Popular science abstract

Soccer, most popular youth sport in Europe, is a game of speed, skill, and split-second decisions that challenges the body and mind. Yet, despite its intensity and complexity, training programs for young soccer players often rely on generalized routines rather than individual needs. However, in today's world of sports, every detail matters. The project sets out to change that by introducing a more individualized and evidence-based approach to personalizing aerobic training using wearable technology and advanced data analysis.

The athlete body responds to training in highly individual ways. Heart rate (HR) and heart rate variability (HRV) provide a window into how the heart adapts to stress and recovers afterwards. These indicators are especially useful in team sports, where measuring oxygen use directly for each player is not feasible.

Previous studies suggest that HRV-guided training can lead to better endurance, faster recovery, and even lower training loads. However, this method has never been rigorously tested in youth soccer players.

Our research group has demonstrated that including respiratory data significantly improves VO_{2peak} prediction, and that HR and breathing dynamics correlate with HRV and athletic experience. We introduced a machine learning-based tool for nonlinear causal analysis and showed that adding causal features enhances prediction accuracy.

The study will involve over 200 young athletes, randomly assigned to either a standard training group or an intervention group. The latter will receive training guided by HR and HRV data, alongside structured breathing exercises designed to enhance post-training recovery. These breathing techniques reduce resting heart rate and may prepare the athlete for the next challenge faster.

In parallel, a second group of over 100 players will be observed over several months. Their progress will help researchers identify how physiological responses to training evolve with age, fitness level, and seasonal workload. The results will be centile-based reference charts, something like "growth curves" for internal performance capacity, as well as models enabling for longitudinal prediction based on previous data.

All athletes will wear Pneumonitor 4, a device developed by the research team that records ECG, breathing patterns through the chest, and physical movement in a compact, comfortable form. It uses a non-invasive technique called impedance pneumography, which allows for easy and comfortable measurement of breathing without the need for complex equipment. Heart activity can be registered using the same set of electrodes. This allows coaches and scientists to track performance in real time.

The research team will analyze the data using machine learning and causal modeling to predict which training works best, for whom, and why. The information collected will be utilized to help predict performance and understand how athletes respond to different types of training. One of the main goals is to build a diagnostic framework that gives coaches and practitioners concrete, individualized feedback to guide training decisions. The results of the study will also guide the development of an improved version of the Pneumonitor device.

By combining knowledge from exercise physiology, cardiovascular physiology, and biomedical signal analysis, this project aims to improve the way young athletes are monitored and supported in their training, ultimately helping them perform better during matches.