Maximizing the submaximal: 20 years of monitoring cardiovascular adaptation through submaximal HR response in team sports

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In collaboration with

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Headline

Submaximal effort testing has been widely used since the mid-20th century to assess cardiovascular function in clinical and general populations (Table 1). Pioneered by Bruce in 1949, these methods include protocols such as the Astrand test (1954), Physical Work Capacity 170 (1976), and various walking and cycling tests like the 6- and 12-min walk tests (1985, 1976), the Rockport Fitness Test (1987), and the YMCA submaximal cycling test (1989), among others (Bruce 1949, Åstrand 1954, Haber 1976, Bassey 1976, McGavin 1976, Guyatt 1985, Kline 1987, Franks 1989, Ebbeling 1991, Singh 1992, Broman 1971). These were developed primarily to evaluate health status, aerobic capacity, and rehabilitation progress in non-athletic or clinical populations using heart rate (HR) responses to controlled workloads.

Over time, these principles were adopted in sports science research. Since the 1980s, HR responses to submaximal exercise have been used to monitor aerobic adaptations in individual athletes from endurance disciplines (Costill 1985, Houmard 1990, 1994, D'Acquisto 1992, Jeukendrup 1992, McConell 1993, Flynn 1994, Stone 1981, Haykowsky 1998, Hooper 1995, Martin 2000, Rietjens 2001, Dressendorfer 2002, Neary 2003). More recently (i.e., post 2000s), these submaximal testing approaches have been adapted for use in team sports. Initially focused on controlled running protocols as embedded monitoring tools (Buchheit 2014a, Shushan 2022), these runs have since expanded to include sport-specific drills and, more recently, invisible testing approaches where training itself becomes the test (Mandorino 2025). Advances in wearable technology, data analytics, and statistical modeling have further refined the interpretation of HR responses, enabling smooth integration into routine monitoring frameworks (Delaney 2018, Leduc 2025). Importantly, submaximal testing and its variants measure physiological responses to exercise ranging from generic to sport-specific formats, offering insight into cardiorespiratory status. However, they do not capture true sport-specific fitness, which remains a performance precondition that cannot be directly assessed (Mandorino 2025, Verheijen 2025).

Aim

In this paper, we build on the recent work of Buchheit & Hader (2025) on monitoring load and response, focusing specifically on metabolic responses. We explore the principles, methodologies, and applications of HR-derived indices from submaximal tests in elite team sports, highlighting their advantages, challenges, and continued evolution. In addition to outlining the physiological basis and practical implementation, we provide clear guidelines for interpreting changes and trends, present real-world case studies to illustrate their use, and discuss potential confounding factors. A practical decision tree is also included to support accurate interpretation and help inform training decisions. While the very large majority of research to date has been conducted on young to adult elite male athletes, the underlying principles and recommendations presented here are intended to apply transversely across populations, including female athletes and other groups, even though further research is warranted in these areas.

When did we (authors) start?

I (MB) personally started in 2005, monitoring young elite handball players (Buchheit 2008b), recreational runners preparing a 10 km race in 2007 (Buchheit 2010a), testing young and professional football players in 2009–2014 in Qatar (Buchheit 2010c, 2011b, 2012, Aspire Video) and Iran (Buchheit 2014b), Australian football players from 2011–2013 (Buchheit 2013b, 2015b, Racinais 2014, Carlton FC Video) and even monitored the youth Australian soccer team during a camp in Bolivia! (Buchheit 2013a). I then also brought the test everywhere with me in my journey, in PSG from 2014 to 2020 (Buchheit 2016, 2020, Lacome 2018a, 2018b, PSG Video), to Lille OSC in 2021-2023 (Buchheit 2023), and Olympique de Lyon in 2023, to Aspetar (present). I also contributed to applied projects in several top leagues, including the English Premier League (Thorpe 2015, 2016 and 2017) and the Bundesliga (Altmann 2021), and Gaelic National League Division 1 (Malone 2017), among others—alongside numerous clubs I've consulted for since 2020, many of which have adopted the submaximal tests as part of their routine monitoring.

In parallel, the co-authors of the present manuscript also began implementing submaximal tests in their respective contexts, across a wide range of levels and with both male and female athletes (Figure 1). Among these are soccer players from countries including Australia (Shushan 2023a, 2024a, 2025; MacKenzie 2025, Video 1 & Video 2), Israel (Dello Iacono 2022), United States, Iran (Rabbani 2017, 2018, 2019, 2020), Portugal, Qatar (Younesi 2021a, 2021b), Greece (Rabbani 2024), the UAE (Rabbani 2023), UK (2011 to 2015 England Women and 2014 to 2020 Hull, Newcastle Red Bulls [formerly Falcons], Video), the Netherlands (Houtmeyers 2022), and Germany (Altmann 2021, 2023) as well as elite senior athletes from the Australian rugby league (NRL; Scott 2018, 2022), Australian football league (AFL; Arguedas-Soley 2024, Video 1, Video 2 & Video 3), and elite German badminton (Schneider 2020).

This current paper expands on my (MB) 2014 publication on HR monitoring and submaximal tests (Buchheit 2014a), which has driven significant research over the past decade. With over 100,000 views and ranking among my top three most cited papers on Google Scholar, that work highlights the relevance and impact of submaximal tests in applied sports science. The studies cited here reflect the continued evolution of the approach, as it has been adapted to new contexts and environments, leading to further research and innovation over the years.

Table 1. A historical summary of common tests adopted in clinical settings (Taken from Shushan 2022). HR: heart rate. RPE: ratings of perceived exertion.

Tests	Year	Activity	Description	Outcome Measures	Reference
The Bruce Physical Index Test (PFI)	1949	Walking	A single-stage to a max of 10 minutes at 0.77 $m \cdot s^{-1}$ and 10% grade	Duration, oxygen uptake difference, HRR	Bruce & Pearson 1949
Aerobic Capacity Fitness Test	1954	Cycling	6-min at workload eliciting HR steady-state between 125–170 bpm	HR	Åstrand & Ryhming 1954
Cyclic Step Test	1971	Cycling	Supine cycling at 3 workloads: 0, 300, 650 $kpm \cdot min^{-1}$	HR, ventilation	Broman & Wigertz 1971
Modified Bruce Physical Index Test	1971/1973	Walking/ Running	Multi-stage with progressive increases in grade (up to 10%) and speed (~10 $km \cdot h^{-1}$)	Duration, oxygen uptake difference, HRR	Bruce, 1971; Bruce 1973
Physical Work Capacity 170 (PCW170)	1976	Cycling	3 incremental workloads until HR of 170 bpm or 75% HR max	Power (W)	Haber 1976
Self-Paced Walking Test (SPWT)	1976	Walking	3 self-paced 250 m walking bouts	Time, speed, stride freq., mean HR	Bassey 1976
12-min Walk Test (12-MWT)	1976	Walking	12 minutes self-paced walking	Distance	McGavin 1976
6-min Walk Test (6-MWT)	1985	Walking	6 minutes self-paced walking	Distance	Guyatt 1985
1-Mile Track Walk Test (1-MTW/Rockport)	1987	Walking	1-mile walking; requires two similar test trials	Duration and HR	Kline 1987
YMCA Cycle Ergometer Submaximal	1989	Cycling	3-stage cycling to reach ~85% HR max	Power (W)	Franks 1989
Single Stage Submaximal Treadmill Walking Test	1991	Walking	4 minutes, 3-speed stages (1.2-2 $m \cdot s^{-1}$) at 0, 5, and 10% incline	HR and RPE	Ebbeling 1991
Modified Shuttle Walking Test	1992	Walking/ Running	10-m shuttles across 12 levels (0.5-2.37 $m \cdot s^{-1}$)	HR and RPE	Singh 1992

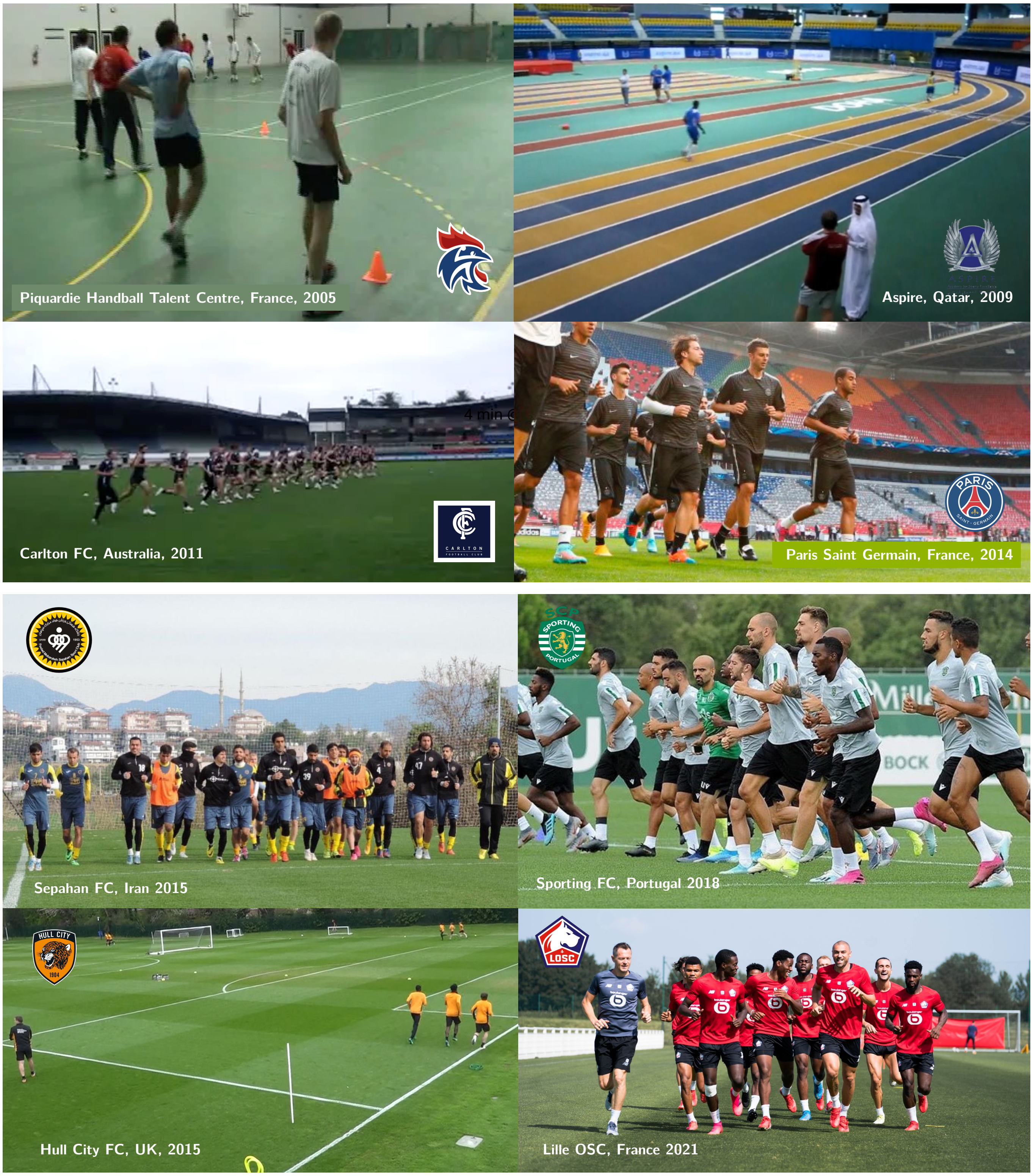

Piquardie Handball Talent Centre, France, 2005
Aspire, Qatar, 2009
Carlton FC, Australia, 2011
Paris Saint Germain, France, 2014
Sepahan FC, Iran 2015
Sporting FC, Portugal 2018
Hull City FC, UK, 2015
Lille OSC, France 2021

Fig. 1. **Examples of global contexts where submaximal runs have been implemented over the past 20 years. We (MB) generally either run alongside players using a stopwatch or provide them with one directly. The run is segmented into 15-sec loops (Figure 9), with a reset each time, so players only need to reach the cones at the right moment. This setup makes it easy to check pacing without interrupting the flow. No whistles involved, just light jogging and natural pacing, which feels less like a test and more like part of the session. When using shuttle protocols, it can be useful to provide players with an audio cue, particularly if they are spread out across the field. See Shaun McLaren pacing players with a whistle in mouth while running alongside them checking the watch. An impressive skill developed over years, notably without ever swallowing the whistle.**

1. Why submaximal testing? Benefits, purpose, and key considerations

The core purpose of submaximal tests is to evaluate how athletes respond to a standardized bout of exercise, on the assumption that this is indicative of physiological function and predictive of maximal (aerobically-related) performance capacity (Buchheit 2014a, Buchheit & Hader 2025). Testing maximum performance capacities (e.g., high-intensity intermittent running ability, time- or distance-based trials) is of importance for physical profiling, but impractical due to the exhaustive and time-consuming nature of test protocols (Shushan 2022). Submaximal tests provide a practical, efficient alternative solution to this problem that is particularly beneficial in team-sport environments (e.g., large groups of athletes, congested training and competition schedules).

The low physiological cost of submaximal tests allows for frequent assessments without disrupting regular training or inducing fatigue, making it particularly valuable during congested schedules when maximal efforts are neither feasible nor safe (Buchheit 2014a, Shushan 2022). Unlike maximal tests, which can be heavily influenced by motivation and effort variability, submaximal tests rely on physiological responses, such as exercise HR, that are less prone to conscious manipulation; "you simply cannot cheat a submaximal test".

Repeating these tests weekly or biweekly enables clearer tracking of fitness trends and reduces the influence of day-to-day fluctuations, providing a more stable and reliable view of long-term training effects. These sentiments are shared by team-sport practitioners from around the world (24 countries, >10 sports) who are implementing submaximal tests in their environments (Figure 2).

An additional reason to implement submaximal tests is to counter the persistent but simplistic belief that teams who run more during matches are necessarily fitter, and more likely to win (Mandorino 2025). This logic often shapes post-match narratives: if the team wins, running data are ignored; if it loses but out-runs the opponent, it's dismissed as "bad luck"; if it runs less, the fitness staff is blamed. While partly humorous, this flawed reasoning remains common. Recent work (Mandorino 2025) shows match running has little direct link to outcome, and that fitness alone doesn't explain performance. In this context, submaximal testing offers objective, routine data to support better analysis and protect performance staff from misguided conclusions (Figure 3)!

1.1 Why HR-derived indices and which ones?

As detailed in Table 1, the submaximal test concept was originally developed in clinical settings in the 1940s (Bruce 1949) as a means of assessing cardiorespiratory fitness (via function) in patients where maximal testing was not appropriate (Shushan 2022). The successful adaptation to team-sport athletes shares these commonalities: cardiorespiratory fitness are key physical qualities but are impractical to assess via traditional means.

The rationale behind using measures such as submaximal exercise HR (HRex) is grounded in cardiovascular efficiency (Figure 4). At a fixed workload, HR is influenced by cardiac output, stroke volume, and oxygen demand at the muscle level. As fitness improves, oxygen demands decrease, and stroke volume increases, leading to a lower HR for the same workload (Figure 5). Conversely, reduced fitness can result in a higher HR response. This is the theoretical basis for HRex of which there is a plethora of empirical support (discussed in subsequent sections). While there is strong evidence for the use of HRex in tracking cardiovascular fitness changes, its application to fatigue monitoring remains more speculative, with several assumptions and shortcuts often made. These aspects are explored in detail in the following sections.

There are other possible HR-derived indices such as HR recovery (HRR) and HR variability (HRV), which have an equally strong physiological basis. However, our research and experience have shown that these measures are typically noisier (less reliable), more impractical due to increased test time and analytical processing, and do not provide additional value on top of HRex itself (Buchheit 2014a):

- Exercise HR (HRex). The most straightforward and widely used measure, collected in the final 30–60 seconds of a test (Buchheit 2014a, Shushan 2023c).
- HR recovery (HRR). Post-exercise HRR is intended to reflect both cardiovascular fitness and autonomic nervous system status. However, it is also highly sensitive to blood acidosis, which limits its added value compared to HRex—since higher relative intensities lead to greater anaerobic contribution and, consequently, slower HRR (Buchheit 2010b, 2011a, 2014a).
- Heart rate variability (HRV) during and after exercise. It has limitations in both reliability and practicality. During exercise, HRV reflects a mix of responses and typically disappears around the first ventilatory threshold, making it an indirect and inconsistent marker of cardiovascular fitness. Post-exercise HRV, like HRR, is influenced by multiple factors and requires more time, processing, and player compliance; factors that have led to its reduced use in applied settings (Buchheit 2014a, Thorpe 2016).

Exercise HR is to date the most scientifically studied (Shushan 2022) and practically utilised (Buchheit 2014a, Shushan 2023b) measure, likely due to its stability, ease of collection, and strong correlation with cardiovascular fitness adaptations. This shall be the focus for the remainder of the current paper. That is, the use of HRex as a measure of cardiorespiratory adaptations over time. For this, we draw on 20 years of applied experience and research to provide a practical guide to those implementing submaximal tests. Recent advances in software solutions, such as the updated Firstbeat platform, have further simplified both the implementation and near-instantaneous analysis of HRex (Figure 6), making it more practical than ever in elite team sports.

