Dose–Response Associations Between Heart Rate–Derived Load Measures and Changes in High-Intensity Intermittent Performance in Gaelic Football: Time to respect the physiological profile of the player?

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Heart rate zones | **TRIMP** | **Training load** | **Dose–response** | **Gaelic football** | **Physiological profile** | **High-intensity intermittent performance** | **30-15 Intermittent Fitness Test** | **Anaerobic speed reserve**

Headline

The dose-response (D-R) relationship is fundamental to training monitoring, where external training load combines with athlete characteristics to influence internal load and subsequent metabolic, neuromuscular, or performance adaptations (Impellizzeri et al., 2005; Akubat and Van Winkel, 2014). Internal training load methods must demonstrate D-R relationships with training outcomes to be considered valid monitoring tools (Manzi et al., 2013; Malone et al., 2019). Heart rate (HR) zones offer a practical method for quantifying internal training load and, more specifically, cardiovascular strain, allowing coaches to monitor physiological stress and intensity distribution (Laursen & Jenkins, 2002; Seiler, 2010). Research demonstrates that improvements in aerobic capacity and performance are associated with time spent in different HR zones (e.g., > 90% maximal HR) (Seiler & Kjerland, 2006; Stagno et al., 2007; Castagna et al., 2011; Manzi et al., 2013; Stöggl & Sperlich, 2014 Malone et al., 2019; Ellis et al., 2020).

However, a critical contextual factor in the D-R relationship is the impact of physiological profile types, characterised by muscle fibre composition (Lievens et al., 2020) and Anaerobic Speed Reserve (ASR) - the difference between maximal aerobic speed and maximal sprinting speed (Buchheit & Laursen, 2013). Different physiological profiles may display distinct D-R relationships. Endurance profiles with higher baseline aerobic capacity may experience diminishing returns over time and, therefore, require greater stimulus to achieve positive performance adaptations. These profiles have efficient recovery kinetics accompanied by a strong resistance to fatigue, which allows them to sustain higher training volumes (Bellinger et al., 2020). However, without sufficient intensity variation, the expected D-R slope for improvements will diminish. In contrast, speed profiles have lower baseline aerobic fitness and therefore may exhibit a steeper slope of adaptation initially, showing increased gains from the same training dose when compared to endurance profiles before these performance adaptations plateau. While speed-oriented athletes may adapt quickly to high-intensity training, they possess less efficient recovery capacity and are more susceptible to fatigue, overload and injury if loading progressions are too aggressive. Hybrid profiles then balance these two alternative characteristics, facilitating repeated high-intensity efforts with moderate recovery kinetics (Støren et al., 2017; Sandford, Laursen & Buchheit, 2021; Maturana et al., 2021; Yang et al., 2023). To date, it is unknown if these profiles need to be appreciated by practitioners and if the physiological profile influences individual responses to training load prescription.

Aim

The purpose of the current investigation was to revisit the HR Zone D-R within team sport athletes. We aimed to understand, for the first time, the potential impact of the physiological profile of players (Endurance, Hybrid, Speed) on the D-R relationship between time in HR zones, Edwards TRIMP, and changes in high-intensity intermittent performance, as quantified through the 30-15IFT, across an 11-week in-season training period.

Methods

Twenty-six (age 24.5 ± 4.2 years; height 177.9 ± 4.1 cm; body mass 81.5 ± 4.5 kg) Gaelic footballers of the same squad, a top division 1 team, with a minimum playing experience of 3 years, were followed during the in-season period of the 2025 season (11 weeks). Based on a modified anaerobic speed reserve ratio (SRR) (Sandford, Laursen and Buchheit, 2021), players were split into 3 distinct groupings of: Endurance (n = 7; SRR: < 1.70), Hybrid (n = 9; SRR: >1.70 - < 1.80), and Speed (n = 10; SRR: >1.80), allowing for a deeper understanding of specific profile D-R relationship across the observational window.

