Same GPS Numbers, Different Level? Conventional External-Load Metrics Show Limited Differentiation Across a Professional Football Development Pathway

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GPS | **External load** | **Player development** | **Match demands** | **Athlete monitoring** | **Professional football** | **Academy football** | **Competitive level** | **Development pathway** | **Readiness for progression**

Headline

Micro-electromechanical system (MEMS)-derived metrics are routinely used to quantify match demands (1) and may provide reference values when preparing developing players for senior football (2, 3). However, analysis of 551 player-match observations across First Team, Reserve, and U18 football demonstrated considerable overlap in external-load metrics after accounting for repeated observations, match-level clustering, and primary playing position. These findings suggest that conventional MEMS-derived summary metrics should be interpreted cautiously when used as indicators of readiness for progression within professional football pathways.

Aim

Micro-electromechanical system (MEMS) devices incorporating global positioning system (GPS) technology are widely used in football to quantify external load and inform player monitoring (1). Match-derived external-load metrics are used as reference values when preparing academy players for progression towards senior football (2, 3). However, greater competitive level does not consistently correspond with greater locomotor output, with previous studies demonstrating substantial overlap in conventional external-load metrics across developmental and competitive standards (2-7). Recent work has also questioned whether aggregate distance- and speed-based metrics adequately represent the multidimensional demands of football (8, 9). Therefore, this report examined whether commonly used MEMS-derived external-load metrics differentiate First Team, Reserve, and U18 match play within a professional football development pathway after accounting for repeated observations, match-level clustering, and playing position.

Design

Observational cohort study of competitive match-play external-load profiles across three levels of a professional football development pathway.

Methods

External-load data were collected from 43 male professional football players from a Scottish Premiership club across a 22-week competitive period (July 2019 – March 2020). Players contributed observations within First Team, Reserve, and U18 squads, with some players appearing at more than one level during the study. Goalkeepers were excluded, and only full match (90 minute) observations were retained (10). The final dataset comprised 551 player-match observations across 95 competitive matches (First Team: 273 observations; Reserves: 173; U18: 105).

Players wore the same 10-Hz global positioning system (GPS) and 100-Hz triaxial accelerometer MEMS device (Optimeye X4, Catapult Sports, Melbourne, Australia) throughout the study to minimise inter-unit variability (11). Mean satellite count was 10.4 ± 1.9 and horizontal dilution of precision was 0.89 ± 0.25.

Variables were included in the analysis due to their use in both practice and research (1, 12). External-load variables included total distance, PlayerLoad, low-speed running distance (< 14.4 km·h^{-1}), high-speed running distance (19.8 – 24.98 km·h^{-1}), sprint distance (> 24.98 km·h^{-1}), maximum velocity, accelerations (> 2 m·s^{-2}), decelerations (> 2 m·s^{-2}), and high-intensity actions.

Linear mixed-effects models were fitted separately for each outcome, with development level and primary playing position included as fixed effects and player and match included as random intercepts (13). Estimated marginal means, 95% confidence intervals, and Tukey-adjusted pairwise comparisons were calculated using the emmeans package in R (14), with differences expressed as standardised mean differences (SMDs). The study was conducted in accordance with the Declaration of Helsinki, with ethical approval obtained from the institutional research ethics committee (SHS/22/03).

Results

Adjusted external load estimates did not demonstrate a consistent hierarchical pattern across U18, Reserve, and First Team match play (Table 1; Figure 1). The clearest differences were observed for low-speed running distance, within First Team samples accumulating greater distances than Reserves (SMD = 1.25; 95% CI 0.52 to 1.98) and U18 players (SMD = 1.07; 95% CI 0.22 to 1.91). Maximum velocity also differentiated levels, with higher values observed in First Team compared with U18 samples (SMD = 0.68; 95% CI 0.17 to 1.18), and Reserves compared with U18 samples (SMD = 0.41; 95% CI 0.02 to 0.80).

For all remaining external-load variables, 95% confidence intervals encompassed zero. First Team samples demonstrated higher point estimates for sprint distance than U18 samples (SMD = 0.32; 95% CI -0.30 to 0.95), whereas U18 players demonstrated higher high-speed running distance (SMD = -0.48; 95% CI -1.15 to 0.19) and PlayerLoad (SMD = -0.65;

95% CI -1.51 to 0.21). Differences in accelerations, decelerations, and high-intensity actions were small with no clear differences between development levels.