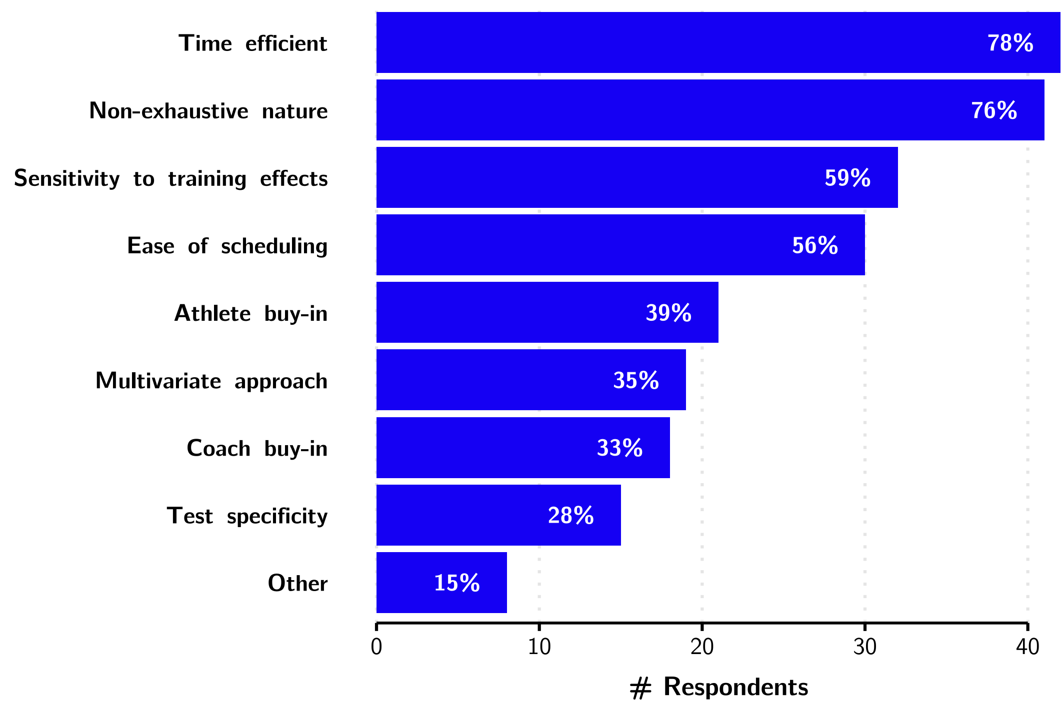


Fig. 2. Reasons why team sport practitioners from around the world use submaximal testing. These data are taken from a survey of 66 practitioners across 24 countries (Shushan 2023b).

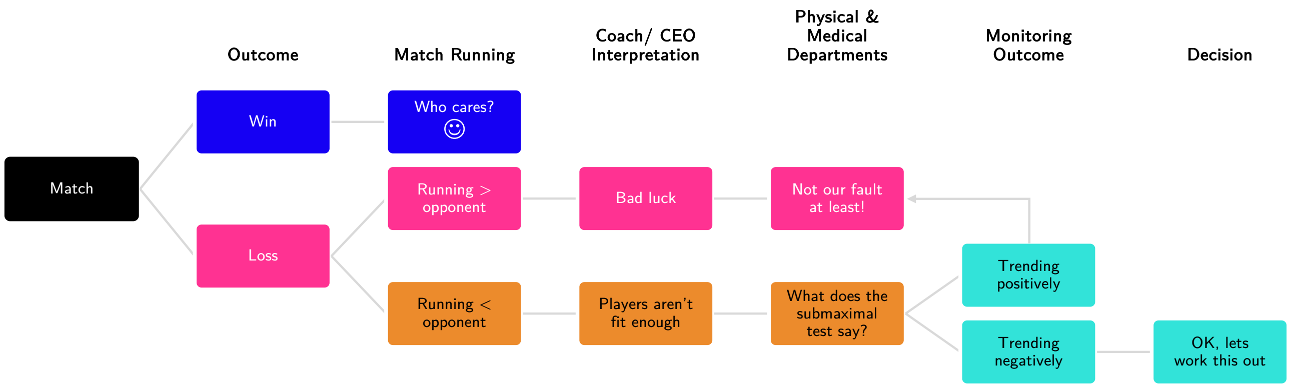


Fig. 3. Match outcome decision tree and typical post-hoc interpretation of match running performance. This flowchart humorously illustrates how match results are often interpreted across departments. When a team wins, running metrics are typically ignored. In contrast, losses prompt scrutiny. If the team out-ran the opponent, the narrative shifts to "bad luck," exonerating physical staff. If it ran less, fitness is questioned, leading to submaximal tests data being consulted. A positive trend provides reassurance, while a negative trend prompts corrective action. This highlights both the limited utility of match running as a Key Performance Indicator (KPI) and the protective value of structured monitoring tools like submaximal tests. Adapted from practical field experience and supported by Mandorino (2025).

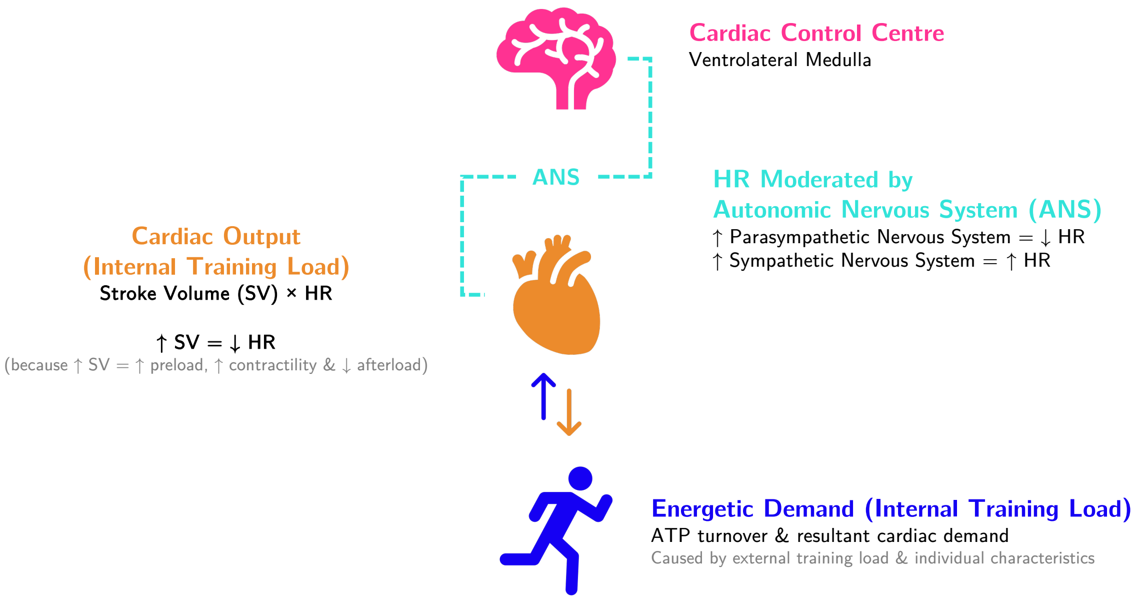


Fig. 4. **Cardiac autonomic control of HR during exercise and the associations with stroke volume (SV), cardiac output and energetic demand. These mechanisms form the physiological basis of HRex as a theoretically justified indicator of cardiorespiratory function and related physical qualities such as aerobic capacity (in the right context - i.e., a submaximal test).**

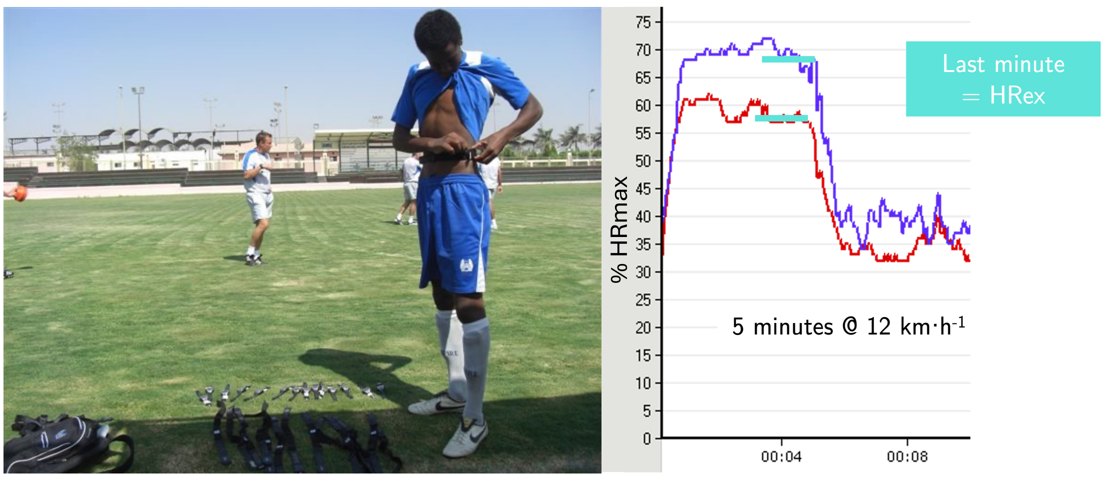


Fig. 5. **Submaximal tests at Aspire in 2009 using individual watches and the classic Polar software; HR data downloaded manually, one player at a time! The trace on the right shows a clear adaptation, with a ∼10% reduction in HRex during the same 12 km·h^{-1} run following a 2-week-long training camp in Egypt.**

Fig. 6. Example of live HR monitoring during a group submaximal run in elite team sports. Using a team-based telemetry system, players' HR responses are captured simultaneously and processed within seconds through advanced software. This provides practitioners with near-instant feedback to support real time decision-making. In contrast, as illustrated in Figure 5, earlier approaches required post-session processing that could take hours before results were available.

1.2 Other non-HR-based submaximal tests measures

While the focus of the current manuscript is exclusively HRex, it is worth noting for completeness that other types of data can be collected during or following submaximal tests to gain complementary insights. We have written detailed descriptions of these outcomes, including their theoretical justifications, plausible mechanisms as training effects and measurement properties elsewhere (Buchheit 2014a, Shushan 2022, 2023c).

- Lactate response. While considered by many practitioners as a gold standard for assessing aerobic fitness, lactate measurement is invasive and often impractical in field settings. The principle is straightforward: for a given workload, higher lactate concentrations indicate lower cardiovascular fitness, and vice versa. I've (MB) often had to demonstrate to my colleagues that HR responses offer similar value, given the strong correlations between changes in lactate and HRex (Figure 11). However, while technology is evolving and invasive measurements of blood lactate along with other bio-markers, may become possible in the future through sweat analysis, further research is required to explore these methods before its recommended use (Buchheit & Hader 2025).
- Ratings of perceived exertion (RPE). Often overlooked, RPE response to submaximal tests behaves similarly to HR and lactate: lower perceived effort at a fixed workload reflects improved cardiovascular fitness (Buchheit 2013a, Buchheit & Hader 2025). While collecting 20 to 40 RPE post submaximal tests is a challenge in practice, its main value lies in detecting mismatches between subjective and physiological responses which can be particularly useful when HRex shows unexpected changes (e.g., under extreme fatigue). In such cases, RPE can serve as a helpful complementary indicator (see section 1.6).
- Kinetic and kinematic outcomes. These are typically derived from microelectrical mechanical systems devices (e.g., accelerometers mounted on the foot or between scapula) to estimate neuromuscular function (Buchheit 2015a, Shushan 2023a). Metrics such as ground contact time, force load and impulse, or cumulative acceleration, especially during intermittent fixed, high-intensity protocols, can inform on running economy and/or efficiency or neuromuscular freshness (Barrett 2016, Buchheit 2018, Cormack 2013, Garrett 2019, Gerhardy 2024, Fitzpatrick 2019, Leduc 2020a, 2020b, Shushan 2023a). While this line of work holds strong potential, it falls outside the scope of the current paper (Buchheit & Hader 2025).

1.3 Typical protocols in elite sports: standardized runs and alternative approaches

Submaximal tests fall into distinct categories, with the choice of protocol depending on feasibility, sport demands, and standardization constraints (Figure 7). The choice of protocol may also be dictated by the intended type of assessment and outcome measures (e.g., cardiovascular vs neuromuscular training effects, or generic vs specific fitness). These considerations are discussed in subsequent sections.

A. Controlled running protocols (V1 – standard tests)

- **Continuous fixed** – Exercise is performed at a fixed running intensity (typically between 10 to 14 km·h^{-1}) for a duration of 3 to 5 minutes, with the aim of eliciting a steady-state physiological response. The exact intensity is less important than ensuring it remains consistent, and can be administered as part of the warm-up without or following a short activation and/or preparatory routine. The speed often depends on fitness level, age, and gender. Currently, one the most commonly used protocol in professional male adult football is 4 min at 12 km·h^{-1} (Shushan 2023b, 2023c). Examples include linear runs over an oval (e.g., Aspire young players Video or the Swans Video), 8-shaped runs (PSG Video) and shuttle runs (Carlton FC Video, Falcons Video, Flames Video and GWS Giants Video).
- **Continuous incremental** – Exercise includes a structured progression of speed within (single) or between (multiple) exercise bout(s), whereas each bout lasts for several minutes (e.g., 4-min runs with progressive increases in speed, 3 sets × 3-min bouts at 10, 11, and 12 km·h^{-1}). These submaximal tests are commonly used in cycling and endurance sports to assess physiological responses across varying intensities.
- **Intermittent incremental** - Exercise involves fixed, built-in rest periods, with intensity increasing between repetitions. These protocols commonly include shortened versions of maximal field-based tests, such as the 30-15 In-

termittent Fitness Test (Buchheit, 2008a) and the Yo-Yo Intermittent Recovery Test (Bangsbo, 2008).

- **Intermittent fixed** – Exercise is structured with repeated bouts performed at a constant speed and rest intervals. These protocols are typically conducted at higher intensities (e.g., ∼18 km·h^{-1} in female football players, Video 2 or ∼24 km·h^{-1} in male pro football players, PSG Video) and are often used to monitor mechanical outcome measures alongside HR-derived indices (Shushan 2023a, Leduc 2020a, 2020b).

Note that in the present paper, we focus exclusively on run-based protocols. However, the same principles can be applied to other modalities that use a fixed external workload, such as cycling at 130 to 180 W for example. This approach has been adopted in applied settings; for example, during Robin Thorpe's years at Manchester United (2010–2019), submaximal tests were often conducted on the bike rather than on the pitch due to practical, logistical, and even sociological constraints, while still allowing HR-based monitoring (Thorpe 2015, 2016 and 2017). Steve Barrett did the same during his time at Hull (2014-2020), while I (MB) have also used the cycling exercise mode for many long term return-to-play cases, either at PSG, Lille, OL or Aspetar (e.g., ACL).

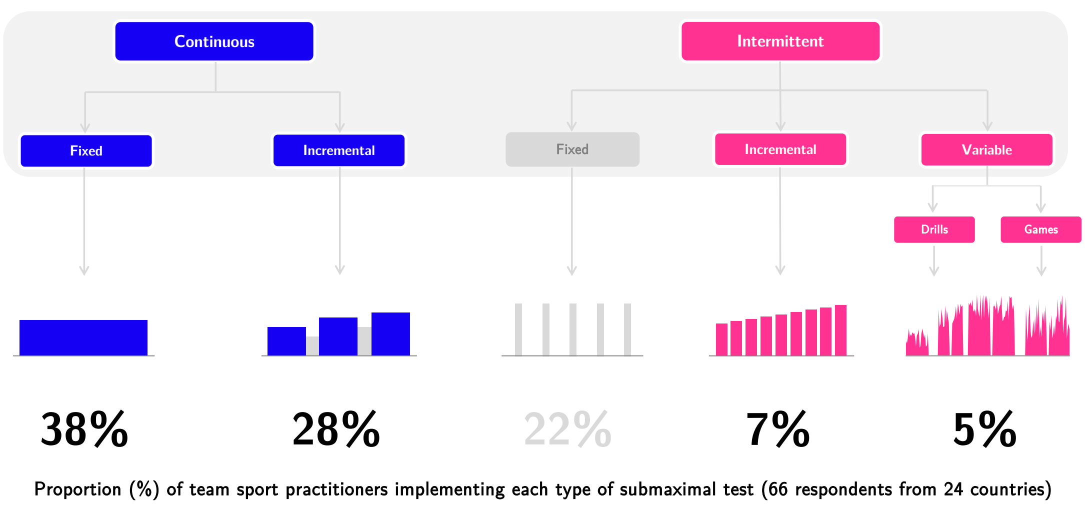


Fig. 7. Types of submaximal tests protocol. Each category is defined by two factors: (1) the exercise regimen, either continuous or intermittent, and (2) how exercise intensity is manipulated, whether fixed, incremental, or variable (adapted from Shushan 2022 & 2023c).

From full analysis to minimal burden: the shift from 5+5 to a 4-min protocol

While we initially used a full HR analysis including HRex, HRR, and post-exercise HRV as part of the 5+5 protocol (Buchheit 2008b, 2010a, 2010c, 2011b, 2012, 2013a, 2014), we gradually discontinued the 5-min post-effort period and all recovery-related measures. These variables did not provide us additional useful information, and the process added unnecessary burden, particularly given the practical difficulty of asking players to stand still post-exercise. We also found that 3 to 4 minutes of exercise was just as effective as 5 minutes for reaching a steady-state HR (Shushan 2023c). In line with the goal of minimizing burden, we reduced the effort duration to 4 minutes—an approach that remains widely used today, with some practitioners opting for even shorter 3-min protocols (Shushan 2024a, Shushan 2025, Arguedas-Soley 2024), since there appears to be reasonable agreement between HRex at 3 and 4 minutes in continuous protocols (Figure 8).