Players trained 2-4 times a week, with matches played on weekends as part of the team's competition schedule. The training time during the observed period was 21% devoted to ball drills and 13% generic aerobic training, with 22% of the training time spent on technical tactical skill development, and 10% of the time spent in matches. Strength and sprint training accounted for 14% of all the training time. The remaining time (20%) was spent with warm-up routines. During the data collection period, training and match sessions were 40–120 minutes in duration. To prevent detraining effects, players who did not complete competitive fixtures undertook additional conditioning sessions consisting of linear shuttle running at 90-105% of VIFT with 10-15 seconds of running and 15-20 seconds of recovery (Buchheit & Laursen, 2013). Non-playing players also completed small-sided games and linear technical drills to maintain their weekly training load in line with match-playing squad members (Lacome et al., 2018; Malone et al., 2021).

During the observational window, Players' HR were monitored during each training and match session (Polar Team System, Polar Electro, OY, Finland). A total of 25 training sessions and 6 match sessions were monitored (n = 570). Physiological anchors were considered by the HR attained at selected percentages of HR_{max}. Training HR was categorised as time $\geq$ 80% HR_{max} and $\geq$ 90% HR_{max}. The magnitude of internal load was assessed using the time spent within the different %HR_{max} training zones. This also allowed for the calculation of Edwards TRIMP within the cohort (Edwards, 1994). Before and post the training period, players were assessed for high-intensity intermittent running performance by means of a 30-15 Intermittent Fitness Test (Buchheit, 2010). Testing took place at similar time points across a training week to avoid diurnal effects on test outcomes. Quantification of the training dose-response was established by analysing the distribution pattern of players' time spent $\geq$ 80% and 90% HR_{max} and Edwards TRIMP, along with any changes in high-intensity intermittent running performance (VIFT).

Statistical Analysis

Results are reported as mean ± SD with 90% confidence intervals. Associations were assessed with Pearson's correlations and interpreted as trivial (<0.1), small (0.1–0.29), moderate (0.3–0.49), large (0.5–0.69), very large (0.7–0.89), nearly perfect (0.9–0.99), and perfect (1.0) (Hopkins, 2017). Linear mixed models quantified differences in intensity distribution and performance changes between pre- and post-observation, with least squares means used for comparisons. Effect sizes (d) were classified as trivial (<0.2), small (0.2–0.6), moderate (0.6–1.2), large (1.2–2.0), and very large (>2.0). Differences were considered real if exceeding 75% of the smallest worthwhile change (0.2 × between-athlete SD).

Results

Distribution of HR profile with reference to physiological profile

The distribution of time spent $\geq$ 80% HR_{max}, $\geq$ 90% HR_{max} and Edwards TRIMP relative to physiological profile across the observational period is shown in Figure 1. Pairwise comparisons demonstrated unclear effects. For time $\geq$ 80% HR_{max}, differences were unclear when comparing Speed to Endurance (d = 0.22; 95% CI -0.81 to 1.26) and Endurance to Hybrid (d = -0.56; 95% CI -1.62 to 0.50). For time $\geq$90% HR_{max}, unclear differences were observed between Speed and Endurance (d = 0.04; 95% CI -1.02 to 1.10) and between Endurance and Hybrid (d = -0.13; 95% CI -1.22 to 0.95). Edwards TRIMP comparisons similarly indicated unclear effects (d = -0.56 to 0.21) across the physiological profiles.

