# Preventing Musculoskeletal Injuries in Racehorses: Integrating Training Data and the Role of the Respiratory System.

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## 1. Introduction

Musculoskeletal injuries are the leading cause of serious injury and death in Thoroughbred racehorses and represent a significant ethical and welfare concern for the equine sporting industry.[1-3] Despite extensive investigation and research[1-4], incidents continue to occur, accompanied by growing public concern.[3,5,6] While many studies focus on data derived from races, the majority of musculoskeletal injuries occur during training.[2] The development of additional monitoring tools to identify horses at increased risk during training may enable early intervention and ultimately reduce injury rates in racehorses.[2,7]

## 2. Technology

Wearable technology has consistently ranked as the leading fitness trend among human athletes in 2023 and 2024, according to the American College of Sports Medicine.[8] These devices, including fitness trackers, heart rate monitors, and GPS units, have also been adapted for use in equine athletes.[9-12] Such technologies offer real-time monitoring of physiological and biomechanical parameters, and hold significant potential to transform racehorse management.

A wide range of commercial devices are currently available for use in horses and can be broadly categorised by their primary focus on the cardiovascular system, the locomotor system, or a combination of both.[10-12] In Australia, two widely used systems are E-Trakka® and Equimetre® (Arioneo), which measure key performance metrics including heart rate, stride length and frequency, recovery rate, split times, and distance covered.[9-13] Notably, the Equimetre® also records a single-lead ECG validated against the Televet® system and provides an additional measure of heart rate variability.[9,10] These devices are routinely used during training sessions, jump-outs, and official trials. The American Association of Equine Practitioners (AAEP) is currently conducting a year-long study involving over 700 two-year-old racehorses using various different biometric sensors to monitor training.[14]

While the aforementioned devices are focused on monitoring during training, several technologies are now being deployed during racing. The British Horseracing Authority (BHA), in collaboration with the University of Surrey, is currently piloting the use of heart rate monitors capable of capturing ECGs during races in the UK.[15] Stridemaster® devices, which focus on stride parameters, has been used during races in Tasmania.[4] In addition, the Sleip® application, which employs markerless video analysis to assess gait symmetry, is increasingly used by Racing NSW veterinarians.[16] Whilst several objective gait analysis systems are widely used in clinical veterinary practice (including Equinosis[17], Equigait[18], EquiMoves[19]), the Sleip® application offers practical advantages through its lack of external sensors and the accessibility it provides to both owners and trainers.[20]

## 3. Musculoskeletal Injury

Musculoskeletal injury (MSI) is the most common cause of lost training days and can result in early retirement or death in racehorses.[21] Most catastrophic injuries are associated with bone failure resulting from mismatched loading cycles and bone adaptation, leading to cumulative fatigue and failure.[6] These injuries can occur when horses first enter training or return after a rest period, with damage accumulating rapidly when loading exceeds the bone's capacity to adapt.[6] Alternatively, they may follow a prolonged period of high-intensity exercise where the training load has exceeded bone's ability to repair.[6]

Numerous investigations have identified a wide range of risk factors for bony injury at both the individual horse and environmental level.[1-3] Additional consideration is given to the differences between horses first entering training as 2-year-olds versus mature horses, with the 2-year-old horses experiencing a higher rate, and different types, of MSI compared with older horses.[1,2] A recent focus on training practices has highlighted the critical role of training load on bony response and adaptation[23], in combination with strategic rest periods to facilitate repair.[4,21,22] Several studies have discussed that reducing the distances covered at high speed and increasing the number of days worked at a slower pace may be effective in reducing or preventing bony MSI[2,4,21,22] when compared with complete rest.[1] Following a diagnosis of MSI, many studies recommend adjusting training protocols to include adequate rest periods alongside reduction in training intensity and duration, to prevent the accumulation of microdamage.[5] However, more detailed information about the exact workload of horses would assist in making more precise adjustment to training programs.

Whilst bony injuries are often the primary focus in MSI discussion, due to the acute and catastrophic nature of fractures, soft tissue injuries – including tendonitis of the superficial digital flexor tendon (SDFT), are also significant, frequently proving to be career-ending.[5,24,25] These injuries account for almost half of racecourse limb injuries[26] and are responsible for 25% of fatal injuries in South Korea.[24] The prevalence of SDFT injuries in Thoroughbred racehorses used for flat racing is reported between 3.4-11.1%.[24,25] Following successful rehabilitation, fewer than 50% of horses return to racing, and more than half of those subsequently reinjure.[5,25,27] A recent investigation in South Korea found that SDFT injury risk increased in horses with fewer gallop training days in the preceding 60 days, more canter training days in the last 180 days, or having a period of no fast exercise for over 90 days in the year prior to injury.[24] This further highlights the need to balance training effects across the different physiological systems.

Wearable technologies, using accelerometers and GPS, can accurately measure stride length and frequency.[4,12, 28] A key objective in using these devices is the early identification of sub-clinical injury, which may be shown through a reduced stride length.[6] A recent investigation by Wong et al. (2023) assessed speed and stride characteristics in relation to MSI during racing in Tasmania.[4] This study showed that for every 0.1m/s reduction in speed and each 10cm decrease in stride length, the estimated injury risk increased 1.18x and 1.1x respectively, with both speed and stride length declining more markedly in the six races prior to injury.[4,6] In human athletes, shorter stride lengths and higher stride frequencies at a given speed are associated with a reduced risk of injury, due to lower peak vertical ground reaction forces.[4,29] It is proposed that horses may reduce both speed and stride length in response to pain caused by undetected or impending injury.[4]

Several investigations have demonstrated substantial inter-horse variation in stride characteristics.[11,12,28] Sprinters tend to have a shorter stride lengths and a higher stride frequencies, which is beneficial to achieving higher speeds, while stayers have a longer stride lengths and lower stride frequencies, which, along with greater endurance capacity, are advantageous in longer races.[12] These differences highlight the importance of individual-level monitoring and the development of a longitudinal stride profile and database for each horse. Although many studies have focused on race data collected at maximal speeds[4,12] these findings are not always directly applicable to training scenarios. In addition, the incidence of MSI during training remains low, with only a small proportion (0.47-0.56%) of horses experiencing SDFT or other MSIs, respectively.[2,24] However, collecting and analysing training data provides a greater number of measurement points, offering a more comprehensive opportunity to monitor stride evolution and identify subtle changes that may precede injury.