Real-world examples of implementation in the field

The measurement properties of HRex are remarkably robust, with no meaningful influence of athlete or protocol design features on validity or reliability (Shushan 2023c). This means that practitioners can create their own bespoke controlled running protocols which fit their environment, with a handful of constraints in mind (Shushan 2024b).

First, duration should be at least 3 minutes for the aforementioned reasons, although we would recommend experimenting with 4 minutes in the first instance to check if there are any meaningful differences in HRex when compared between the end of the 3rd and the 4th minute (Figure 8). When using shorter protocols such as 3 minutes, analysing HR data from the final 30 seconds (rather than the last 60 seconds) may be more appropriate, as it is likely to better reflect the period closest to steady state (typically reached around 2:30 minutes).

Second, HRex should be expected to fall between 75% and 90% HRmax. Practically, this intensity range supports more comfortable pacing. Higher values likely eliminate the 'submaximal' nature and lower values may not provide a substantial enough stimulus to truly test cardiovascular function.

Sensible rules-of-thumb can then be made to help guide the final design of a running-based submaximal test. For example, if selecting a shuttle-based protocol to help with pitch space constraints, shuttle lengths of $>$ 20 m are probably more appropriate than $<$ 20 m to reduce excessive acceleration/deceleration demands and the added metabolic consequence they may bring. For shuttle-based protocols, shuttle time (T) can be estimated as T = (D / S) - CoD, where D is the shuttle distance, S is the desired running speed and CoD and CoD is the time taken for a single change of direction, which can be reasonably assumed as 0.7 seconds (Buchheit 2008a). For example, to run 50 m shuttles at a speed of 12 km·h^{-1}, the time to complete each shuttle (cone to cone) is 14.3 seconds. It can be more pragmatic to estimate T as an even integer, to facilitate manual pacing via a whistle. For example, running the same 50 m shuttle in exactly 16 seconds renders a running speed of 11.76 km·h^{-1}, which can be easily controlled via a whistle being blown every 8 seconds, signifying either a 180° change of direction or massing the shuttle midway point (25 m, which can be marked with cones). This is shown in Figure 9 and Table 2, along with some other running-based submaximal tests protocols we have successfully implemented.

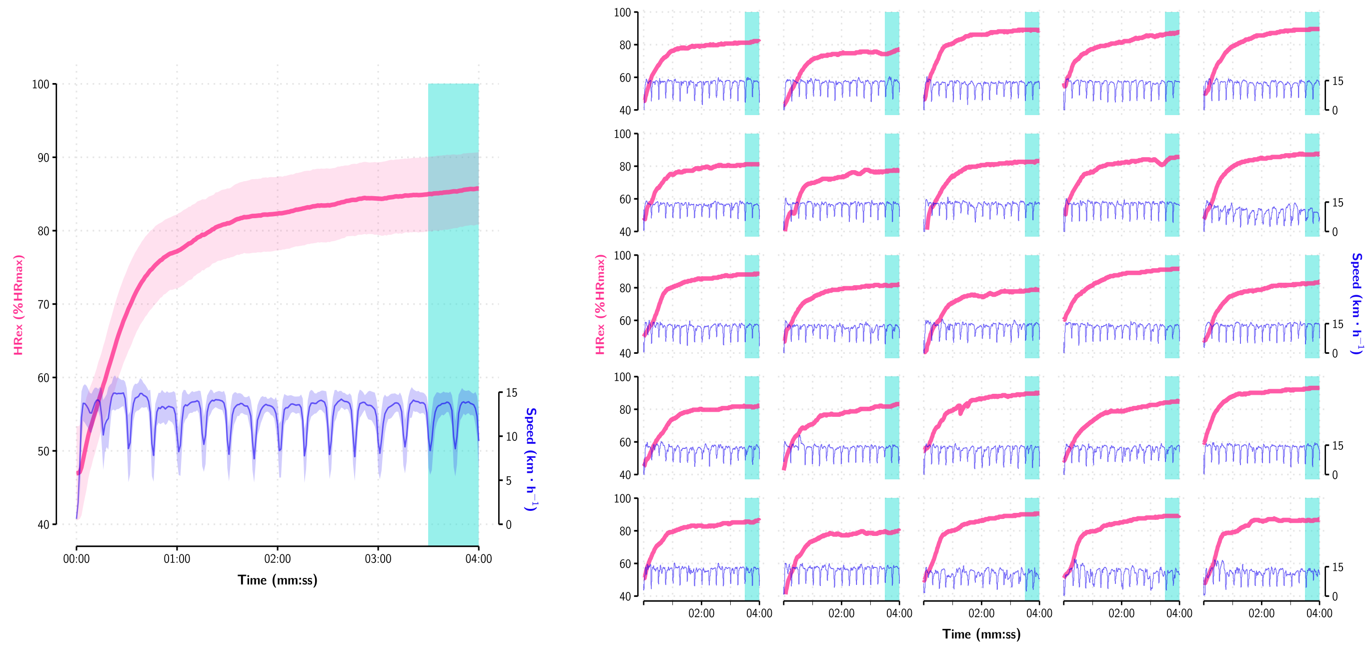


Fig. 8. HR responses during a 4-min submaximal run at 12 km·h^{-1} (50 m shuttles). The left panel shows group mean ± SD for HR (pink line and shading) and speed (blue line and shading) traces across 37 male senior players. The right panel displays individual HR (pink) and speed (blue) traces for a random subset of 25 players. Turquoise shaded areas indicate the time window used for HRex collection in the last 30 seconds of the test (Shushan, unpublished data).

Table 2. Examples of continuous-fixed protocols in various team sports with adapted (shuttle) distances and speed. *Actual speed is based on the assumption that completing a 180° change of direction (COD) after each shuttle takes approximately 0.7 seconds. The number of shuttles/intervals are derived from a duration of 3 or 4 minutes, separated by a slash (Taken from Shushan 2024b).

Sport	Marking	Distance	Shuttle/Interval time	Speed	Actual Speed*	N shuttles
Football (soccer)	8-shape run	50 m	15 sec	12.0 km·h^{-1}	12.0 km·h^{-1}	12/16 90° CODs
Football (soccer)	Box to box	72 m	22 sec	11.8 km·h^{-1}	12.7 km·h^{-1}	8/11
Rugby League	Try line to halfway	50 m	15 sec	12.0 km·h^{-1}	12.6 km·h^{-1}	12/16
Rugby Union	Try line to halfway	50 m	15 sec	12.0 km·h^{-1}	12.6 km·h^{-1}	12/16
Australian Football	Track (oval)	50 m	15 sec	12.0 km·h^{-1}	12.0 km·h^{-1}	–
Netball	Touchlines (length)	30.5 m	9 sec	12.2 km·h^{-1}	13.2 km·h^{-1}	18/24
Basketball	Touchlines (length)	28 m	8.5 sec	11.9 km·h^{-1}	12.9 km·h^{-1}	21/28

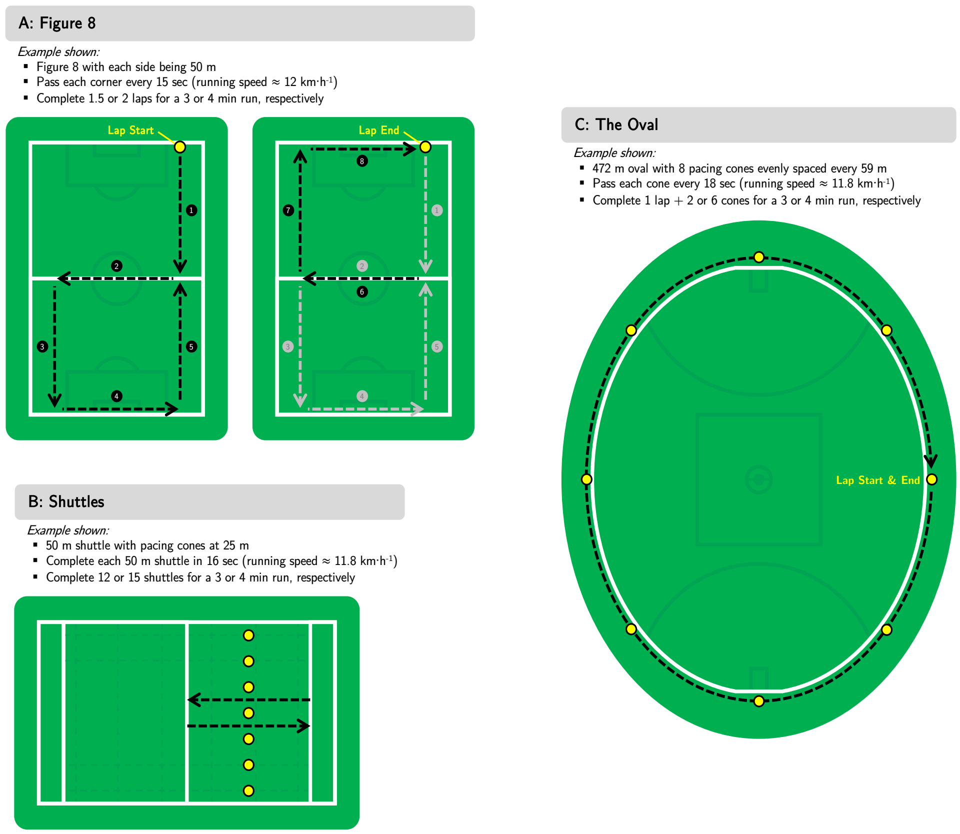


Fig. 9. Examples of common submaximal tests across various team sports. A) Figure 8 run on a FIFA standard football pitch (PSG Video). Running at 12 km·h^{-1} requires players to run each 50-m segment in 15 s (which is pretty easy to control with any stopwatch). Players run for 4 minutes in an 8-shape to balance the laterality of the changes of direction for 2 full laps (total 800 m). When running the test with the entire squad, groups of 6-8 players can start at different cones and follow each other on the course, so that all players can perform the run altogether (taken from Buchheit 2023). B) Shuttle run on a 100 × 70 m rugby union pitch (Falcons Video). The tryline to halfway is exactly 50 m and having players run this length in 16 seconds renders an average running speed of ∼11.8 km·h^{-1} (which accounts for an assumed change of direction time of 0.7 seconds). Pacing cones can be placed 25 m, allowing for a pacing visual check or pacing whistle every 8 seconds. 15 shuttles (7 returns plus 1 out) is enough for a 4 minute run (750 m), and just 12 shuttles (6 returns) are needed for 3 minutes (600 m). C) Oval run on a pitch with a 472 m circumference (165 × 135 m diameter). One lap can be divided into 8 pacing cones placed exactly 59 m apart on the pitch boundary. Passing each cone every 18 seconds gives a running speed of ∼11.8 km·h^{-1}. Similar to the Figure 8 run, our colleagues in AFL would typically start clusters of players on each cone, with a staff member in each to control the pacing via a stopwatch (Swans Video). Completing 1 lap plus 2 or 6 cones is enough for a 3 or 4 min run (590 or 826 m), respectively.

B. Uncontrolled running protocols (V1.2)

To further improve the feasibility and practicality of submaximal running protocols and reduce the need for tightly controlled running protocols, an alternative approach involves the HR–running speed (HR–RS) index. Originally proposed by Vesterinen et al. (2014) for monitoring aerobic adaptations in endurance athletes, the HR–RS index leverages the linear relationship between HR and running speed, calculating the absolute difference between theoretical and observed speeds. The equation uses HRex and running speed collected during a submaximal (uncontrolled-speed) run, combined with individual data such as standing HR, maximal HR, and the maximal speed obtained from a prior maximal test (e.g., maximal aerobic speed [MAS]). In our study (Rabbani et al., 2019), we demonstrated that the HR–RS index, when derived from the first 4 minutes of an early-session jogging exercise, improved meaningfully after different training blocks and served as a valid tool for tracking aerobic adaptation in an elite soccer player during the preparation phase. Therefore, deriving the HR–RS index from the early, general part of a session (e.g., jogging) may serve as a feasible alternative to fully structured submaximal test protocols. However, it should be noted that the current evidence of this approach remains limited, and further research is warranted to confirm its broader applicability.

C. HR responses to sport-specific actions

Beyond conventional embedded running protocols (V1), two further approaches have emerged to integrate submaximal testing into applied sport environments with minimal disruption. The first (V2) involves structured sport-specific drills, such as fixed passing patterns (Buchheit 2013b, Shushan 2025), standardized kicking drills (Arguedas-Soley 2024, GWS Giants, AFL Video), and consistent-sided games (Houtmyers 2022; Owen, 2020; Stevens 2016). The second (V3) pushes this further by embedding monitoring into unconstrained football-specific activities, including medium- to large-sided games and tactical drills (Lacome 2018a; Mandorino 2024).

In both V2 and V3, HR responses are analyzed using statistical models to account for variations in external load, providing insights into cardiovascular adaptation and fatigue. HRex from these formats generally correlates well with data from standard running protocols (r > 0.6), offering a practical supplement, though not a replacement. Full details on these approaches appear later in the manuscript (Section 3).

1.4 Empirical evidence for the validity of HRex in team sports

In a recent meta analysis (Shushan 2023c) we found large, negative association between HRex and various validated measures of fitness (r = -0.58 90% CL: -0.58 to -0.64) from 73 groups of athletes nested within 29 studies (total athlete sample; n = 1055). This affirms the construct (convergent) validity of HRex as a measure of fitness in team athletes. The next two figures presents a series of our work assessing the relationships between changes in HRex and changes in various validated measures of fitness, which provides additional evidence of construct validity. We begin with data from youth Aspire football players showing the link between HRex and changes in MAS (Buchheit 2012, Figure 10). We also include in Figure 10 results from a study in semi-professional Australian football (soccer) players assessing the relationship between HRex and changes in MAS (Shushan 2024a), alongside more recent findings in Australian female football players showing an association with changes in maximal time-trial performance (MacKenzie 2025). We then present findings from the PSG cohort, where HRex changes aligned closely with changes in the speed associated with 4 mmol·L^{-1} of blood lactate (Buchheit 2020, Figure 11). Similar relationships were observed with the Yo-Yo test in professional Scandinavian players (correlation coefficient of 0.64, with HRex changes of 5% associated with 5% changes in Yo-Yo performance, Buchheit 2011b) and Gaelic football players (r = 0.64, Malone 2017). Slightly lower associations than in the above examples were found based on large samples in professional male (0.54), female (0.47), and youth soccer players (0.40) in Germany (Altmann 2021, Walter 2025, Altmann 2023). Across all datasets and populations, the associations are consistently moderate to strong (average correlations around 0.6 90% CL: 0.4 to 0.8), regardless of the cardiovascular fitness variable used. These findings are consistent with the prediction intervals (i.e., the range of expected relationships in future studies or practices) reported in our 2023 meta-analysis (Shushan 2023c). This supports the relevance of HRex monitoring, but also confirms that it only partially explains performance outcomes, as other physiological and neuromuscular factors also contribute.

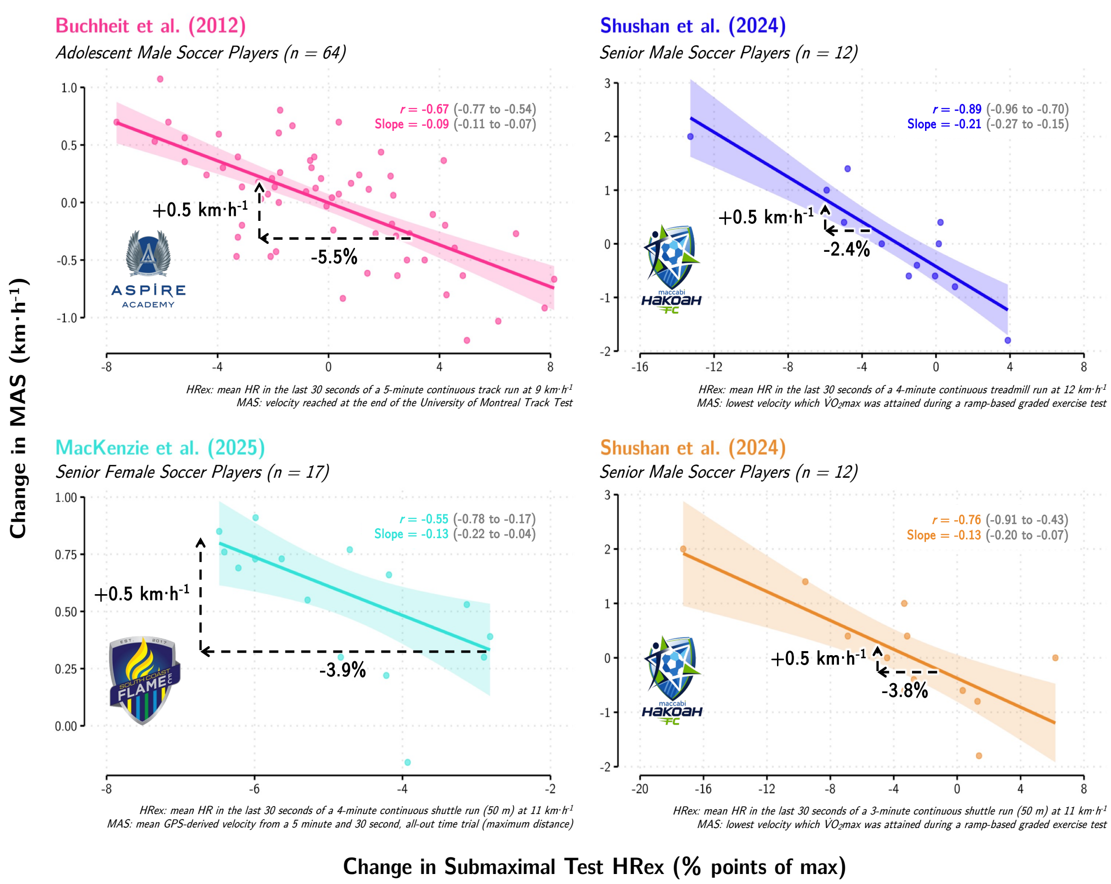


Fig. 10. Relationship between changes in HRex and changes in various measures of maximal aerobic speed (MAS) in youth male Aspire football players (Upper Left, Buchheit 2012), senior female soccer players (Lower Left, MacKenzie 2025) and senior male soccer players (Upper and Lower Right panels, Shushan 2024a). Overall, results suggest that across different submaximal and maximal test protocols, a 4 to 5% points reduction in HRex typically equates to a ~0.5 km·h^{-1} increase in maximal aerobic speed.

