Title:

Training loads and microcycle periodisation in Italian Serie A youth soccer players

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Abstract:

Microcycles are fundamental structures for training prescription and load management, helping to optimise training effects and performance. This study quantified external and internal loads of Italian Serie A youth soccer players across competitive weeks and their periodisation within microcycles. Data were collected from 90 players belonging to four age groups (under-19, -17, -16, -15) across a season. Methods of monitoring external [duration and global navigation satellite systems (GNSS)] and internal load [heart rate (HR) and rating of perceived exertion (RPE)] were employed. Linear mixed models determined differences in training loads across age groups, training days and player positions. Under-19 and under-17 players trained five times per week, while younger players trained four times. Late-stage academy players (under-19 and -17) demonstrated higher weekly accumulated external and sRPE training load compared to their younger counterparts ($p < 0.05$ between groups). Weekly accumulated HR internal loads were higher in under-15 players ($p < 0.05$ between groups). Marked fluctuations of daily load were observed across microcycles in under-19 and under-17 groups ($p < 0.05$ between days). These findings highlight progressive increases in training load throughout the development pathway, with late-stage academy players training with higher frequency, volume and marked periodisation compared to younger players.

Keywords: monitoring, external load, internal load, periodisation, football.

Introduction:

Training load monitoring is a fundamental aspect of contemporary sports science research and practice (Coutts et al., 2018). After two decades of research and application across various sports settings, the concept of training load has been refined as a higher-order construct reflecting the amount of physical training that the athletes do and experience (Impellizzeri et al., 2022). As a multidimensional construct, it encompasses various measures and can be quantified using indicators of external and internal load (Jeffries et al., 2022). In team sports, external load can be quantified using camera systems and microtechnologies such as global navigation satellite systems (GNSS), which enable the tracking of player activities including distances in different velocity zones and events associated with changes in velocity (e.g., accelerations and decelerations) (Torres-Ronda et al., 2022). Internal load can be quantified using heart rate (HR) sensors and rating of perceived exertion (RPE) to capture physiological and perceptual responses during exercise, respectively (Impellizzeri et al., 2005). Given the demands of team sports, various physiological and musculoskeletal systems are subjected to distinct physiological and biomechanical load-adaptation pathways (Vanrenterghem et al., 2017). Thus, a single measure cannot encapsulate all dimensions of the training load construct (Jeffries et al., 2022). To effectively quantify the training stimulus and identify how players are coping with the training programme, a combination of external and internal load measures is therefore essential (Impellizzeri et al., 2019).

The importance of the training process is particularly relevant within professional youth soccer academies, where pathway development programs are in place to maximise the chance of success (McBurnie et al., 2021; Ryan et al., 2017). Throughout adolescence, youth players face unique challenges due to the increasing training and match demands (Hannon et al., 2021) alongside the inconsistency in the timing and tempo of their physical growth and maturity (Johnson et al., 2022). To ensure sustained physical development, a systematic approach to training load monitoring is recommended; this guarantees that youth athletes undergo positive adaptations and progress during years of rapid growth, thereby mitigating the risks of negative outcomes such as injuries and illnesses (Towlson et al., 2020). Despite the widespread use of training monitoring systems among youth soccer academies (Salter et al., 2021), longitudinal studies integrating both external and internal load across different age groups are scarce within the youth population. To date, published research on youth soccer players has predominantly quantified training load using a single dimension of load (Brownlee et al., 2018) and often over a short period (Coutinho et al., 2015). Only a single study has documented seasonal training loads in youth soccer players across multiple age groups; notably, this study exclusively reported external load measures (Hannon et al., 2021).