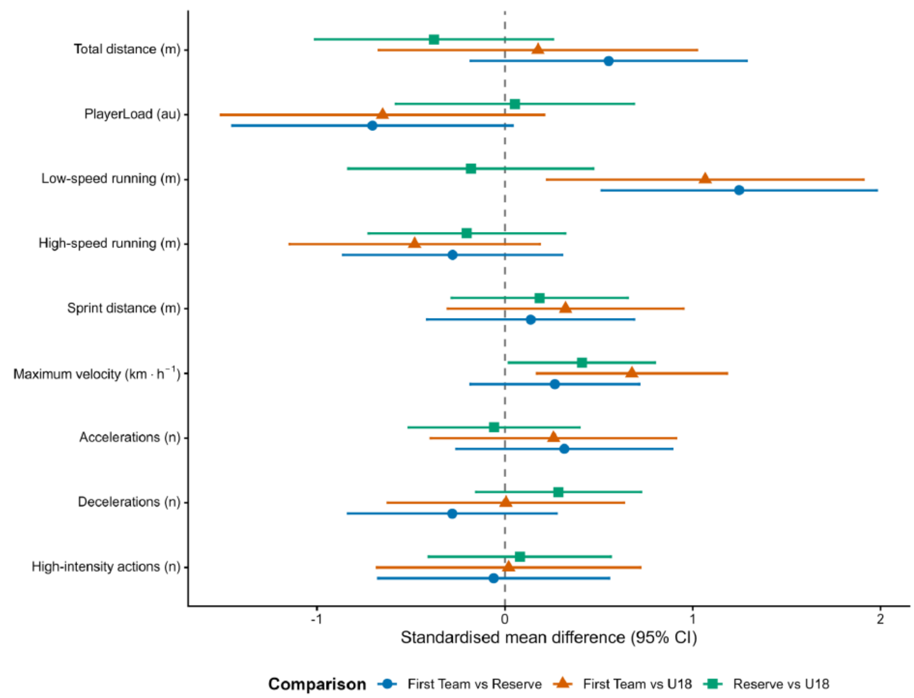

Fig. 1. Standardised mean differences (95% confidence intervals) in MEMS-derived external-load metrics between First Team, Reserve and U18 match play. ***Positive values indicate greater values for the first-named group in each comparison, whereas negative values indicate greater values for the second-named group.***

Table 1. Estimated marginal means (95% confidence intervals) for GPS-derived external-load metrics across First Team, Reserve and U18 match play, adjusted for primary playing position and repeated observations within players and matches.

Variable	First Team	Reserve	U18
Total Distance (m)	10,475 (10,229 to 10,721)	10,256 (10,019 to 10,493)	10,405 (10,130 to 10,680)
PlayerLoad (au)	913 (876 to 950)	953 (918 to 989)	950 (909 to 991)
Low-Speed Running (m)	8,415 (8,250 to 8,581)	8,070 (7,910 to 8,231)	8,120 (7,932 to 8,308)
High-Speed Running (m)	480 (438 to 522)	506 (465 to 547)	525 (477 to 573)
Sprint Distance (m)	161 (137 to 186)	154 (130 to 177)	143 (115 to 171)
Maximum Velocity (km·h^{-1})	30.6 (30.1 to 31.1)	30.2 (29.8 to 30.7)	29.7 (29.1 to 30.2)
Accelerations (n)	41.2 (37.8 to 44.7)	38.9 (35.7 to 42.2)	39.4 (35.6 to 43.1)
Decelerations (n)	31.5 (28.7 to 34.2)	33.2 (30.6 to 35.8)	31.4 (28.4 to 34.4)
High-intensity Actions (n)	120 (111 to 128)	121 (113 to 129)	119 (110 to 129)

Key: m = metres; au = arbitrary units; n = number.

Discussion

The principal finding of this report was that commonly monitored MEMS-derived external-load metrics did not demonstrate a consistent hierarchical pattern across U18, Reserve, and First Team match play. Although low-speed running distance and maximum velocity differentiated some levels, most variables showed substantial overlap. These findings suggest that progression towards senior football is not characterised by a simple increase in conventional external-load metrics.