1.5 What HRex does not capture

While HRex provides a useful measure of cardiovascular status and adaptation, it does not fully capture the broader spectrum of performance readiness. Several factors contribute to the limitations of relying solely on HRex data, especially in team-sports contexts. In particular, HRex does not reflect the following:

- **Neuromuscular status:** Correlations between changes in HRex and performance in aerobic-based tests (MAS tests, 30-15IFT, Yo-Yo) consistently hover around 0.7 (Figures 10 and 11), indicating that only about 50% of the variance is explained by cardiorespiratory fitness, which is the primary component assessed by HRex. The remaining unexplained variance likely reflects other factors, particularly neuromuscular contributions that affect running economy and efficiency, which are not captured by HRex (Figure 12).
- **Generic vs Sport-specific fitness:** We've seen numerous cases where, in pre-season HRex drops consistently during general preparation but then plateaus or even spikes again in early competitive phases, in line with common perceptions from coaches and players of being "fit but not yet match fit" (Lacome 2018a, Mandorino 2024). The same trend appears during a return-to-training phase after a prolonged time-loss injury; a player's HRex steadily decreases throughout on-field rehab and structured reconditioning. However, once back in full team training, their HR responses to actual sport-specific work remain elevated, sometimes even leading to a rebound increase in HRex in the following week(s). While there's no direct experimental validation yet, we interpret this as evidence that HRex reflects only generic aerobic fitness. This has led us to explore more targeted submaximal tests (i.e., V2 and V3) which use intermittent, sport-specific drills as necessary complements to standard HRex testing (Section 3).
- It is important to clarify that what is assessed through submaximal tests and its variants (V2 and V3) are physiological responses to generic or sport-specific exercises. These responses provide insights into a player's physiological state and readiness but are distinct from the concept of "football fitness" (or any other team sports) as defined by Raymond Verheijen (Verheijen 2025). Football fitness refers to the ability to perform football actions at the required frequency and intensity for 90+ minutes. It is a precondition for performance but cannot be measured directly, highlighting the value of submaximal tests and their alternative formats as indirect monitoring tools (Mandorino 2025).

1.6 Are we also measuring fatigue with HRex?

Interpreting submaximal test results requires careful distinction between positive fitness adaptations and signs of maladaptation, such as accumulated fatigue or overtraining. A sustained decrease in HRex at a fixed workload over several weeks generally reflects improved cardiovascular efficiency. However, similar reductions have also been observed in cases of non-functional overreaching or parasympathetic dominance, as shown in Le Meur's study (2017, Figure 13), where overtrained athletes displayed lower HRex alongside higher RPE and impaired subjective training effects. These contrasting outcomes highlight the importance of contextualizing HRex changes using additional information, such as training load data, subjective training effects, and performance markers.

Short-term changes in HRex after periods of heavy training or heat exposure are often related to acute plasma volume expansion, a central cardiovascular adaptation. Our work (Buchheit 2013b; Scott 2022, Mackenzie 2025) and the work of others (Malone 2017) has demonstrated a moderate to strong, inverse relationship between acute training load and HRex both between- and within-players (i.e., greater acute training load = lower HRex). We have also seen HRex substantially reduce at the end of repeated 5-day training microcycles (e.g., in an assumed fatigued state) when compared to the beginning (e.g., in an assumed 'fresh' state), which was consistent with increments in fatigue-related blood biomarkers (serum concentrations of creatine kinase and urea) and worsening of subjective training effects (Short Recovery Stress Scale; Schneider 2020). While fatigue often coexists during periods of increased acute training load, these HR changes are unlikely the direct cause of this acute fatigue. Acute fatigue typically activates sympathetic drive, and when coupled with neuromuscular fatigue, worsens running economy; both responses that should elevate, rather than lower, HRex. These fatigue-related increments in HRex can be confirmed by (worsening) subjective training effects and performance measures. A drop in HR due to parasympathetic dominance requires more time and chronic exposure, not just a few days of hard training. Misinterpreting short-term HR decreases as fatigue is a common mistake. A more likely explanation is acute plasma volume expansion (discussed in subsequent sections). Conversely, if the training load has decreased substantially (e.g., after prolonged breaks or detraining periods), HRex can also rise, likely due to cardiovascular deconditioning and plasma volume reduction. This has been documented in youth soccer players after a 4-week off-season break (Ruf 2022).

Whether acute changes in training load systematically affect HRex remains debated. Field observations sometimes suggest that heavy training and fatigue can transiently alter HRex. However, available research remains cautious. For example, Borresen and Lambert (2008) found no significant effect of acute load changes on submaximal HR, and Mujika (2004) concluded that tapering (i.e., reductions in training load) does not substantially affect resting or HRex. Together, these studies suggest that HRex is relatively stable against short-term variations in load, whether increased or decreased.

Importantly, transient HRex shifts, whether increases or decreases, often normalize quickly (e.g., following a weekend of rest). This pattern indicates that most short-term fluctuations reflect early-stage fatigue, autonomic adjustments, or minor deconditioning, rather than deeper maladaptations such as overtraining. Careful integration of the time course, supporting metrics, and physiological context remains essential for accurate interpretation.

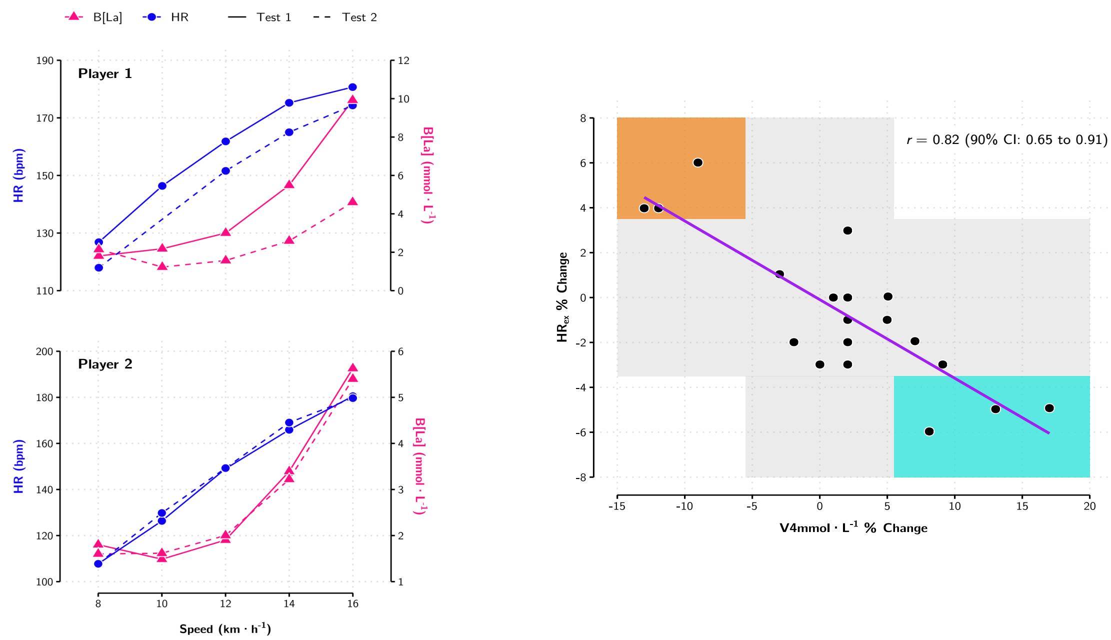


Fig. 11. Correlation between HRex and changes in speed at 4 mmol·L^{-1} of blood lactate (V4mmol) in professional footballers (PSG, taken from Buchheit 2020).

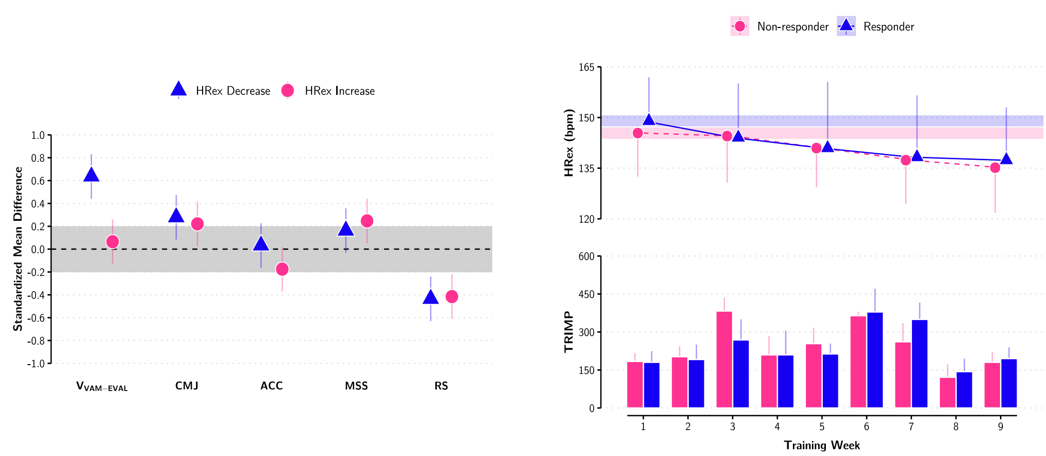


Fig. 12. Left: Data from youth players at Aspire, grouped by whether they showed a substantial increase or decrease in HRex. We then examined how these changes aligned with other physical performance tests conducted at the same time. HRex was not sensitive to changes in neuromuscular performance, as there were no between-group differences in countermovement jump (CMJ), acceleration (10-m sprint), maximal sprinting speed (fastest 10-m split over a 40-m run), or mean repeated-sprint performance (10 × 30 m). An important takeaway is that an increase in HRex is not necessarily negative, and a decrease in HRex did not always coincide with lower fitness. However, a drop in HRex was clearly associated with improvements in maximal aerobic speed (MAS, Vam Eval)—the only consistent link observed. Right: This panel shows data from our 8-week study on amateur runners preparing for a 10-km race. While all participants showed a decrease in HRex, the measure was not sensitive enough to differentiate those who improved their 10-km performance from those who did not. This may be due to the non-responders improving their aerobic fitness but lacking neuromuscular gains or arriving at the race with accumulated fatigue. Once again, this highlights that HRex does not reflect the full spectrum of physical performance components.

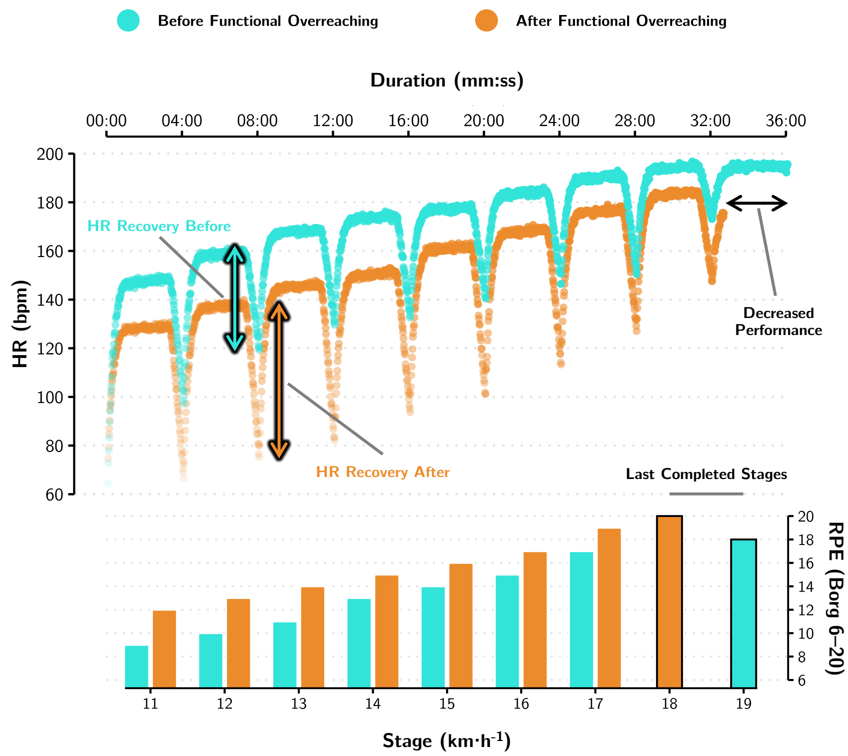


Fig. 13. Typical example of responses of HR and ratings of perceived exertion (RPE) before and after the overload training period in a participant developing functional overreaching (i.e., decreased performance and high perceived fatigue). Note that the HR and HR recovery response at the beginning of the test (i.e., low-intensity running) could suggest a good adaptation to training when considered in isolation. The combination with RPE values analysis indicates the development of the functional overreaching state (Adapted from Le Meur 2017).

1.7 Confounding factors and standardization strategies

There are two main categories of confounding factors that can influence HR during submaximal tests: acute (immediate) effects during exercise, and short-term physiological shifts related to training load, travel, or specific environmental stress.

Acute external factors

- **Hydration status, caffeine, and nutrition:** Dehydration increases cardiovascular strain and elevates HR, while caffeine and recent food intake can also acutely influence HRex. In principle, standardizing conditions improves data quality. However, in practice, it is often more realistic to ensure consistency rather than strict control. For example, if players routinely drink coffee before training, it is better they continue to do so when tested, maintaining similar conditions across assessments. The priority is minimizing variability by testing in comparable contexts, rather than disrupting established routines and habits.
- **Temperature and humidity:** Heat stress increases cardiovascular strain, leading to elevated HRex values. A 10°C change in heat index is typically associated with a ~1% increase in HRex. Figures 14 and 15 below illustrate the strategy we developed during the PSG period to account for the acute effects of environmental conditions, particularly temperature and humidity, for monitoring HRex trends. We observed substantial differences between pre-season camps held in hot, humid locations like Miami or Asia compared to colder conditions in Paris, irrespective of actual fitness status. Since then, I've (MB) consistently applied this adjustment method across all environments I've worked in, using the following equation: $HRex_{(adj)} = HRex_{(obs)} - 0.1 \times (T_{(obs)} - T_{(avg)})$, where $T_{(obs)}$ refers to the day of measurement and $T_{(avg)}$ to the average historical temperature for this specific context/group of players.
- **Circadian rhythm and jet lag:** If an athlete's autonomic system is misaligned with the local time zone (e.g., due to recent travel), HR may be artificially lowered. For example, parasympathetic activity peaks around 4 a.m.—if this corresponds to 9 a.m. local time after eastward travel, HRex may appear falsely suppressed.
- **Cardiac drift:** With prolonged exercise and dehydration, HR can rise disproportionately relative to oxygen consumption, a phenomenon known as cardiac drift (Coyle, 2001). This disrupts the normal HR/$\dot{V}O_2$ relationship, potentially creating a misleading impression of decreased cardiovascular efficiency when in fact the issue is simply fluid-related. To mitigate this confounding factor, we perform submaximal runs and standardized drills (V1 and V2) as the first training activity of the day (morning sessions or warm-ups), and this consideration has been incorporated into predictive models (V3) as a crucial adjustment variable (Mandorino 2025).