Designing periodised training programmes for high-level academy players presents unique challenges due to the numerous contextual and individual factors that influence the training process (Pass et al., 2022). To address these challenges, coaches and sports scientists utilise periodisation as a training principle and planning tool, aiming to organise training programmes for effectively preparing athletes for optimal performance (Mujika et al., 2018). Although different definitions and models of periodisation exist, they commonly adopt similar structures, organising training periods into macro-, meso- and micro-cycles (Mujika et al., 2018). In recent years, there has been growing interest in the training load distribution of professional soccer players during weekly microcycles (Buchheit et al., 2021), which represent fundamental blocks of the training plan. Published literature has mainly examined training load microcycle periodisation in professional adult soccer players (Anderson et al., 2016; Kelly et al., 2020; Malone et al., 2015; Martín-García et al., 2018), with limited information available on the youth soccer population. As adolescent players possess markedly different physical and physiological characteristics required for soccer performance (Radnor et al., 2018), detailed investigations of training loads and periodisation practices of the youth soccer population are warranted. With varied training approaches across European countries (Roca & Ford, 2020), the description of the distribution of training load from different academy environments is of interest to practitioners and can facilitate the design of contextualised training plans for youth soccer players.

This study aimed to quantify external and internal training and match load sustained by high-level youth soccer players from an Italian Serie A academy throughout a competitive season. The specific objectives of the study were to quantify accumulated weekly training loads and analyse the periodisation of daily training loads within the competitive microcycles in multiple academy age groups.

Methods:

Subjects:

A group of 93 outfield youth soccer players from the under-19 (*n* = 25; age: 18.2 ± 0.5 years; body mass: 75.8 ± 6.5 kg; height: 181.9 ± 7.7 cm; predicted adult height: 100.0 ± 0.5 %), under-17 (*n* = 22; 16.5 ± 0.3 years; 70.4 ± 6.6 kg; 180.2 ± 5.9 cm; 99.4 ± 0.6 %), under-16 (*n* = 22; 15.6 ± 0.2 years; 67.5 ± 6.8 kg; 177.1 ± 5.8 cm; 98.0 ± 1.0 %) and under-15 (*n* = 24; 14.5 ± 0.3 years; 63.2 ± 8.5 kg; 175.3 ± 6.1 cm; 96.1 ± 1.3 %) squads of a professional soccer academy in the Italian Serie A were initially recruited to participate in this study. Subjects were classified as highly trained (Tier 3) or elite (Tier 4) athletes based on a participant classification framework (McKay et al., 2022). Sample size estimation was not appropriate for this work. This study was conducted within the set-up of a professional football club, providing the advantage of being able to evaluate the whole group of players per age group. We have, therefore, assessed the "entire population" of interest (Lakens, 2022). Further, even if a smaller sample size was required, we would not be able to exclude players while if a larger sample size was required, we would not be able to recruit additional players of similar level and training programme to the existing ones. Written informed consent was provided by parents or legal guardians and players. The study was ethically approved by a University Research Ethics Committee (22/SPS/025) and was conducted following the Declaration of Helsinki.

Experimental Design:

Absolute training and match data were collected across a full competitive season from August 2021 to June 2022. External and internal loads were quantified using GNSS (Apex Pro Series, 10Hz, STATSports, Newry, Northern Ireland), HR sensors (Polar H10, Polar, Kempele, Finland) and RPE. For the current study, only weekly microcycles with one match per week from the competitive periods were considered for analyses. From these competitive microcycles, only the main team training sessions and matches were included in the analysis, while individual sessions (i.e., individualised or rehabilitation) were excluded. Other training weeks (e.g., pre-season and international window) were not considered for the analysis. Weekly training loads (i.e., accumulative training and match load for a specific week) were computed for each player and each competitive week, with players required to have completed all of the team's training sessions that specific week and at least 70% of the competitive match. Periodisation of daily training loads was analysed with respect to the distance from MD: MD-5, MD-4, MD-3, MD-2, MD-1 (Malone et al., 2015). With this approach, 90 players, 970 weekly microcycles and 5784 individual sessions (598 matches and 5186 training observations) were included in the final analyses.

Procedures:

Training microcycles: Training sessions of the competitive microcycle (Table 1) were comprised mainly of technical and tactical drills including technical circuits, possession games, phase of play drills (e.g., offensive and defensive situations) and training matches (e.g., small-, medium- and large-sided games). As part of the club's physical development programme, players were exposed to athletic development sessions, including conditioning runs on MD-5, sprinting and agility training on MD-3 and MD-2. In addition to pitch-based training, gym-based sessions were performed on MD-4 and MD-2 to develop players' physical capabilities (strength and power). On MD, players took part in official competitive matches of different durations based on their age group as regulated by the Italian Football Federation: under-19 and under-17: 90 minutes, under-16: 80 minutes, and under-15: 70 minutes. All the age groups trained for the whole season on official full-size pitches of the same dimensions. The training session content was planned weekly by the coaching staff.