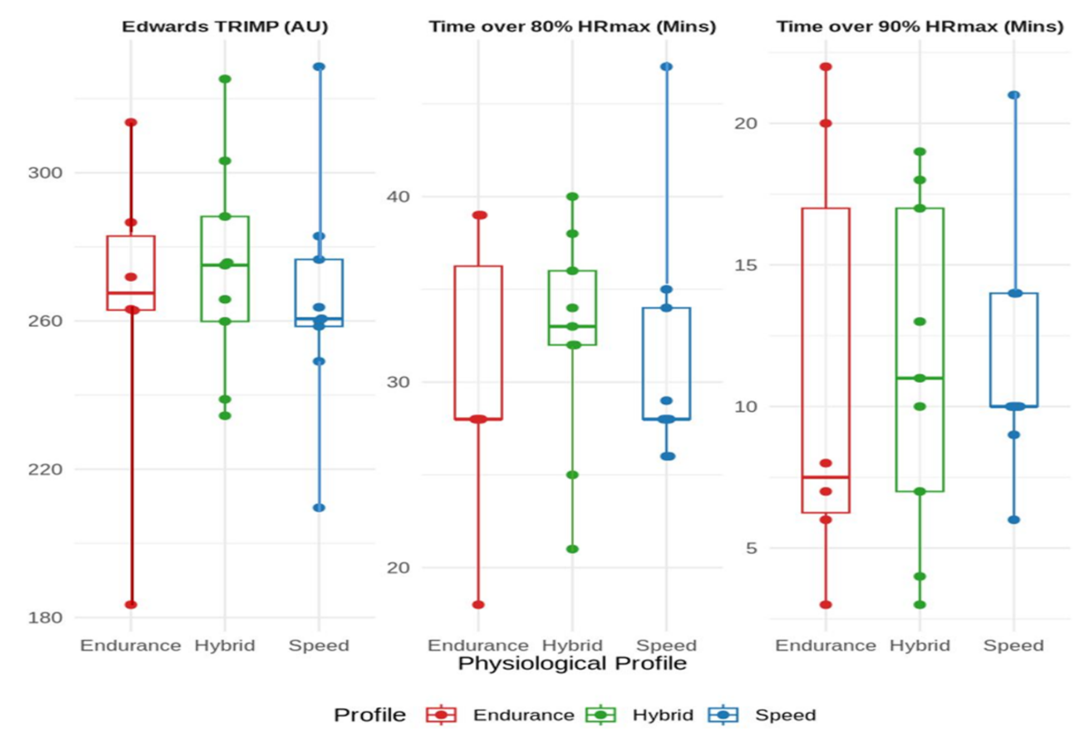

Fig. 1. The distribution of time over 80% HR_{max}, time over 90% HR_{max} and Edwards TRIMP across the 11-week observational period with respect to Physiological Profile within Gaelic Football Players.

Pre and Post Changes in 30-15 IFT

Relative pre- to post changes in VIFT across the observational period are shown in Figure 2. From an absolute change perspective, athletes showed a significant increase in VIFT from pre to post (19.6 ± 0.8 to 21.0 ± 0.9; d = 1.68; large). The mean improvement of 1.38 km·h^{-1} (90% CI: 1.08 to 1.69).

Hybrid athletes showed a large increase in VIFT from pre to post (19.3 ± 0.6 to 20.9 ± 0.8; d = 2.9; large). Endurance athletes also showed a large improvement from pre (20.3 ± 0.9 to 21.6 ± 0.7; d = 1.4; large). Similarly, Speed athletes improved from pre (19.3 ± 0.7 to 20.6 ± 0.9; d = 1.6; large).

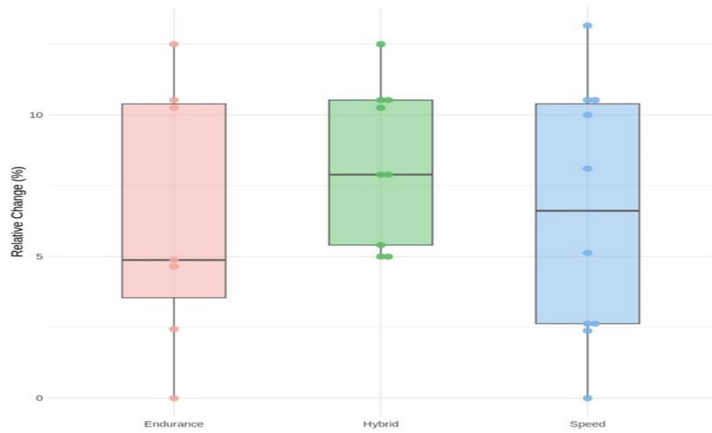

Fig. 2. The relative change in 30-15IFT with respect to physiological profile across the observational period.