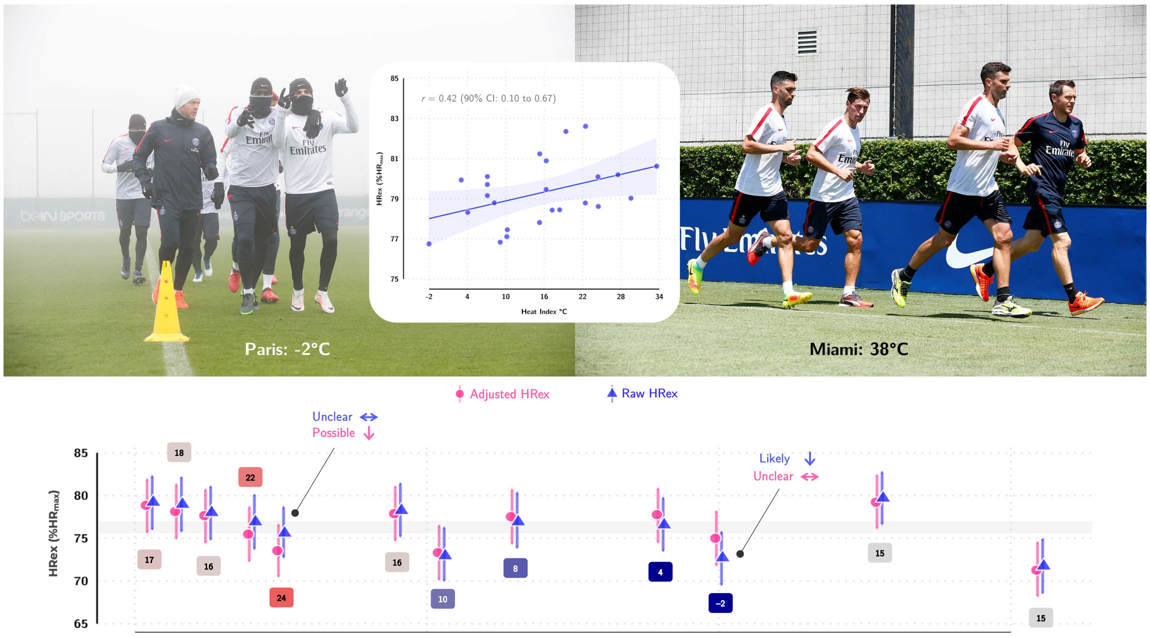


Fig. 14. Upper panel: relationships between HRex during a 4-min run and heat index (index that combines air temperature and relative humidity in an attempt to determine the human-perceived equivalent temperature in °C). Lower panel: intra-player changes in HR response (observed, unadjusted [blue] and adjusted based on heat index [red]) to the 4-min run (grey area represents the season mean ±1%). During the 5th run, the unadjusted HRex value suggests unclear variation in fitness, while the adjusted HR based on the heat index (+24°C) suggests a possible improvement (decreased HR). During the 10th run, the temperature was -2°C; observed, unadjusted data suggest likely increased fitness, while the variation may in fact be unclear when considering adjusted HRex (Adapted from Lacome 2018b).

Short-term physiological effects

Beyond these acute influences, transient changes in fluid balance driven by recent training contents (intensity, duration) and programmation (rest days vs consecutive training days), travel, or previous heat exposure can also affect HRex. These are primarily mediated through shifts in plasma volume, which influence stroke volume and myocardial efficiency. While not purely artifacts, these changes can over- or underestimate true cardiovascular fitness levels depending on timing. The timing of the test within the microcycle, and in relation to recent high-intensity sessions, travel, or heat exposure, is critical to minimize noise in HR responses.

The role of plasma volume in modulating HRex

One of the less intuitive but important influences on HRex is plasma volume (Buchheit 2009). Increases in plasma volume, whether driven by acute rises in training load (Buchheit 2012; Schneider 2020), heat exposure (Stanley 2014, McDonald 2025), or both (Buchheit 2011b; 2012, 2016; Clancy 2025), lead to an increase in stroke volume, which in turn lowers HR for a given submaximal workload (Figure 16). While this reduction may resemble a cardiovascular fitness gain, it primarily reflects a central, fluid-mediated adaptation rather than a large peripheral or metabolic improvement (i.e., changes in muscle-level oxygen extraction or mitochondrial capacity). This increased circulatory efficiency contributes to better cardiovascular function, and although temporary, it is still a real adaptation. Increases in $\dot{V}O_2$ max have also been reported following plasma volume expansion, further supporting the physiological relevance of these changes (Inglis 2025). In practice, this means that reductions in HRex following intense training blocks or heat exposure should be interpreted with caution, as they may overstate the magnitude of actual structural cardiovascular and metabolic fitness gains.

In practice, this has two implications:

1. Practitioners must acknowledge the potential for short-term increases in plasma volume, whether from intense training or heat, to artificially magnify the apparent improvement in HRex. While a real adaptation, it may not correspond to deeper, long-term structural fitness gains.
2. Submaximal tests should be conducted after at least one day of training to help stabilize plasma volume. Testing after full rest days may result in artificially elevated HRex values due to resting-induced fluid loss, masking the true physiological status. Ideally, the training day prior to a submaximal test would be light to moderate (e.g., recovery/low loading). But since this may not always be possible, and there will be natural week-to-week variation in session content, intensity and volume, quantifying prior day(s) training load may be useful when interpreting changes in HRex (e.g., visual inspection for [in]consistency or statistical adjustment).

Importantly, HR can also drop in the context of acute increases in training load that may be associated with accumulated acute fatigue, such as after several days of heavy training (Schneider 2020; Scott 2022) (Figure 17). In these cases, the reduction may not signal improved cardiovascular fitness, but rather a physiological response to short-term overload or stress. As discussed in the section above on overtraining, interpreting changes in HRex requires contextual data. This includes subjective measures such as RPE collected immediately or minutes after the run, or more global subjective training effects that are related to physical domains (e.g., fatigue, soreness, recovery). Discrepancies between physiological and perceived effort can help identify whether a drop in HRex is beneficial or potentially maladaptive.

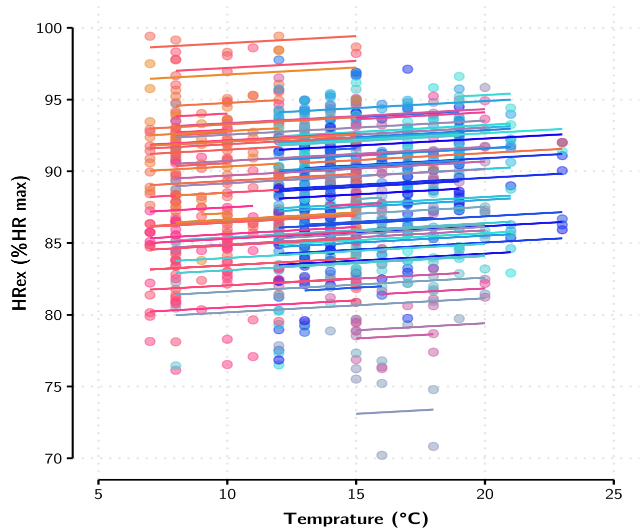


Fig. 15. **Individual players' submaximal HRex responses (4-min run at 11 km·h^{-1}) across varying ambient temperatures during an in-season period (March to June) in the Women's Australian Premier League (NPL). Data were collected from 95 players across 6 senior and reserve teams, contributing a total of 877 observations. Coloured scatter and line represents within-athlete trends derived from repeated measures correlation (r = 0.11, 90% CL: 0.05 to 0.17; p = 0.002). A separate linear mixed model estimated a mean increase of 0.9% points in HRex for every 10°C increase in ambient temperature (90% CL: 0.4 to 1.4% points), accounting for repeated measures via random intercepts for each player (Shushan, unpublished data).**

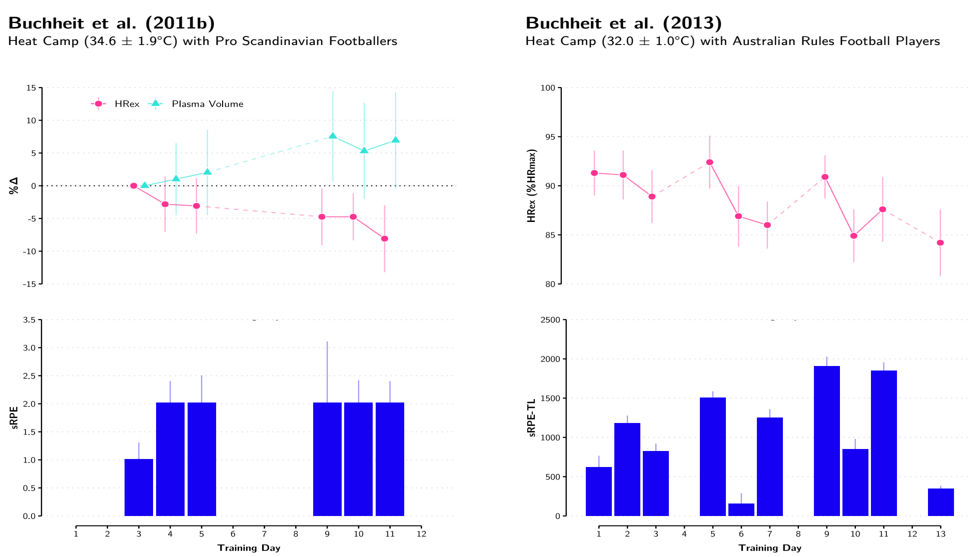


Fig. 16. **Left: Concurrent changes in HRex and plasma volume during a heat-based training camp in Doha (34.6 ± 1.9°C) involving professional Scandinavian football players (Buchheit 2011b). The strong association between plasma volume expansion and reductions in HR markers illustrates a central, fluid-driven adaptation in the early phase of heat exposure. Right: Daily HRex values in Australian rules football players across a similar training camp in Doha (32 ± 1○C, Buchheit 2013). While acute drops followed intense training sessions and returned to baseline after rest days, highlighting short-term plasma volume effects, the actual fitness improvement is seen in the overall downward trend across the camp. If a linear line were drawn through the data, it would reflect the cumulative cardiovascular fitness adaptation, beyond day-to-day fluctuations.**

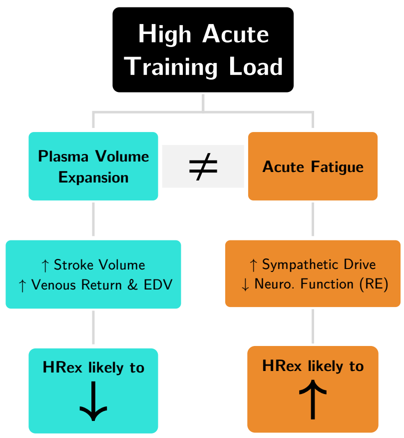


Fig. 17. Plausible mechanisms explaining the influence of high acute training load (TL) on HRex. Notably, reductions in HRex caused by high acute TL are likely independent of fatigue and more likely the result of acute plasma volume expansion. Conversely, increments in HRex could be attributed to fatigue-related perturbations in the cardiac autonomic and neuromuscular systems.

Key points for interpretation:

- Sustained decrease in HRex over several weeks → Likely indicates positive adaptation (improved cardiovascular efficiency), but could also signal non-functional overreaching if associated with poor subjective training effects and declining performance.
- Short-term decrease in HRex after heavy training or heat exposure → Likely due to plasma volume expansion and reflective of some positive central adaptations; while it can be associated, it's unlikely a direct consequence of acute fatigue (Figure 17).
- Short-term increase in HRex → Could result from neuromuscular fatigue, reduced running economy and sympathetic activation after intensified training (Figure 17), or from detraining and cardiovascular deconditioning after a substantial load reduction (i.e., injury or in-season break, Section 2).

1.8 When to perform the test? Seasonal and microcycle considerations

During pre-season training periods, or any other training phases with a targeted cardiometabolic focus, it can be beneficial to perform a submaximal test once per week to track the expected improvement in cardiovascular fitness. The anticipated positive response would be reductions in HRex across weeks (some analytical techniques to evaluate this are described in subsequent sections). Absence of this trend might indicate that the player is not responding favourably to training load and so adjustments or further assessments can be made. We have used historical data from prior pre-seasons can also be used to benchmark players and give them specific targets for returning from the off-season (e.g., a lower HRex than the start of the previous pre-season) or to improve by following the pre-season training phase (e.g., a lower HRex than what was achieved at the end of the previous pre-season) (Section 2).

During the in-season phase, a frequency of at least two tests per month (or, one test every other week) seems a reasonable recommendation to balance the need for continued repeated measures at a higher frequency than other fitness tests with both competition preparation and recovery, and reducing test monotony/burden.

Both pre- and in-season testing should be performed at consistent points of the microcycle and at the same time of day for reasons previously discussed. At least 2–3 days post-match and following a light, non-rest day is recommended to mitigate the influence of fatigue and plasma volume expansion on HRex. In football, this leaves MD+4/MD-3 as the most practical option. MD+2 is often a day off or dedicated to recovery, making it unsuitable for testing. MD+3/MD-4 is also not always feasible as it directly follows MD+2, which is often a rest day or highly individualized recovery. As a result, players would arrive at MD+3/MD-4 with varying training status, which may introduce inconsistencies that could still confound test results. In addition, MD+3/MD-4 is usually an intensive day focused on high-density small-sided games, so a submaximal run may not align with the session content (Buchheit 2021). By contrast, MD+4/MD-3 is typically designed as an extensive training day emphasizing volume, which makes adding a 4-min standardized run (≈800–1000 m) more straightforward. Importantly, performing the test consistently on MD-3 also ensures standardization relative to the intensive MD-4 session that precedes it, even if the content of that day is not fully optimal. This balance of practicality, alignment with training focus, and week-to-week consistency makes MD-3 the preferred time for HR-based submaximal testing in football.

Finally, submaximal test can be introduced early in the return-to-play process, as soon as the player is cleared to run at the required speed (e.g., 12 km·h^{-1}). This initial test provides a reference point to evaluate the effectiveness of off-feet conditioning strategies in relation to pre-injury baseline and helps quantify how much metabolic conditioning work remains. Given the simplicity and ease of the test, weekly assessments are recommended during this period. They can be easily embedded into individual sessions and continued until the athlete reintegrates into full team training (Section 2).

To conclude, we recommend the following testing frequency:

- Regularly during pre-season to track improvements.
- At least every two weeks during the competition to monitor improvement, maintenance, or decline.
- At consistent points in the microcycle (e.g., commonly three days post-match) to reduce variability.

1.9 Interpreting changes and making decisions

Accurate interpretation of HRex changes requires distinguishing between clear changes, which exceed measurement noise (typically >2 × the typical error; TE), and practically meaningful changes, which reflect a true physiological impact. Not all clear changes are necessarily meaningful for performance, which highlights the need to consider both statistical reliability (TE) and practical relevance (so-called smallest worthwhile change; SWC) when making training decisions.

A. Typical error of measurement

Our meta-analysis (Shushan 2023c) confirmed that, despite variations in protocol structure, HRex remains a stable and reliable measure across multiple approaches (Figure 18).

HRex is highly stable, with a test-retest error of approximately 1.6 percentage points of HRmax, meaning changes typically need to exceed ±3% points to be considered true/real, and not simply 'noise' (i.e., minimum detectable change; MDC*).

*technical footnote: this is based on an alpha (α) = 0.1 (i.e., 80% confidence interval for the true change to be > 0). For an α = 0.05 (i.e, 90% confidence interval), the MDC is 3.7% points.

B. What constitutes a meaningful change?

A ∼4–5% points decrease in HRex is associated with a 0.5 $\text{km}\cdot\text{h}^{-1}$ improvement in MAS (Buchheit 2012; Shushan 2025) and a similar change in $\dot{V}O_2$ max (Shushan 2025) (Figure 10). Recent studies also show that a 4% points decrease in HRex corresponds to a ∼6% improvement in velocity at 4 $\text{mmol}\cdot\text{L}^{-1}$ of lactate (V4mmol), another well-established physiological benchmark (Altmann 2021, 2023, Walter 2025). When applying threshold combinations of 4.5% for HRex and 6% for V4mmol, full agreement between the two markers is observed in 60–70% of cases, with partial agreement in 30–40% and full mismatches being extremely rare. These findings are based on approximately 600 paired tests conducted in professional male, female, and youth soccer players in Germany. Altogether, whether MAS, $\dot{V}O_2$ max, or V4mmol is used as the reference, the conclusion remains consistent: a 4–5% points change in HRex reflects a true and meaningful improvement in cardiorespiratory fitness.

Given that MAS (or sometimes lactate) test outcomes are widely understood and used by coaches, I (MB) gradually moved toward reporting HRex changes directly in terms of equivalent performance changes. Rather than commenting on HR, I now communicate expected changes in test outcomes (e.g., "+0.5 $\text{km}\cdot\text{h}^{-1}$"), making the data easier to interpret and act upon in practice.

C. Interpreting the changes

Overall, clear interpretation requires combining the typical error (∼1.6% points) with the practical smallest worthwhile change (∼4–5%). Changes smaller than 2–3% are likely noise. Changes greater than 6% can be considered both real and practically meaningful. This approach ensures decisions are based on both measurement precision and physiological relevance, as outlined in Table 3.