These findings are consistent with previous comparisons across competitive standards, which have reported non-linear differences in match-running demands (5). Likewise, Vigh-Larsen et al. observed greater relative total distance, and acceleration and deceleration frequencies in U19 players compared with both U17 and senior players (6). Conversely, Morgans et al. reported limited differences between academy and senior Scottish Premiership players (7).

The present analysis accounts for repeated observations within players, clustering within matches and primary playing position. Despite these adjustments, there remains no uniform hierarchical gradient across the external load metrics examined. This is particularly apparent when considering high-intensity activity. U18 players accumulated numerically greater high-speed running distance than First Team players, whereas First Team players accumulated greater sprint distance and achieved higher maximum velocities. High-intensity actions, which combined high-speed running, sprint, acceleration, and deceleration efforts, were almost identical across levels. Therefore, conclusions regarding whether senior football is physically "more demanding" depend substantially on the metric selected to represent demand.

The greater low-speed running distance observed during First Team match play represented the clearest difference between levels. However, this should not necessarily be interpreted as evidence of greater physical demand. Low-speed locomotor activity may be influenced by playing style, tactical organisation, possession, formation and other contextual factors of match play (15). These factors were not measured in the present study and therefore the mechanisms underlying this difference cannot be determined. Similarly, the progressively higher maximum velocities observed from U18 to Reserve and First Team football may reflect differences in physical capacity, match opportunity, tactical context, or a combination of these factors. The present data describe the external outputs achieved during competition, but cannot determine the mechanisms responsible for them.

This distinction has implications for the use of GPS data as developmental benchmarks. Practitioners may compare academy players against senior reference values when assessing physical preparation for progression. However, achieving a similar total distance, high-speed running distance or number of high-intensity actions does not necessarily demonstrate that a developing player has experienced, or is prepared for, equivalent senior match demands. Similar outputs may arise through different tactical behaviours and movement demands. Recent debate has therefore questioned the extent to which conventional aggregate and speed-zone metrics adequately represent the multidimensional demands of football (8). Newer approaches have proposed moving beyond distance accumulated within predefined speed thresholds towards measures that better account for movement context, directionality, mechanical characteristics and action density (8, 16). The present findings are consistent with the rationale underpinning this development, conventional MEMS-derived metrics provide useful descriptions of locomotor output but demonstrate limited consistency in differentiating stages of the professional pathway.

These findings do not demonstrate that conventional MEMS-derived monitoring lacks value, nor do they establish that newer metrics provide superior measures of match demand. Monitoring remains a valuable practice for quantifying external workload, monitoring exposure, and informing player preparation. Rather, the present findings highlight the limitations of interpreting isolated MEMS-derived outputs as standalone indicators of competitive demand or readiness for progression. Their applied value may be enhanced when interpreted alongside positional role, tactical and technical information, match context, and individual physical capacity.

Practical applications

- Conventional MEMS-derived external-load metrics should not be assumed to increase progressively from U18 to Reserve and First Team football.
- Similarity to senior-team values for total-distance, high-speed running, or high-intensity actions should not be interpreted in isolation as evidence of readiness for senior competition.
- External-load metrics should be interpreted alongside positional, tactical, and individual context when evaluating player development and informing training decisions.

Limitations

- Data were collected from a single professional football club and may not generalise to other development pathways.
- Match-context variables (e.g., opposition quality, possession, and tactical formation) were unavailable and may have influenced external-load outputs.
- Playing position was based on each player's primary position rather than their role during individual matches.
- Only full-match observations were analysed, limiting applicability to substitutes.
- Finally, only conventional MEMS-derived metrics were examined, preventing comparison with emerging multidimensional monitoring approaches.

Conclusion

These findings challenge the assumption that progression towards senior football is characterised by systematically greater conventional MEMS-derived match loads. Practitioners should therefore be cautious when using isolated senior team external load values as benchmarks of developmental progression or readiness. Conventional external load measures may be more informative when interpreted as part of a broader performance profile incorporating tactical, positional, technical, and individual context.

Conflicts of interest

The authors declare no conflicts of interest.

Data availability statement

Data are available on request. Requests for the anonymised dataset supporting the findings of this study should be submitted to the corresponding author.

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