*** Table 1 ***

Quantification of external load: External load was quantified using GNSS. The GNSS device was placed inside a custom-made manufacturer-provided vest that held the unit on the upper back between the shoulder blades, allowing exposure of the GNSS antennae to acquire satellite connection. Each player wore the same GNSS unit for the whole experimental period and the units were turned on around 15 minutes before their use to obtain a sufficient satellite signal and to synchronise the unit clock with the atomic clock in the satellites (Beato et al., 2023). The number of satellites connected during sessions was 17 ± 4, and the horizontal dilution of precision was 0.5 ± 0.1. At the end of each session, data were downloaded and then cropped from the start of the first activity to the end of the last drill or end of match play on Sonra software (version 4.1.31, STATSports, Newry, Northern Ireland). This tracking system provides valid and reliable estimates of distance and velocity during team sports activities, including linear and multidirectional movements (Beato et al., 2023; Coutts & Duffield, 2010). Sessions with "estimated data" either due to malfunctioning hardware or players forgetting to wear the GNSS were removed from the analysis (5% of the initial dataset). The external absolute load measures selected for the analyses were duration (min), total distance (m), distance covered > 20 km/h (m), distance covered > 25 km/h (m), accelerations > 3 m/s^2 (count) and decelerations < -3 m/s^2 (count). These measures are linked with the intermittent and high-intensity nature of soccer and are deemed important for optimising the training process (Buchheit & Simpson, 2017).

Quantification of internal load using heart rate: Internal load was quantified using HR sensors. HR sensors use an electrocardiogram to measure heart rate and monitor the cardiovascular response during exercise (Drust et al., 2007). Each player wore the same HR sensor around the chest immediately below the chest muscles and with the connector placed in a central and upright position. At the end of each training and match session, HR data were transferred and downloaded on Sonra software using Bluetooth technology. HR traces of each player were visually examined on Sonra software to verify recording quality. In case of signal loss or multiple drops within a session, HR data were removed (19% of the initial dataset). HR sensors were not worn during the MD sessions, thus no data were presented for this specific day of the microcycle. The maximal heart rate (HRmax) of each player was assessed using the Yo-Yo intermittent recovery test (Bangsbo et al., 2008). The HR internal load measures selected for the analyses were time spent > 85% HRmax (min) and time spent > 90% HRmax (min). These thresholds reflect the intensities recorded during soccer matches and are utilised for aerobic fitness development (Dellal et al., 2012).

Quantification of internal load using rating of perceived exertion: Internal load was also quantified using the session rating of perceived exertion (sRPE) method, measured using Borg's CR-10 scale (Foster et al., 2001; Impellizzeri et al., 2004). sRPE was collected around 30 min following each training session and match. sRPE training load (sRPE-TL) for each session was subsequently calculated by multiplying the player's sRPE by the duration of the session (Foster et al., 2001). sRPE [arbitrary units (AU)] and sRPE training load (AU) were used for the analyses.

Statistical Analysis:

Data were analysed using mixed modelling as a flexible approach to account primarily for the unbalanced repeated measures nature of the data (e.g., differing frequency of observations of players) (Newans et al., 2022). Linear mixed models were used to detect the variability of external and internal load measures across the different age groups, training days and player positions. Age group, training day and player position were included in the model as fixed effects, while individual players were random effects (Table 2). Estimated marginal means and 95% confidence intervals (CI) were calculated for each mixed model. A Bonferroni correction was applied to adjust for pairwise multiple-test comparison. The magnitude of differences was computed using Cohen's *d* effect size. Threshold criteria for effect size statistics were interpreted as follows: < 0.20, trivial; 0.20–0.59, small; 0.60–1.19, moderate; 1.20–1.99, large; > 2.00, very large (Hopkins et al., 2009). Statistical significance was set at $p < 0.05$. Data presented are calculated as mean and standard deviation (SD), or 95% confidence interval (CI). Analyses were conducted using JAMOVI statistical software (the jamovi project, version 2.3, Sydney, Australia).