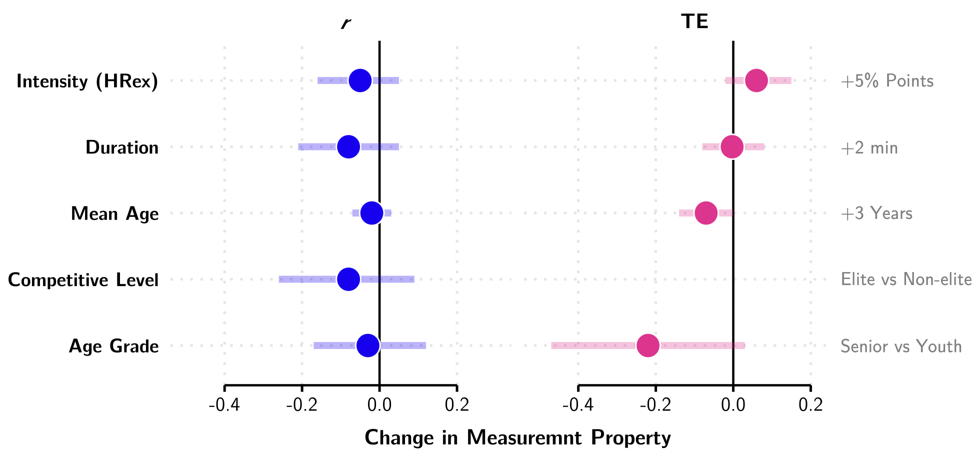


Fig. 18. Forest plot showing point estimates with 95% confidence intervals from mixed-effects meta-regression models examining modifying effects on Pearson's r italic (left) and typical error of measurement (TE; right). Effects are expressed per 3-year increase in mean age, 5-percentage point increase in submaximal test exercise intensity (HRex), 2-min increase in duration, age category: senior vs. youth, and competition level: elite vs. sub-elite. (Redrawn from Shushan 2023c).

Table 3. Interpretation of changes in HRex based on the typical error (∼1.6% points) and the practical smallest worthwhile change (4–5%).

Change in HRex (%)	Interpretation	Actionable?
< 3%	Within 2x the typical error (i.e., below MDC)	No — likely noise
3–6%	True change, but only possibly meaningful?	Caution — consider retest to confirm trend
> 6%	True change that is likely meaningful	Yes — adjust training accordingly

D. Many measures make light work

The task of interpreting true and meaningful changes is easier accomplished when multiple repeated measures of HRex are analysed, as opposed to paired changes. This is because the noise is reduced, or smoothed out, increasing the precision of the estimates and reducing uncertainty. During periods of targeted cardiometabolic training, like pre-season, when HRex is expected to reduce with accumulated training, linear regression can be used to estimate the change in HRex as a function of time. Consider a simple linear model where y = HRex and x = week number; the resulting slope coefficient represents the change in HRex associated with ±1 week of training. This estimate has a confidence interval and can be re-scaled to represent the entire training phase (i.e., change over all assessed weeks), before being scaled against the SWC (Figure 19).

When the goal of analysis is not to assess trends, but simply to look at the change between two tests, precision can be improved by averaging several tests. When this is done the TE reduces by a factor of $\sqrt{k}$, where k is the number of tests averaged. When averaging 4 tests, the TE is halved, which gives a value of ±0.8% points for HRex (the known TE of 1.6 divided by $\sqrt{4}$) (Hopkins 2004). From a practical perspective, this may be useful when comparing a player's recent scores with their data from several months ago, such as at the end of pre-season (which might be their lowest of the season) or prior to an injury (which might be used as a minimum target for return-to-play). Averaging several measures to represent these periods improves precision when comparing with the average of recent scores.

E. Further decision-making based on test results

To support practical decision-making, Figure 20 outlines a simple framework for interpreting changes in HRex in context. By integrating recent training load, subjective training load and effects, and the direction of HRex change, practitioners can better judge whether a player is adapting positively, failing to respond, or showing signs of overload. This interpretation is not just theoretical—it directly informs programming decisions at the individual level. For example, if a player's HRex is trending down and they're reporting positive subjective training effects, we may simply acknowledge the progress and maintain course. If there's no improvement despite adequate load, it may be necessary to increase training to stimulate adaptation. Alternatively, if HRex is dropping sharply but subjective training effects suggest fatigue, we may be seeing early signs of overload, requiring adjusted recovery strategies.

In practice, deciding to increase conditioning load must consider the primary objective in team sports: availability for technical-tactical training. Any added work should be non-disruptive. This often leads to choosing non-weight-bearing modalities (e.g., upper-body circuits, cycling, pool sessions) to avoid excess neuromuscular strain. In this context, heat-based training can also be effective, amplifying internal load with minimal mechanical demand, making it a valuable strategy to enhance cardiovascular fitness without compromising the main team sessions.

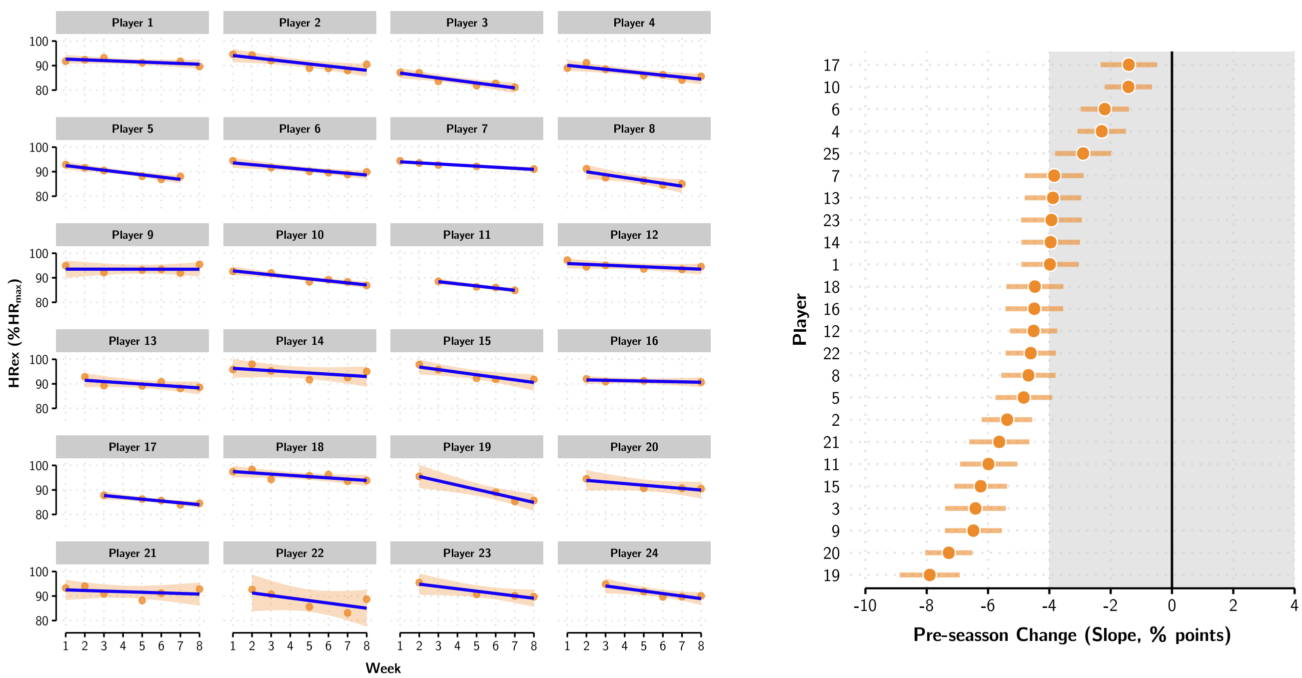


Fig. 19. Analysis of individual female senior soccer players' (Australian National Premier League) changes in HRex across pre-season training. The left panel summarises each player's data using linear models to estimate slopes (i.e., rates of change) from weekly repeated measures assessments. The right panel displays these slope values with associated 80% CIs, interpreted relative to a smallest worthwhile change (SWC) threshold (Mackenzie 2025). Note that the CIs on the right are derived from a pooled model (i.e., they are all the same). This can be useful when each player has a low sample of observations (typical of pre-season).

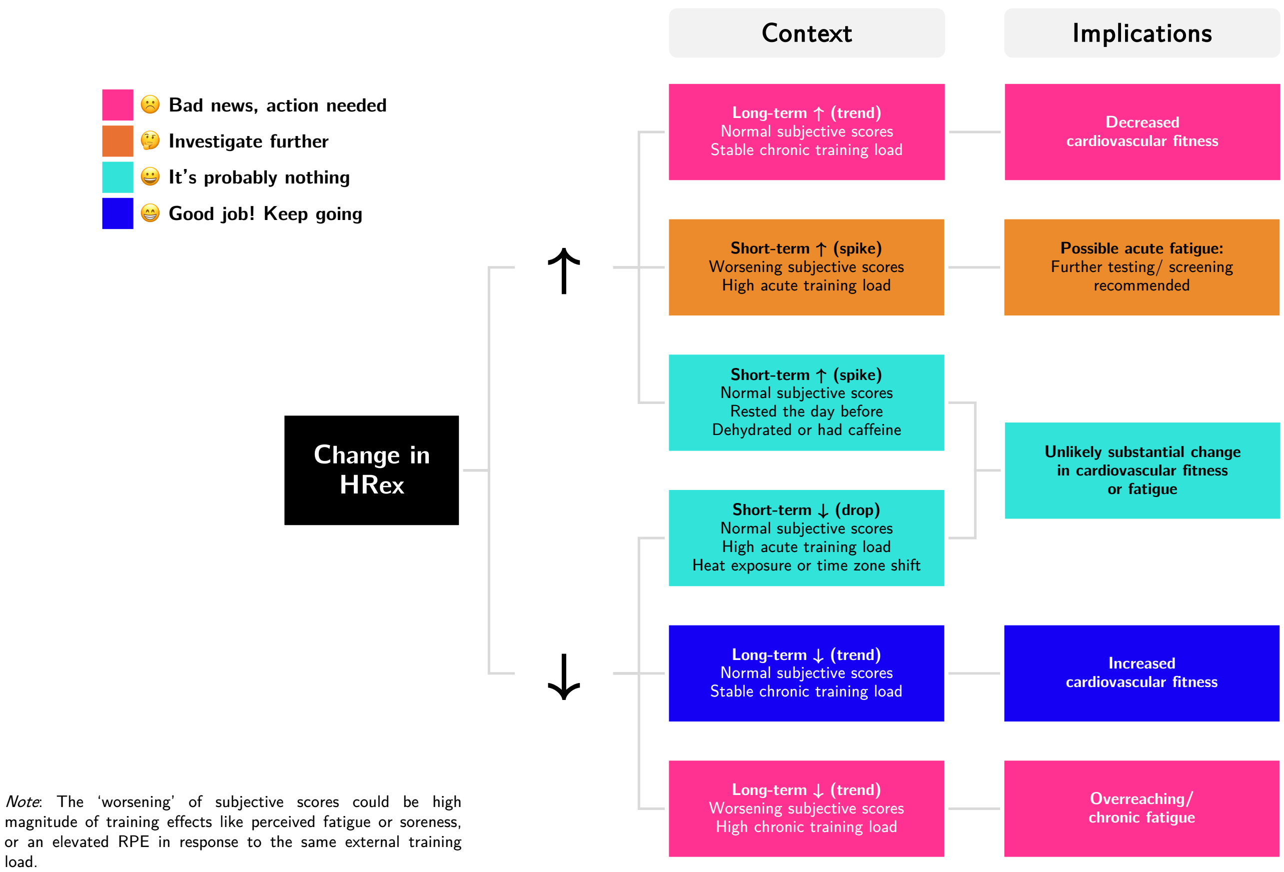


Fig. 20. Decision tree for interpreting changes in HRex. A decrease or increase in HRex can reflect either positive adaptation or negative strain, depending on the context. The decision process integrates recent training load, heat exposures, subjective measures (e.g., RPE, subjective training effects), and timing of the test to help determine whether the observed change is likely due to improved fitness, acute fatigue, detraining, overreaching or other transient factors. This framework supports more informed decision-making by combining physiological data with contextual insights.

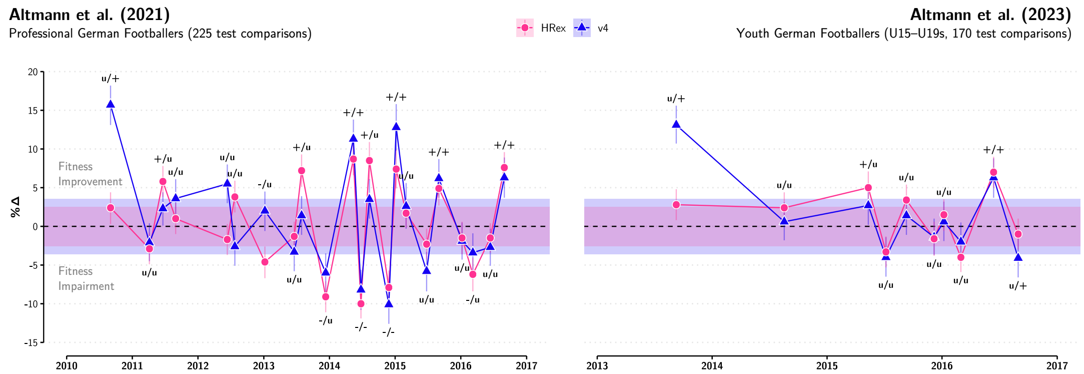


Fig. 21. Strong association between changes in HRex and changes in speed at 4 mmol·L^{-1} of blood lactate in professional Bundesliga players (left) (Altmann 2021) and youth players (right) (Altmann 2023), highlighting the value of anchoring HRex trends to an absolute physiological reference.

1.10 The need for absolute fitness measurement

While submaximal tests are valuable for monitoring relative improvements in cardiovascular efficiency, they do not not indicate absolute cardiovascular fitness levels. HRex, even when normalized to HRmax, has only weak correlations with $\dot{V}O_2$ max, lactate thresholds, or performance test outcomes (Buchheit 2012). It lacks the precision and agreement necessary to establish as a standalone anchor for benchmarking standards or training prescription (e.g., MAS values). A reduction in HRex at a fixed workload signals positive adaptation; however, without a reference point such as MAS, $\dot{V}O_2$ max, lactate threshold, or maximal field tests like the 30-15IFT or Yo-Yo, it cannot confirm whether an athlete has reached performance standards or guide the accurate prescription of training intensities. For these purposes, maximal performance anchors remain essential.

For meaningful interpretation, HRex trends should be anchored to at least one absolute fitness assessment performed concurrently. This pairing allows HRex changes to be translated into estimated changes in performance or physiology (as in the rationale for determining the SWC in HRex). Once this link is established, future changes in HRex can be interpreted proportionally in relation to the original absolute benchmark. To illustrate this point, Figure 21 shows the strong association between changes in HRex and changes in the speed corresponding to 4 mmol·L^{-1} of blood lactate. On the left, data from a professional Bundesliga football players (Altmann 2021) show a clear, tight relationship between improvements in HRex and increased lactate threshold speed. On the right, similar findings are observed in a youth player (Altmann 2023), further reinforcing the link. The consistency across levels highlights how anchoring HRex trends to an absolute physiological measure enhances both the accuracy and interpretability of submaximal tests.

2. Case studies

The following case studies illustrate how HRex monitoring can be applied to assess the effects of training breaks, camps, and return-to-play processes. The first examples are from my (MB) time consulting with the Adelaide Crows in the AFL (Buchheit 2015b, Figure 22) and later as Head of Performance at PSG (Buchheit 2016, Figure 22). In both cases, HRex clearly reflected group-level fitness changes following either a Christmas break or an intensive pre-season training camp. However, the underlying mechanisms likely differed between the two situations.

At PSG, the substantial drop in HRex after the pre-season camp in Asia (with temperatures reaching around 35–38°C) probably reflected the combined effects of cardiovascular fitness gains and heat exposure, consistent with other reports following intensive training camps (Buchheit 2011b, 2012, 2016; Clancy 2025, Ruf 2022). In contrast, the observed drop in HRex after the Christmas break with the Adelaide Crows (despite reduced training loads) was somewhat unexpected. As discussed earlier (see section 1.7), reduced activity typically leads to an increase in HRex due to a loss of plasma volume. At the time, we hypothesized that this improvement instead reflected neuromuscular recovery and a rebound in lower-limb strength (evidenced by better maximal theoretical horizontal force, MTP, and acceleration actions during a standardized handball game, Figure 22). This could have led to improved running economy, reducing the physiological cost of submaximal running and lowering HRex, despite little to no actual cardiovascular improvement.

A more recent study from TSG Hoffenheim academy players provides a contrasting example (Figure 23). After a 4-week winter off-season break, in which the first 2 weeks involved no endurance-oriented training, and the last 2 weeks included 4–5 endurance sessions per week consisting of zone 2 and HIIT, players showed an elevated HRex, which is typical following a period of detraining.

This response is likely due to the longer duration of reduced activity and a greater reduction in training load compared to the AFL players, who maintained some important training routines (i.e., training 5 times per week over 2 weeks, including HIIT and strength work) during their Christmas break (Figure 22, Buchheit 2015b, Ruf 2024).

Another case features a Lille OSC player returning from an ACL injury (Buchheit 2023, Figure 24), where pre-injury HRex benchmarks helped guide his reconditioning. By implementing individual, off-feet conditioning, we accelerated his return to running and safely progressed him back into team training. A final case presents a similar approach applied to a player who, despite being uninjured, was out of team training for four months (Figure 25).

