriate for the runner. For instance, Baggaley et al. assessed changes in average loading rate of the vertical ground reaction force curve in 32 recreational runners in response to a prescribed 5–10% increase in preferred running step rate (shortened step length) (Baggaley, Willy, & Meardon, 2017). Average vertical loading rate is highly correlated with tibial shock ($r^2 = 0.95$), a measure that can be readily quantified by a tibia mounted accelerometer and is associated with tibial stress injuries in runners (Hennig, Milani, & Lafortune, 1993; Milner, Ferber, Pollard, Hamill, & Davis, 2006). Runners who were in the top quartile for loading rate (mean baseline loading rate: 83.7 BW/s) experienced a large (−24.7%) reduction in loading rate with the step rate increase (Baggaley et al., 2017). Importantly, the increase in number of loading cycles with the cued 5–10% increase in step rate was outweighed by the proportionally larger reduction in loading rate. Runners in the bottom quartile for loading rate (mean baseline loading rate: 33.9 BW/s) however, experienced no change in loading rate with the step rate increase (Fig. 1) (Baggaley et al., 2017). As such, the low impact

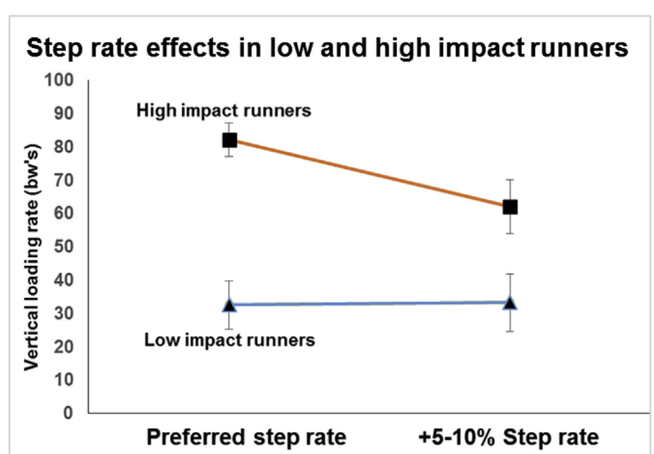

Fig. 1. The average loading rate of the vertical ground reaction force was only reduced in high impact runners with a prescribed increase in step rate. The low impact runners did not reduce loading rates with the step rate increase. Thus, the added number of gait cycles necessitated by the cued increase in step rate would result in greater cumulative loading across a training run for the low impact runners. This example illustrates a clear need to assess baseline running mechanics and any corresponding response to an intervention. Data adapted from Baggaley et al., 2017.