*** Table 2 ***

Results:

Weekly accumulated training loads

No significant interactions were observed between age groups and player positions ($p > 0.05$), except for weekly distance covered > 25 km/h ($p = 0.017$). Weekly distance covered > 25 km/h was higher in under-19 wide defenders (494.6 ± 182.5 m) than in under-16 wide defenders (250.5 ± 121.6 m; $p = 0.024$; $d = 1.65$) and under-15 wide defenders (221.4 ± 115.9 m; $p < 0.001$; $d = 1.85$). Additionally, weekly distance covered > 25 km/h was higher in under-19 wide defenders (494.6 ± 182.5 m) than in under-19 wide midfielders (264.9 ± 131.4 m; $p = 0.034$; $d = 1.42$), under-19 central midfielders (139.0 ± 73.5 m; $p < 0.001$; $d = 2.57$) and under-19 central defenders (180.0 ± 98.7 m; $p < 0.001$; $d = 2.15$). A significant main effect of player position was observed for weekly distance covered > 20 km/h and weekly distance covered > 25 km/h ($p < 0.001$). Weekly distance covered > 20 km/h was higher in wide defenders (1585.5 ± 609.4 m) than in all the other positions ($p < 0.001$ for all comparisons; $d = 0.48$ to 0.95). Weekly distance covered > 25 km/h was higher in wide defenders (304.9 ± 173.0 m) than in central defenders (176.9 ± 100.0 m; $p < 0.001$; $d = 0.89$), central midfielders (170.1 ± 115.8 m; $p < 0.001$; $d = 0.92$) and wide midfielders (210.4 ± 142.5 m; $p < 0.05$; $d = 0.59$). Additionally, it was higher in attackers (255.0 ± 129.7 m) compared to central defenders ($p < 0.05$; $d = 0.66$). No significant differences were observed between other player positions ($p > 0.05$). A significant main effect of age group was observed for all weekly external and internal training load measures ($p < 0.001$). Weekly external and internal loads performed during competitive microcycles for each age group are displayed in Figure 1 and Table 3.

*** Figure 1 ***

*** Table 3 ***

Periodisation of training loads

A significant interaction was observed between training days and age groups for all external and internal training load measures ($p < 0.001$). Periodisation of external load during competitive microcycles for each age group and training day is displayed in Figure 2, Figure 3, and Figure 4. Periodisation of internal load during competitive microcycles for each age group and training day is reported in Table 4.

*** Figure 2 ***

*** Figure 3 ***

*** Figure 4 ***

*** Table 4 ***

Discussion:

The purpose of this study was to quantify the external and internal load experienced by four teams within an Italian Serie A youth soccer academy across a competitive season. To the authors' knowledge, this is the first study that characterised both external and internal loads in a cohort of high-level youth soccer players across multiple age groups. Analyses of the results highlighted that weekly accumulated training loads increase progressively, with late-stage academy players training with higher external loads and sRPE-TL compared to their younger counterparts. Periodisation of loading within the competitive microcycle varied across age groups and training days, with marked fluctuations of daily load across the microcycle in the under-19 and under-17 groups as opposed to a less evident loading distribution in the younger groups.