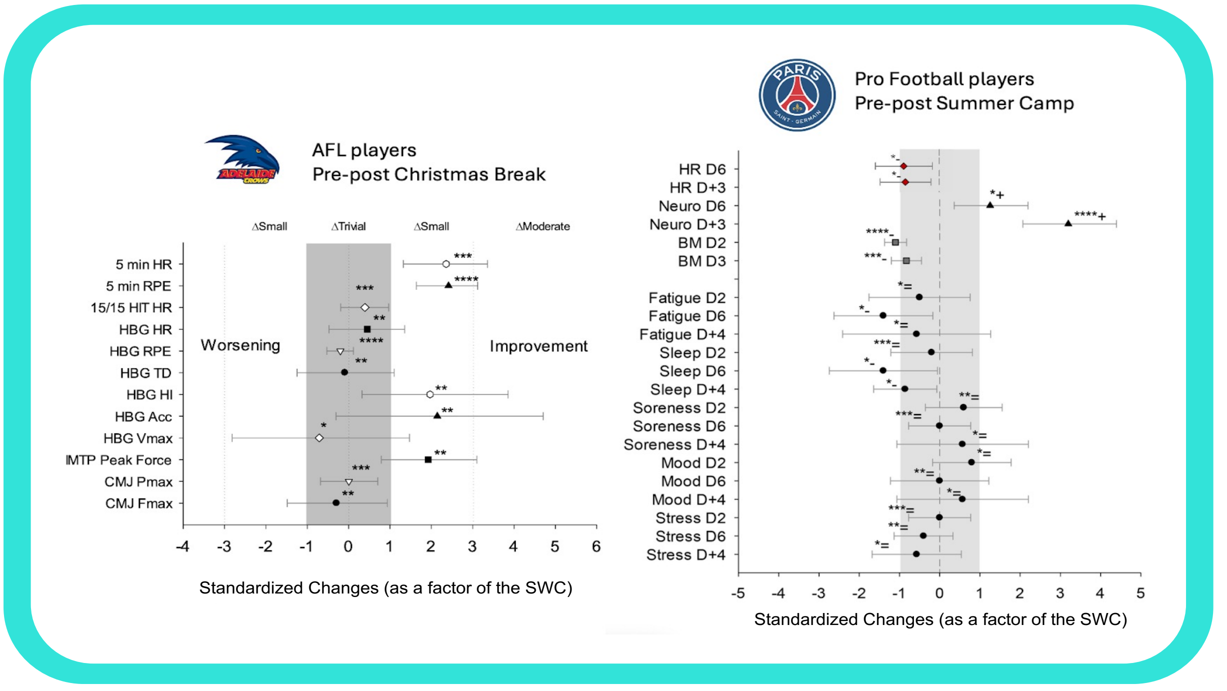


Fig. 22. Left: AFL Adelaid Crows (Buchheit 2015b). standardized changes (90% confidence intervals) in physiological and performance measures (lower panel) after the Christmas break. Abbreviations: HBG, standardized handball game; 15/15 HIT, high-intensity training; HR, heart rate; RPE, rating of perceived exertion; TD, total distance; HI, high-speed running (>17 km·h^{-1}); Acc, acceleration distance (>3 m/s2); Vmax, maximal velocity reached during the HBG; IMTP, isometric midthigh pull; CMJ, countermovement jump; Pmax, maximal power; Fmax, maximal force. Right: PSG summer camp in Asia (Buchheit 2016). Heart-rate (HR) response to the submaximal run, neuromuscular efficiency index (Neuro), body mass (BM), and the different wellness measures during (letter D with numbers for the number of days into the camp) and after the camp (letter D+ with numbers for the number of days after the camp). Change *possibly substantial, **likely substantial, ***very likely substantial, ****almost certainly substantial.

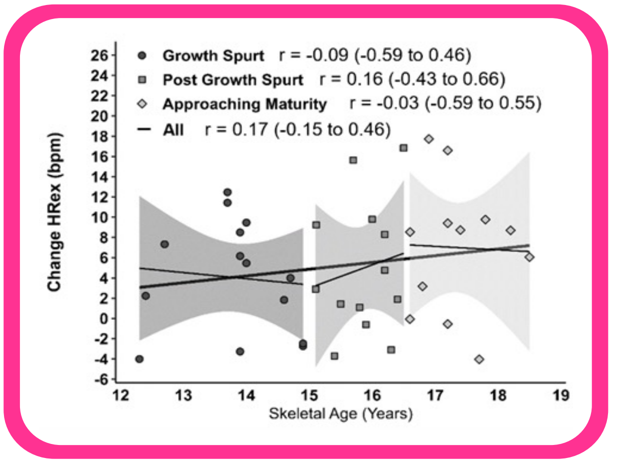


Fig. 23. Christmas break study with TSG Hoffenheim academy players (Ruf 2024). Linear correlations (95% confidence intervals) for all three maturation groups and the entire sample between skeletal age measured prior to the Christmas break and changes in HRex. Across the entire sample, HRex increased by 5.3 ± 6.2 bpm after the Christmas break, corresponding to a standardized mean difference of 0.51 (95% CI: 0.06 to 0.96).

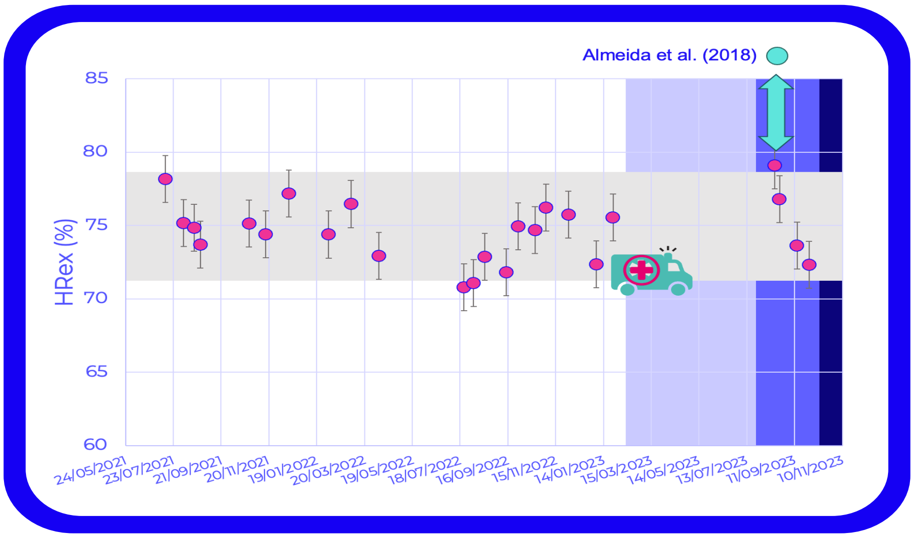


Fig. 24. CChanges in HRex recorded during the final minute of a 4-min run at 12 km·h^{-1}, tracked over a 2.5-year period in a pro football player before an ACL injury, and then through the return to running, individual training, and eventual reintegration with the team. Notably, the highest HR observed during detraining was lower than expected based on $\dot{V}O_2$ max-related HR changes reported in the literature (as estimated from Almeida 2018), suggesting a smaller cardiovascular decline than typically documented. HR was adjusted for ambient temperature (Figures 15 and 16). The horizontal area represents the smallest worthwhile change in HR (+/- 5%), which is equivalent to a change of +/- 0.5 km·h^{-1} in MAS (Figure 10). Error bars: Typical error of the measure (1.6%).

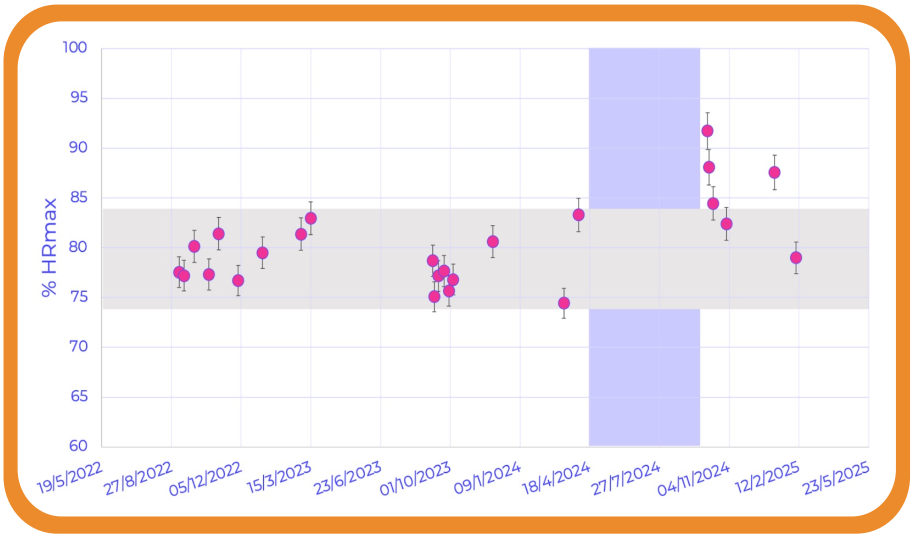


Fig. 25. Changes in HRex for a player who had been with a club for 1.5 years (August 2022 to April 2024), but experienced a premature contract termination before the end of the season, resulting in a 4-month period without team training (blue vertical zone, HR reached then >90% HRmax). He later resumed individual work before joining a new club in October 2024, at which point his HRex returned to baseline levels. He then sustained a muscle injury in november 2024, which caused his HR to rise again when he was monitored and returned to run in January 2025, before reaching again 'fit' levels later in February (last data reported). The horizontal area represents the smallest worthwhile change in HR (± 5%), which is equivalent to a change of ± 0.5 km·h^{-1} in MAS (Figure 10). Error bars: Typical error of the measure (1.6% points).

3. Embedding submaximal assessments into sport-specific contexts

Beyond traditional embedded submaximal runs, two innovative options emerge: V2, which centers on sport-specific drills like passing or small-sided games to assess fitness within a more applicable context, and V3, which involves invisible testing that predicts HR responses based on external load and identifies changes in physiology by noting deviations from these predictions.

3.1 Passing drills or controlled small-sided games (V2)

This approach integrates sport-specific, technically focused drills with consistent prescription parameters such as player numbers, spacing, and work-to-rest ratios. Examples include fixed passing patterns, like the Y-shaped sequence in football (Shushan 2025), semi-standardized kicking drills in Australian Rules Football (Arguedas-Soley 2024, GWS Giants, AFL Video), and more tactically complex formats such as

5v5 possession games (Owen 2020) or sided-games with fixed player configurations (e.g., 6v6 plus goalkeepers; Houtmyers 2022; Stevens 2016).

These drills offer potential advantages for capturing reliable HR responses in training settings. Their structured nature, typically with lower tactical complexity and minimal contact, reduces external demand variability and supports standardization. Furthermore, scheduling these drills early in sessions helps limit the influence of accumulated fatigue and cardiovascular drift (Coyle, 2001).

Supporting this rationale, we (see Shushan 2025) evaluated the validity of a football-specific Y-shaped passing drill in semi-professional male players. HRex data were collected over 12 weeks during both a continuous fixed run (criterion protocol) and the passing drill (practical protocol; Figure 26). Adjusting for external load (specifically total and high-speed running distances) improved the relationship between HRex values from the two protocols (Figure 27). The reduction in root mean square error (RMSE) to within the TE of HRex (1.6% points) indicates that the remaining prediction error falls within standard test–retest variability. This suggests that, after controlling for external load, the Y-shaped passing drill offers a valid and practical method for monitoring HRex responses.

From a practical perspective, HRex can be adjusted by preceding the drill-based test (practical) with a standardised 3–4 min run (criterion) for the first handful of tests (e.g., 10 per player). Then, each player's run-HRex can then be predicted, via a linear model, using drill-HRex plus relevant drill external load parameters. Individual corrective equations can then be used to estimate run-HRex using only drill HRex and external loads. Analysing the data in this way borderlines 'V3' approaches to submaximal runs: invisible testing.

Another novel finding from this study was the strong relationship between adjusted HRex from the passing drill and laboratory measures of cardiorespiratory fitness. Compared to raw HRex values from the drill, adjusted HRex showed large to very large correlations with both $\dot{V}O_2$ max and MAS which were comparable in magnitude to those observed for the continuous protocol (Figure 28). In contrast, unadjusted HRex showed only moderate and less consistent relationships. These results support the use of externally adjusted passing drills as a valid alternative to generic run-based monitoring (i.e., V1).

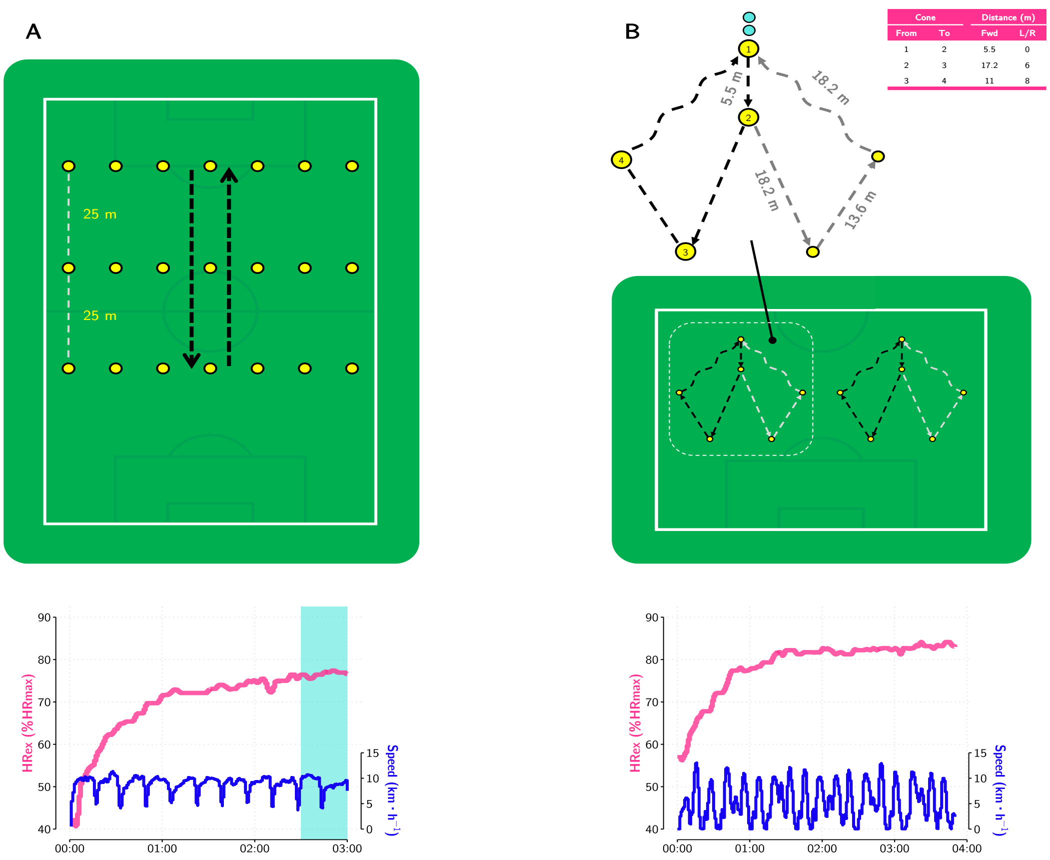
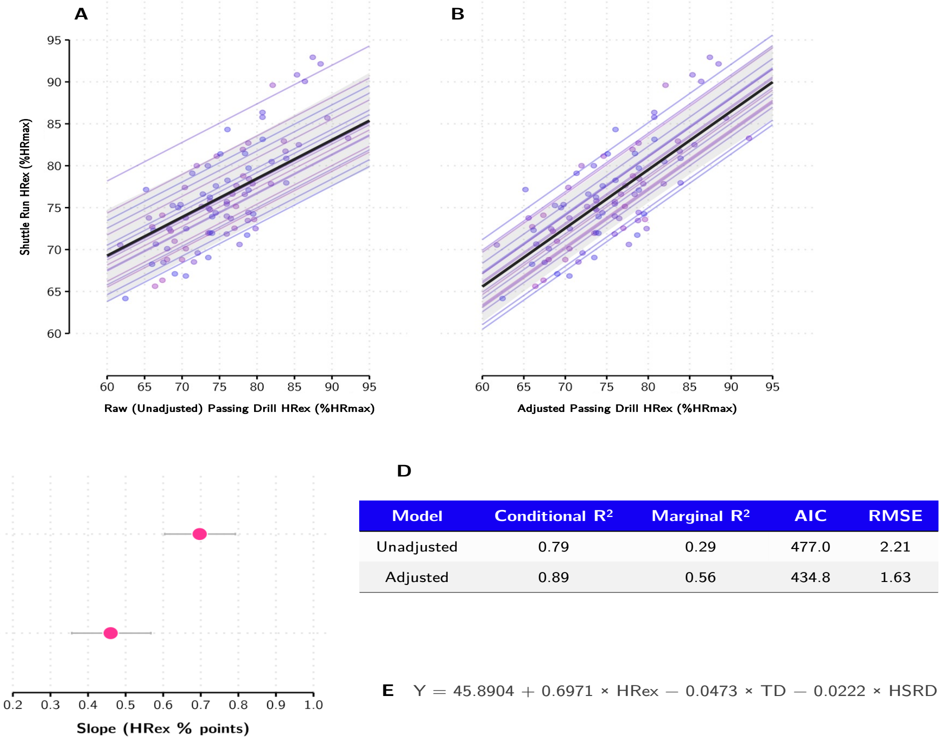


Fig. 26. A visual illustration of submaximal tests, including a continuous-fixed (criterion protocol, panel A) and a intermittent-variable standardised passing drill (practical protocol, panel B). In panel B, arrows and dashed lines represent passing and movement patterns, while shaded arrows represent the alternate direction of movement and passing sequences performed at the end of each drill cycle. The lower panels display instantaneous HR (in pink) and speed (blue) traces for a representative training session (Shushan 2025).