Table 1. Association between HR measurements of internal load and changes in fitness measures with respect to physiological profile. Data presented as r value [90% CI]

Group	Metric	Time >80%	Time >90%	Edwards TRIMP
All (n = 26)	Absolute Change	0.69 [0.47; 0.83]	0.53 [0.25; 0.73]	0.67 [0.43; 0.81]
	Relative Change (%)	0.68 [0.46; 0.83]	0.54 [0.25; 0.74]	0.66 [0.42; 0.81]
Hybrid(n = 9)	Absolute Change	0.58 [-0.01; 0.87]	0.45 [-0.19; 0.82]	0.44 [-0.19; 0.81]
	Relative Change (%)	0.57 [-0.03; 0.87]	0.48 [-0.15; 0.83]	0.42 [-0.22; 0.81]
Endurance (n = 7)	Absolute Change	0.90 [0.57; 0.98]	0.68 [0.02; 0.93]	0.81 [0.29; 0.96]
	Relative Change (%)	0.89 [0.52; 0.98]	0.68 [-0.00; 0.93]	0.80 [0.26; 0.95]
Speed (n = 10)	Absolute Change	0.54 [-0.01; 0.84]	0.47 [-0.12; 0.81]	0.63 [0.11; 0.87]
	Relative Change (%)	0.54 [-0.02; 0.84]	0.46 [-0.12; 0.81]	0.62 [0.10; 0.87]

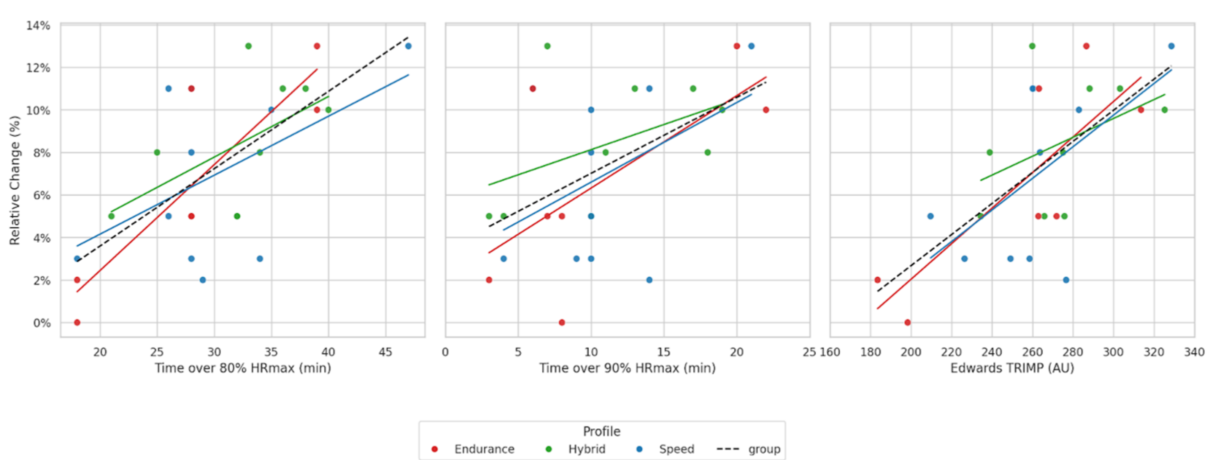

Fig. 3. Regression Analysis between A) average time > 80% HR_{max} (min), B) Average time > 90% HR_{max} (min) and C) Edwards TRIMP (AU) relative change (%) in running performance as a function of the group physiological profile and specific physiological profile.

Association between HR measurements of internal load and changes in high intensity intermittent performance with respect to physiological profile

Moderate to strong associations were observed between HR metrics and changes in VIFT across the cohort (Table 1). For all participants, both absolute and relative changes in VIFT correlated strongly with Time > 80% HR_{max} (r = 0.68-0.69) and Edwards TRIMP (r = 0.66-0.67), with moderate associations for Time > 90% HR_{max} (r = 0.53–0.54). Analyses across physiological profiles showed distinct patterns (Table 1). The endurance profile demonstrated the strongest associations, with absolute change most highly correlated with Time > 80% HR_{max} (r = 0.90 [0.57; 0.98]) and Edwards TRIMP (r = 0.81 [0.29; 0.96]). Hybrid profiles showed only small to moderate associations with wide confidence intervals (Figure 3). Speed profiles displayed moderate correlations with Edwards TRIMP (r = 0.62–0.63), but weaker associations for Time > 80% and > 90% HR_{max}.