Late-stage academy players, those in the under-19 and under-17 age groups, recorded higher duration, external loads and sRPE-TL compared to their younger counterparts (under-16 and under-15), suggesting a progressive increase in accumulated training loads throughout the academy pathway. Our findings appear to be influenced by both the number of training sessions completed throughout the microcycle (under-19 and under-17: 5 training days vs. under-16 and under-15: 4 training days) and the different match-play durations on MD (under-19 and under-17: 90 min vs. under-16 and under-15: 80 and 70 min, respectively). These weekly external training loads are higher than those sustained by English Premier League and Eredivisie youth academy players for total distance and sprinting distance (i.e., > 25 km/h) (Bowen et al., 2017; Hannon et al., 2021; Houtmeyers et al., 2021). Whereas sRPE training loads are lower in our cohort than those reported in Italian national-level and English Premier League youth academy players (Impellizzeri et al., 2006; Wrigley et al., 2012). The progression in weekly loads agrees with previous observations of English Premier League academy soccer players with age group-related increases in external load (Hannon et al., 2021) and sRPE training load (Wrigley et al., 2012). It seems also congruent with training principles and development strategies advised for the long-term athletic development of adolescent athletes (Lloyd & Oliver, 2012). Progressive increases in weekly external loads align also with growth-related changes in body composition (Hannon et al., 2020) and physical performance (Murtagh et al., 2018; Parr et al., 2020). Taken together, increases in weekly accumulated training loads across age groups appear to be the result of weekly scheduling (e.g., number of training days), training strategies, and changes in body composition and physical performance associated with growth and maturation.

HR-based measures revealed greater weekly accumulated time spent at high intensities (> 85% and > 90% HRmax) in under-15 players compared to the older age groups, highlighting the importance of integrating internal load measures with external load to fully quantify training demands and responses in high-level youth soccer. In contrast with our result, time spent > 90% HRmax during training sessions was higher in under-18 players compared to younger counterparts in English Premier League youth soccer players (Wrigley et al., 2012). The reason for the discrepancy between the results of the present study and the ones by Wrigley might be related to the length of the training observation, as we reported HR-based internal loads during a full competitive season as opposed to two weeks in Wrigley's study (Wrigley et al., 2012). Additionally, these differences may also reflect a shift in the training methodology as players progress through the academy pathway, with a focus on technical development (e.g., technical skills from game situations in small group) in the younger age groups and an approach directed towards match preparation (e.g., phase of play with larger group) in older age groups. As a smaller number of players during soccer-specific training demonstrated greater HR intensity (Hill-Haas et al., 2011), differences in time spent at high HR zones could be partially explained by the design of the drills prescribed throughout the microcycle. Notably, multiple individual (e.g., genetics, age) or contextual (e.g., coaching, competitive level) factors can alter or influence the internal load, having an integrated relationship with the training load construct (Jeffries et al., 2022).

Limited variations in weekly training loads were observed between playing positions, with exceptions for high-speed running (> 20 km/h) and sprinting (> 25 km/h) distances. Wide defenders emerged as a distinct position, with unique high-speed running and sprinting demands compared with all other positions during the competitive week. Similar to our findings, accentuated high-speed demands of this tactical role were observed in Spanish La Liga soccer players during the central days of the competitive week (Martín-García et al., 2018), while English Premier League wide midfielders denoted higher high-speed running distances compared with all the other positions across the microcycle (Malone, et al., 2015). Apart from high-speed running and sprinting distances, weekly external and internal loads were similar across tactical roles. This finding agrees with previous research conducted with youth academy players (Maughan et al., 2021). These limited positional differences may be due to the player's stage of development and the training activities adopted at the club, with position-specific drills limited compared to more role-independent drills. In accordance with talent development models, intensified and specialised training (e.g., number of training sessions per week, position-specific training) is generally employed towards the end of the academy development pathway (Ford et al., 2020). However, these results emphasised the unique weekly high-speed running loads experienced by wide defenders, suggesting position-specific needs in terms of players' preparation and development.

Periodisation of daily training loads varied across age groups and training days, suggesting variations in the distribution of the load within the competitive microcycle. Between-age group differences in loading distribution were also observed in English Premier League and Portuguese national-level academy players during a typical microcycle (Coutinho et al., 2015; Wrigley et al., 2012), emphasising the diversified training approaches employed by coaches guiding different academy squads. Of significance, a tendency towards a more structured and periodised microcycle emerged in the older age groups (under-19 and under-17) as opposed to a comparatively less evident structure in the younger counterparts (under-16 and under-15). For instance, accelerations and deceleration counts remained relatively stable throughout the microcycle in the younger age groups, while marked fluctuations in loads were observed in older age groups across a range of external and internal load measures. These different distributions of load observed throughout the microcycle were likely influenced by the number of training days available per week. These findings agree with previous research conducted with an English Premier League academy team, which observed a clear periodisation of loading in under-16 and under-18 age groups only (Hannon et al., 2021). Progression in training methodology throughout the academy pathway may have influenced the training organisation and consequently the periodisation of the load during the microcycle.