## 4. Cardiac System

While MSI account for the majority of race day incidents, cardiac arrhythmias resulting in sudden cardiac death (SCD) are also an important cause of racehorse fatalities.[30] A recent investigation by Nath *et al*. (2022) found that the majority (three-quarters) of SCD incidents occurred during training, and early in a racehorse career.[30] An additional consideration is that over half of sudden death fatalities in horses occur at sub-maximal exercise intensity.[30,31] Although most studies investigating risk factors for training and racing fatalities focus on musculoskeletal causes, the cardiovascular system is an important consideration, particularly given its role in both fatal outcomes and poor performance.

Various types of wearable technology can monitor both heart rate and heart rate variability, with some devices also recording an electrocardiogram (ECG).[9-11,13,32] Heart rate recovery a valuable indicator of exercise intensity and can be used to assess fitness and guide training plans. While these devices do not always permit definitive diagnosis of cardiac abnormalities, due to the limitations of single-lead ECG preventing accurate classification of premature complexes and arrhythmias in some cases[13], they are useful for identifying horses that may require further veterinary investigation or ongoing cardiac monitoring. Further developments are required to enable routine, in-depth cardiac monitoring[33-35], with a potential future role in screening equine athletes.[30]

## 5. Respiratory System

The demands placed on the respiratory system increase substantially during exercise and is considered one of the primary limiting factors of athletic performance.[36,37] During exercise there is a dramatic increase in airflow, which is primarily achieved through diaphragmatic contraction.[38] The resulting increase in airflow and the associated drop in intraluminal pressure within the upper airway can lead to exercise-induced pharyngeal and laryngeal collapse.[36] This is probably caused by the failure of the stabilising muscles of the pharynx and larynx to withstand these pressure changes, ultimately resulting in airflow obstruction.[36,39]

The diaphragm is the primary respiratory muscle[40] and during exercise it competes with other skeletal muscles, particularly the locomotor muscles, for a share of the available cardiac output.[36,41] As the respiratory demands of exercise increase, accessory respiratory muscles are progressively recruited to share the workload and maintain adequate ventilation.[42] Despite this, diaphragm fatigue has been observed at exercise intensities exceeding 80% of $VO_{2max}$ in human subjects[42-44] triggering a respiratory muscle fatigue-induced metaboreflex.[36,41] This metaboreflex diverts blood flow away from the locomotor muscles to preserve respiratory function, thereby impairing limb muscle performance and contributing to overall fatigue.[36,41-44] Although well-documented in human athletes and research dogs[41,45], the occurrence and implications of diaphragm fatigue and the associated metaboreflex in horses remain unknown, as does the potential impact on locomotor fatigue and exercise performance.[36,46]

Targeted training of the respiratory muscles has been used by human athletes to increase the strength and endurance capacity[44], leading to improvements in mechanical efficiency and resistance to fatigue.[36] Respiratory muscle training provides a stimulus to the respiratory muscles in isolated of whole-body training, with most investigations focusing on the inspiratory muscle training (IMT). Studies in human athletes have shown that IMT can alter key physiological markers, such as blood lactate concentration and heart rate during exercise, as well as delaying the activation of the respiratory muscle fatigue induced metaboreflex – helping to preserve blood flow to the locomotor muscles with the attenuation of limb fatigue.[36,44,46]

The application of IMT has been developed and applied in horses, as a non-invasive technique that applies a resistance during inhalation.[36,39, 46-48] Preliminary studies have demonstrated following a period of IMT, there is an increase in the ultrasonographic measurement of diaphragm thickness[36,47], and an increase in inspiratory muscle strength.[36,48] A further investigation in racehorses diagnosed with upper airway collapse during dynamic endoscopy showed a lower grade of vocal fold collapse, palatal instability, and reduced incidence of intermittent dorsal displacement of the soft palate following a period of IMT.[39]

Further investigation is required to understand the role of the respiratory system in exercise induced fatigue in horses, specifically whether this respiratory muscle fatigue-induced metaboreflex occurs, and the role of isolated IMT in horses.[36,46] At present, wearable technology capable of assessing respiratory function is limited. The Quadflow ergospirometer mask remains largely confined to research applications.[49] An 'Equine Smart Bit' is currently in development with a modified mouthpiece which claims to measure blood oxygen saturation, heart rate, body temperature, and respiration.[10,50]

## 6. Summary

The majority of racehorse injuries and fatalities occur during training or as a consequence of it. Advances in technology now enable closer monitoring of a wide range of training parameters, allowing for the development of longitudinal biometric profiles for individual horses. When combined with emerging insights from epidemiological studies, improvements in diagnostic imaging and veterinary detection, these tools offer the potential to design lower-risk training regimens, facilitate earlier injury detection, and identify horses at greater risk. Ultimately, the integration of these approaches aims to prevent injuries and fatalities before they occur.

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