Model	Conditional R^2	Marginal R^2	AIC	RMSE
Unadjusted	0.79	0.29	477.0	2.21
Adjusted	0.89	0.56	434.8	1.63

E $Y = 45.8904 + 0.6971 \times HRex - 0.0473 \times TD - 0.0222 \times HSRD$

Fig. 27. Within-athlete associations between HRex from continuous-fixed (criterion protocol) and intermittent-variable (practical protocol) submaximal tests. Panel A and panel B present scatter plots illustrating these relationships with observed (unadjusted) values and values after controlling for external load parameters (adjusted), respectively. Coloured dots and regression lines represent individual athletes, with the grey ribbon indicating the 90% prediction intervals. Panel C shows the change in relationship slope between the adjusted and unadjusted models, while Panel D provides the agreement statistics for both models. The adjusted predictive equation derived from the adjusted model is presented in Panel E (Taken from Shushan 2025). CF: continuous-fixed submaximal run, HRex: exercise HR.

3.2 Predicting HR response to sided-games (V3)

To reduce the logistical complexity typically associated with submaximal runs (V1) and to avoid the need for planning sport-specific drills within the training schedule (V2), practitioners are increasingly adopting an invisible testing approach (V3). While traditional V1 and V2 assessments remain widely used due to their simplicity and minimal physiological demands, they present limitations: they require additional scheduling, and sometimes face resistance from coaching staff. These factors ultimately constrain their frequency of application throughout the competitive season.

In contrast, V3 monitoring leverages data collected directly from the main parts of training sessions to provide continuous, high-frequency insights into players' cardiovascular fitness, without the need for formal testing procedures. This offers a more efficient, integrated, and non-invasive alternative, as it allows performance tracking without altering the natural flow of training (Leduc, 2025). The underlying principle of this approach is that no assessment captures the physiological demands of football better than the training itself, particularly when characterized by small-sided games and other context-specific exercises. These formats extend to medium- to large-sided game simulations (Lacome 2018a) across varying number of players (e.g., 5v5 to 10v10) and pitch densities (117 ± 65 m^2 per player), or even a broader range of football-specific drills administered in the training such as constrained possession drills, game simulations, and conditioning-based exercises embedded within tactical phases of the training (Mandorino 2024). Furthermore, the "invisible" nature of the process ensures no additional burden is placed on players or coaches, enhancing its practical utility in elite sport environments.

This approach originates from the study proposed by Lacome (2018a), in which the authors employed linear regression to predict HR responses based on external load data. In this framework, external load metrics (e.g., total distance, speed, accelerations, decelerations) served as independent variables, while HR acted as the dependent variable. ΔHR was then defined as the difference between the predicted HR (from the individual regression models) and the actual HR observed during the session. A smaller or negative difference (i.e., lower-than-expected HR for a given workload) is interpreted as a sign of good fitness, suggesting the athlete can tolerate the external demand with a lower internal physiological cost. Conversely, a positive discrepancy could indicate reduced fitness or accumulated fatigue. Importantly, this Fitness Index (FI) reflects only the physiological response to football-specific activity. While useful, this metric should not be mistaken for a direct measure of "football (or any team sport) fitness", which refers to the ability to perform football (or any team sport) actions as frequently as necessary to sustain a high tempo for 90+ minutes (Verheijen, 2025).

However, several limitations can be identified: the analysis was restricted to only 10 players, and separate simple linear regression models were developed for each individual. This strategy limited the generalizability of the predictions and increased the risk of overfitting. In contrast, a key strength of the machine learning (ML)-based approach lies in its capacity to handle high-dimensional datasets and uncover complex, non-linear relationships among variables—interactions that traditional linear models often fail to detect. To improve this concept, the authors (Mandorino, 2024) applied machine learning techniques to predict players' HR responses during training - and created a new metric, the FI. The prediction model identified several significant contributors to HR response, including average speed, elapsed time since the beginning of the session, and mechanical parameters (Figure 29). These results reinforce the idea that total distance alone is too reductive to capture the mechanical demands of soccer that could affect the HR responses, making necessary the adoption of a multivariate approach. Additionally, the variable "minutes since the start of the training session" was particularly relevant, likely due to the phenomenon of cardiovascular drift (see to Section 1.7).

The different indices examined, such as ΔHR (Lacome 2018a) and the more advanced FI (Mandorino 2024), consistently showed decreases from pre-season to in-season. These reductions align with the expected improvements in cardiovascular fitness typically observed during this phase of training (Figure 30).

Finally, when validated against a standardized run (HRex), ΔHR and FI showed a moderate-to-large correlation (Lacome 2018a, Mandorino 2024). This is not a shortcoming; rather, it suggests that FI and HRex may reflect distinct, complementary aspects of fitness (general versus sport-specific fitness, respectively). Notably, HRex variations were associated with cumulative distance only at the start of the season and tended to stabilize thereafter. In contrast, ΔHR and FI continued to vary in response to weekly training loads across the full season. Based on these findings, and the indications presented previously, practitioners are encouraged to adopt a four-quadrant model (see Figure 31) to interpret and monitor player status across the season. This model allows for the differentiation between improvements in generic versus more sport-specific physiological adaptations, ultimately guiding more precise and individualized training adjustments.

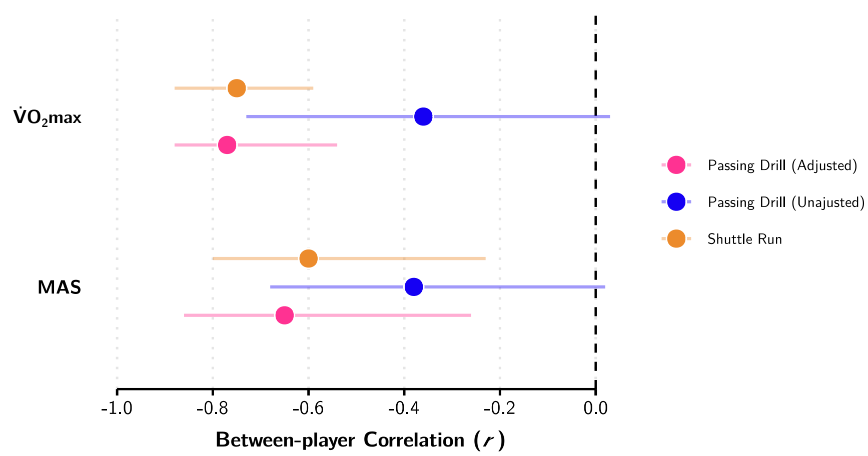


Fig. 28. The associations of HRex with MAS and $\dot{V}O_2$ max in senior male soccer players (n = 13). Relationships are shown with HRex from the shuttle run (criterion protocol) and the passing drill, both observed HRex and HRex when adjusted for drill external training load. While this sample is not large enough to draw definitive conclusions, it appears that adjusting passing drill HRex for external training load improves the association with criterion measures of aerobic fitness, and therefore the validity (construct and discriminant) of the drill-based standardized protocol (Taken from Shushan 2025).

Conclusion

Submaximal testing has evolved into a reliable, valid, and practical tool for tracking cardiovascular adaptations in elite team sports (Buchheit & Hader 2025). Across two decades of applied use and research, the method has demonstrated clear utility in measuring relative changes in (generic) cardiovascular fitness, especially when protocols are standardized and results are interpreted in context. While HRex provides precious information about central cardiovascular efficiency, it does not capture the full spectrum of physical performance, particularly neuromuscular status and true sport-specific fitness (e.g., "football fitness" as defined by R. Verheijen, 2025). Its sensitivity to various confounders, such as plasma volume shifts, heat, hydration, and test timing, requires careful standardization and contextual interpretation. Anchoring HRex responses to absolute performance benchmarks (e.g., MAS, $\dot{V}O_2$ max, lactate thresholds) strengthens their interpretability and actionability.

Moving forward, a combination of traditional, sport-specific, and embedded monitoring approaches, supported by contextual data and decision frameworks, offers a scalable solution for optimizing athlete monitoring.

The inclusion of case studies and practical decision-making models in this paper highlights how submaximal testing can directly inform programming and contribute to better load management and return-to-play strategies in elite environments. While the majority of research and applied use has focused on young to adult elite male athletes, the underlying principles and recommendations discussed here should apply broadly across different populations, including female athletes and non-elite groups, although further dedicated research is needed to confirm specific adaptations and responses.

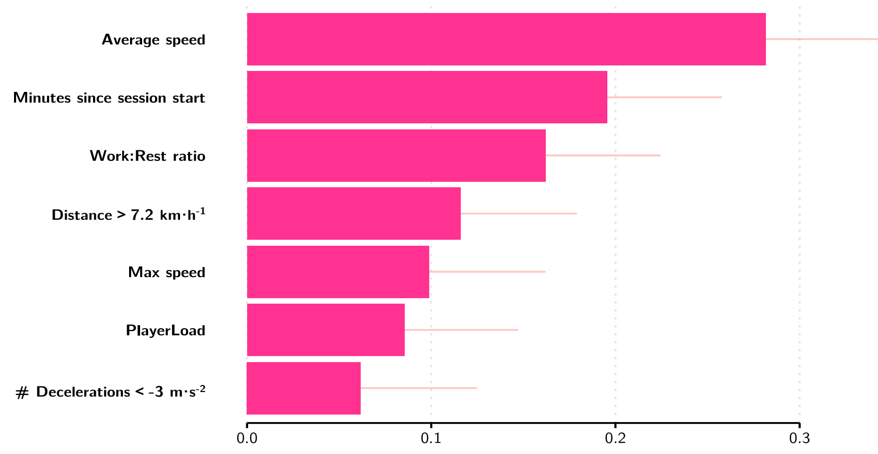


Fig. 29. **Feature importance analysis was conducted on the variables used in the machine learning (ML) model to predict HR responses during small-sided games. Among all variables, average speed emerged as the most influential predictor of HR response. Additionally, several other variables were identified as important, including minutes since the start of the training session, work: rest ratio, distance covered at speeds above 7.2 km·h^{-1}, maximum speed, and mechanical parameters such as PlayerLoad^{TM} and the number of decelerations ($\leq$ -3 m·s^{-2}). These findings underscore the necessity of a multivariate approach to accurately quantify internal load.**

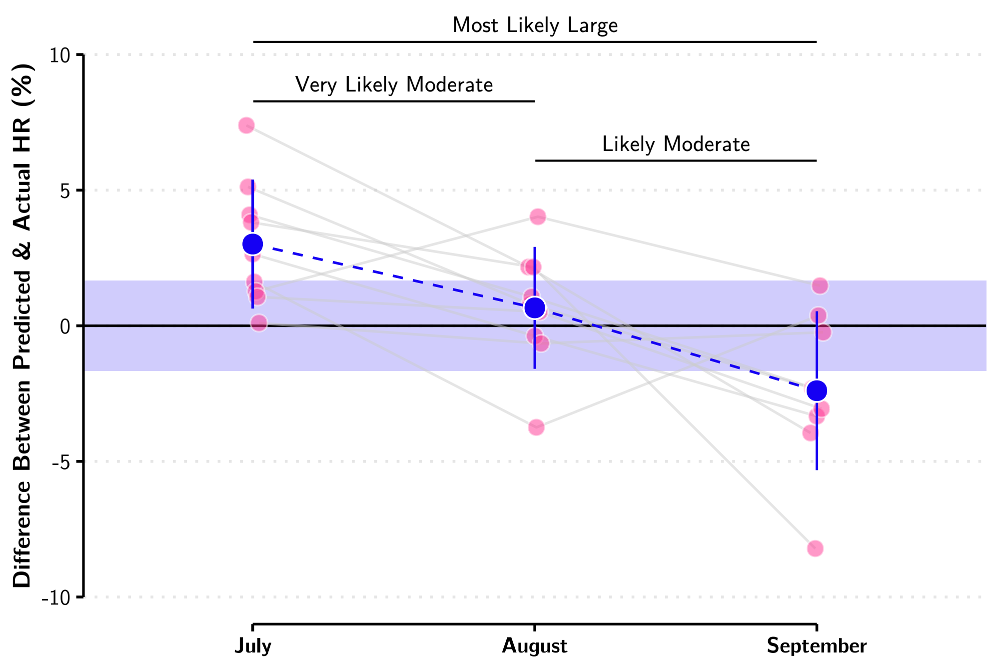


Fig. 30. **Between-month changes in the differences between actual and predicted HR. Data point shades and shapes are set for each player (Taken from Lacome 2018a).**

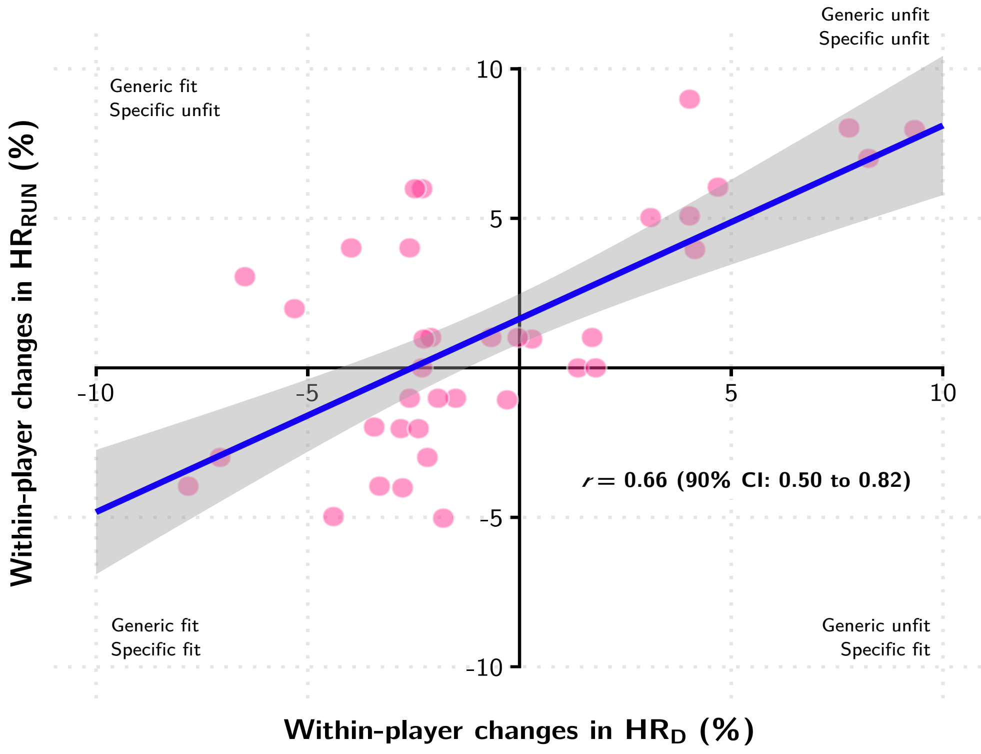


Fig. 31. Relationship between within-player changes in HRΔ and HR_{RUN} in elite soccer players. HR_{RUN}: HRex during the last minute of the 4-min standardized submaximal running protocol. HRΔ: difference between predicted HR from the GPS variables and the actual HR response. y and x axes cut the figure into 4 quadrants. Players in the upper right quadrant present both greater HRΔ and HR_{RUN} values, suggesting that they lack both generic and more specific fitness. Importantly, this Fitness Index reflects only the physiological response to football-specific activity. While useful, this metric should not be mistaken for a direct measure of "football (or any team sport) fitness," which refers to the ability to perform football (or any team sport) actions as frequently as necessary to sustain a high tempo for 90+ minutes (Verheijen, 2025). In the bottom left quadrant, players present both lower HRΔ and HR_{RUN} values, suggesting that these players gained both generic and a more specific fitness. Finally, some players in the upper left quadrant report greater HRΔ values but lower HR_{RUN} values, suggestive of generic fitness but a lack of specific fitness. Note that there are no data points in the lower right quadrant, which would imply an unexpected (less probable) scenario: players unfit at the general level but showing specific fitness (Taken from Lacome 2021a).

Key points

- Submaximal runs and their variants assess a continuum of physiological responses (from generic to specific exercise) and can provide important information about cardiovascular status, but not true sport-specific fitness, which remains a performance precondition that cannot be directly measured.
- Embedded and invisible submaximal tests enable frequent, low-fatiguing monitoring options in team sports.
- Exercise HR (HRex) is a stable, sensitive indicator of cardiovascular adaptation.
- HRex changes correlate moderately with aerobic-related performance measures ($r \approx 0.7$), with each 4–5% HRex change being associated with a 0.5 km·h^{-1} change in MAS for example.
- Considering the error of measurement (1.6% points), and SWC of 4-5%, changes of $\pm$ 6% should be considered as meaningful.
- HRex does not directly reflect neuromuscular status.
- Confounders like heat, hydration, plasma volume, and testing timing must be considered.
- Large short-term decreases in HRex may reflect plasma volume expansion, which enhances cardiovascular function, but can overstate overall fitness adaptations since peripheral changes, such as muscular or metabolic improvements, may be absent.
- Absolute reference tests (e.g., MAS, lactate threshold) are essential for proper physical capacity profiling and exercise prescription.
- Decision trees help distinguish between positive adaptation and overload.
- HRex trends can guide individual training adjustments and return-to-play planning.
- Most research is on (elite) males, but principles should apply across populations (non-elite, youth, females).

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