Italian Serie A youth soccer players encountered their highest load on match day across the competitive microcycle, spanning from under-15 to under-19, as observed for all external and internal load measures. The comparison of daily loads sustained on MD with all the other training days emphasized that certain volumes (e.g., total distance) and intensities (e.g., sprinting distances and sRPE) are experienced only during match-play. This consistent finding across all age groups in our study aligns with previous research (Hannon et al., 2021; Maughan et al., 2021), reaffirming the pivotal role of soccer match-play as a key component of youth players' development pathway (Morgans et al., 2018). This information regarding the physical demands of the match experienced by youth soccer players can serve as a reference point to effectively plan the microcycle. In contrast, a noticeable reduction in training load was observed in the last training session preceding a competition denoted as MD-1 for the older groups and MD-2 for the younger groups. This unloading practice is consistent with findings in both youth (Coutinho et al., 2015; Hannon et al., 2021; Malone et al., 2015; Maughan et al., 2021) and senior soccer players (Anderson et al., 2016; Kelly et al., 2020; Malone et al., 2015; Martín-García et al., 2018) and represents a common strategy employed by technical staff across different competitive levels and age groups (Owen et al., 2017).

MD-5 and MD-3 training sessions emerged as the most physically demanding days, characterised by higher levels of both external and internal loads when compared to the other days within the microcycle. For instance, in under-17 players training load measures peaked on MD-3 indicating a pattern of alternating high and low load days within the competitive microcycle. This observation agrees with previous studies where the central days of the microcycle such as MD-4 and MD-3 exhibited the highest training loads across a range of measures in both youth (Hannon et al., 2021; Maughan et al., 2021; Szigeti et al., 2022) and senior professional soccer players (Fleming et al., 2023; Kelly et al., 2020; Martín-García et al., 2018; Oliva-Lozano et al., 2022). These central days of the microcycle constitute a pivotal component of the week as they generally provide an opportunity to impose higher training loads due to the distance from the previous and subsequent match. Interestingly, a different distribution of the load emerged with under-19 players, with most of the training load measures peaking on MD-5. This suggests an unloading strategy characterised by higher loads during the earlier phase of the training week and reduced loads in proximity to the match. A similar pattern was also observed in under-18 English Premier League soccer players who adopted a decreasing load strategy for sRPE training load (Wrigley et al., 2012). Remarkably, this finding is in contrast with the weekly load distribution observed in adult professional players, where a MD-5 training session is typically characterised by lower demands compared to the subsequent training sessions of the week (Silva et al., 2023). This disparity in load distribution might also be attributed to differences in competition standards and stage of development between the two populations, with coaches of senior players emphasising recovery optimisation and match preparedness (Kelly et al., 2020) compared to a developmental training approach in youth players (Hannon et al., 2021).

Despite attempting to quantify the two constructs of training load using commonly adopted monitoring methods (Dudley et al., 2023), the current research has limitations. Given that this study was conducted with players from four age groups belonging to the same club, the generalisability of our results is limited to other academies. Contextual factors such as training methodologies and socio-cultural aspects may not be representative of other academies, particularly those in different leagues or with varying coaching philosophies. Additionally, limitations include the absence of HR data during competitive matches, the lack of individualised speed thresholds, and the limited details regarding training drills and games performed during the microcycle. This information could have provided us with a better understanding of the overall training stimulus sustained throughout the week. Future studies should aim to investigate the training load characteristics of high-level soccer players from multiple youth academies.