Consistent associations with internal load were observed, but the magnitude of these relationships differed by profile (Figure 3). At the group level, regression intercepts averaged 4.3 ± 0.9% (0.50 ± 0.12 $km \cdot h^{-1}$; 0.05 ± 0.01 $km \cdot h^{-1} \cdot min^{-1}$), with slopes of 0.24 ± 0.05%·min^{-1} for time-based metrics and 0.04 ± 0.01%·AU^{-1} for TRIMP. Endurance profiles demonstrated the lowest y-intercepts (2.1 ± 0.6%; 0.32 ± 0.09 $km \cdot h^{-1}$; 0.06 ± 0.01 $km \cdot h^{-1} \cdot min^{-1}$) but the steepest slopes (0.30 ± 0.05%·min^{-1}), reflecting slower initial responses but greater adaptive gains with increasing exposure. Speed profiles displayed higher y-intercepts (5.4 ± 0.8%; 0.71 ± 0.11 $km \cdot h^{-1}$; 0.04 ± 0.01 $km \cdot h^{-1} \cdot min^{-1}$), but shallower slopes (0.18 ± 0.04%·min^{-1}), indicating earlier but smaller improvements. Hybrids showed moderate y-intercepts (3.9 ± 0.7%; 0.48 ± 0.10 $km \cdot h^{-1}$; 0.05 ± 0.01 $km \cdot h^{-1} \cdot min^{-1}$) with intermediate slopes (0.22 ± 0.03%·min^{-1}). Intensity-specific analysis revealed that an additional 10 minutes at 80% HR_{max} produced 2.5 ± 0.4% (0.5 ± 0.1 $km \cdot h^{-1}$) group-level improvements, with endurance athletes showing greatest sensitivity (3.0 ± 0.5%; 0.6 ± 0.1 $km \cdot h^{-1}$) compared to speed (2.0 ± 0.3%; 0.4 ± 0.1 $km \cdot h^{-1}$) and hybrid profiles (2.5 ± 0.4%; 0.5 ± 0.1 $km \cdot h^{-1}$). At 90% HR_{max}, effects appeared amplified with 3.6 ± 0.6% group-based improvements, with endurance athletes maintaining superior adaptive responses (4.0 ± 0.6%; 0.8 ± 0.1 $km \cdot h^{-1}$) versus hybrid (3.5 ± 0.5%; 0.7 ± 0.1 $km \cdot h^{-1}$) and speed athletes (3.0 ± 0.4%; 0.6 ± 0.1 $km \cdot h^{-1}$).

Discussion

The current investigation has reported how training load distribution and adaptive responses to team-sport training practices within Gaelic football cohorts are influenced by players' physiological profiles of endurance, hybrid and speed. At a group level, regression intercepts and slopes for time-based metrics showed that players could improve running high-intensity intermittent running performance without spending time within the analysed HR zones. However, analysis revealed that for every additional 10 minutes spent at 80% HR_{max} and 90% HR_{max}, positive group-level improvements in high-intensity running performance could be expected. From a practical perspective, the data suggest that an appreciation of the physiological profile of players is warranted, and the application of a one-size-fits-all D-R model may be overly simplistic from an applied perspective (Seiler et al., 2006; Castagna et al., 2011). Given the profile differences in D-R observed within the current investigation, an appreciation of the profile provides an understanding of the training load distribution and response of specific physiological types, showing how individual monitoring beyond surface-level external load and HR data remains critical to ensure that each profile is managed appropriately to achieve the optimal D-R within training environments (Stagano et al., 2007; Manzi et al., 2013).

The dose-response relationship is considered a fundamental principle of training, monitoring and prescription for coaches and sport scientists who aim to maximise players' performance adaptations across training blocks (Akubat and Van Winkel, 2014; Malone et al., 2020; Ellis et al., 2021). Large and significant improvements in 30-15 IFT scores were observed within the current study (Figure 2). However, the mechanisms underpinning these improvements appear to be mediated, at least in part, by differential HR responses (Akubat and Van Winkel, 2014). Correlation analysis revealed strong associations between HR-derived load metrics and running performance changes, particularly for time >80% HR_{max}, time >90% HR_{max}, and Edwards TRIMP. Given that TRIMP disproportionately weights higher-intensity efforts (Edwards, 1994), it is unsurprising that correlations were observed between these measures. Endurance athletes displayed the strongest and most consistent associations, with very large correlations observed for both absolute and relative improvements. Speed and hybrid profiles, by contrast, showed weaker and more variable relationships, pointing toward different adaptation dynamics.

It was not possible to identify an "effective minimal dose-response" for time spent over 80% and 90% HR_{max} due to the Y-intercepts failing to cross zero (Stagno et al., 2007). Profile-specific regressions showed distinct adaptive patterns with respect to time spent over 80% HR_{max}, with endurance profiles demonstrating lower initial responses (y-intercepts) but superior dose-response relationships (steeper slopes) over time, while speed athletes showed earlier improvements but diminishing returns with increased exposure to high-intensity training. Hybrid athletes displayed intermediate characteristics with moderate y-intercepts and slopes, suggesting they possess balanced adaptive capacity that responds moderately to progressive loading but without the pronounced sensitivity observed in other physiological profiles (Støren et al., 2017; Yang et al., 2023). Within the analysis, for every additional 10 minutes at 80% HR_{max}, players could be expected to improve running performance by 3%. Profile-specific responses were also shown with endurance profiles ($\Delta \sim$3%) showing the greatest sensitivity to time over 80% HR_{max} compared to speed profiles ($\Delta \sim$2%) and hybrid profiles ($\Delta \sim$.5%). When time over 90% HR_{max} was considered, an additional 10 minutes appeared to amplify the adaptation effects with a 4% group-based improvement expected. In line with the above, endurance athletes had a superior adaptive response ($\Delta \sim$4%) versus hybrid ($\Delta \sim$3.5%) and speed athletes ($\Delta \sim$3%). This data provides coaches with a potential target "effective dose" of high-intensity (at least high HRs) exposure for eliciting positive physiological adaptations in intermittent team sports athletes (Buchheit and Laursen, 2013).

The findings of this study suggest that HR-based metrics are a more valid marker of metabolic stress for endurance athletes, reflecting the physiological profile of these athletes that is more reliant on central cardiovascular adaptations (Lievens et al., 2020). For speed and hybrid athletes, however, HR-based measures of training load alone may underestimate the total training demands, highlighting the need for practitioners to integrate additional training load and neuromuscular markers to fully capture the training response for these profiles that is more peripheral in nature. Practically, for speed profiles, monitoring should extend beyond HR data to include peripheral variables such as muscle oxygenation dynamics (SmO_2) (Buchheit & Ufland, 2011). These better align with the peripheral metabolic response and increased neuromuscular loading typically experienced by these profiles (Malone et al., 2018; Daniels et al., 2025). For hybrid profiles, a dual approach is recommended with HR-derived measures to capture cardiovascular stress alongside mechanical load indices, ensuring neither central nor peripheral training responses are overlooked. This combined domain load monitoring would allow performance staff to more accurately interpret D-R relationships (Buchheit & Hader, 2005). It must be acknowledged that the current study has several limitations. The small sample size within each physiological profile subgroup limits statistical power, and the observational design meant training loads were not experimentally controlled. While using Time >80% HR_{max} and >90% HR_{max} offers a simple and practical measure of internal load, these binary thresholds may overlook variations in intensity and therefore underestimate differences in adaptive outcomes. Future research should examine whether these relationships hold across larger samples and other team sport environments.

Practical applications

- Endurance athletes show the strongest dose–response associations, making HR-based metrics a valid marker of the central cardiovascular stress in these athletes. In contrast, Speed and Hybrid athletes respond more variably; for these groups, central metabolic stress loading variables such as HR should be complemented with peripheral metabolic loading variables such as muscle oxygenation dynamics (SmO_2). A dual-monitoring approach for Hybrid profiles ensures both central and peripheral training stress are captured.
- For each additional 10 minutes above 80–90% HR_{max}, ∼3–4% improvements in high-intensity intermittent running performance were shown, with endurance profiles demonstrating the greatest sensitivity, hybrids moderate, and speed profiles the least.
- Practitioners need to appreciate that dose–response relationships differ across physiological profiles. As such, D-R expectations and periodisation strategies should be adjusted according to individual physiological characteristics rather than assuming uniform responses.

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