Conclusion:

The findings of this research provide new insights into the training loads and periodisation practices experienced by high-level youth soccer players from an Italian Serie A academy. Weekly accumulated training loads exhibit a progressive increase along the player development pathway: late-stage academy players undergo training with higher session frequency and, elevated external and sRPE training load in comparison to their younger counterparts, with minimal variations observed across different playing positions. Weekly accumulated internal loads reveal distinct patterns, with under-15 players displaying higher HR training loads. Late-stage academy players highlight a more periodised approach by showing marked fluctuations of daily load throughout the microcycle, contrasting with the less pronounced loading distribution evident in the younger counterparts. As the two constructs of the training load provide distinct insights into the loading strategies adopted across a competitive microcycle, it is essential to monitor both external and internal load in high-level youth soccer players. Finally, practitioners working with academy soccer players should understand the influence of individual factors (e.g., age) and contextual factors (e.g., playing position) and adjust the training plans and their periodisation practices to align with specific goals.

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Author contributions:

Conceptualisation: AF, MAR, DJO, TB, KE; Data curation: AF, DFB, TMB; Formal analysis: AF, TMB; Investigation: AF, DFB; Methodology: AF, MAR, DJO, TB, KE; Project administration: AF, KE; Resources: AF, DFB, KE; Supervision: DFB, KE; Visualisation: AF; Writing - original draft: AF; Writing - review & editing: AF, MAR, DJO, TB, TMB, DFB, KE. All authors contributed to the article and approved the submitted version.

References:

Anderson, L., Orme, P., Di Michele, R., Close, G. L., Morgans, R., Drust, B., & Morton, J. P. (2016). Quantification of training load during one-, two- and three-game week schedules in professional soccer players from the English Premier League: implications for carbohydrate periodisation. *Journal of Sports Sciences*, *34*(13), 1250–1259. https://doi.org/10.1080/02640414.2015.1106574

Bangsbo, J., Iaia, F. M., & Krustrup, P. (2008). The Yo-Yo Intermittent Recovery Test. *Sports Medicine*, *38*(1), 37–51. https://doi.org/10.2165/00007256-200838010-00004

Beato, M., Wren, C., & De Keijzer, K. L. (2023). The Interunit Reliability of Global Navigation Satellite Systems Apex (STATSports) Metrics During a Standardized Intermittent Running Activity. *Journal of Strength and Conditioning Research*, *38*(2), 49–55. https://doi.org/10.1519/JSC.0000000000004613

Bowen, L., Gross, A. S., Gimpel, M., & Li, F. X. (2017). Accumulated workloads and the acute: Chronic workload ratio relate to injury risk in elite youth football players. *British Journal of Sports Medicine*, *51*(5), 452–459. https://doi.org/10.1136/bjsports-2015-095820

Brownlee, T. E., O'Boyle, A., Morgans, R., Morton, J. P., Erskine, R. M., & Drust, B. (2018). Training duration may not be a predisposing factor in potential maladaptations in talent development programmes that promote early specialisation in elite youth soccer. *International Journal of Sports Science and Coaching*, *13*(5), 674–678. https://doi.org/10.1177/1747954117752127

Buchheit, M., Sandua, M., Berndsen, J., Shelton, A., Smith, S., Norman, D., Mchugh, D., & Hader, K. (2021). Loading patterns and programming practices in elite football Loading patterns and programming practices in elite football: insights from 100 elite practitioners. *Sport Performance and Science Report*, *1*, 1–18.

Buchheit, M., & Simpson, B. M. (2017). Player-tracking technology: Half-full or half-empty glass? *International Journal of Sports Physiology and Performance*, *12*(S2), 35–41. https://doi.org/10.1123/ijspp.2016-0499

Coutinho, D., Gonçalves, B., Figueira, B., Abade, E., Marcelino, R., & Sampaio, J. (2015). Typical weekly workload of under 15, under 17, and under 19 elite Portuguese football players. *Journal of Sports Sciences*, *33*(12), 1229–1237. https://doi.org/10.1080/02640414.2015.1022575

Coutts, A. J., Crowcroft, S., & Kempton, T. (2018). Developing athlete monitoring systems: theoretical basis and practical applications. In *Sport, Recovery and Performance: Interdisciplinary Insights.* (pp. 19–32).

Coutts, A. J., & Duffield, R. (2010). Validity and reliability of GPS devices for measuring movement demands of team sports. *Journal of Science and Medicine in Sport*, *13*(1), 133–135. https://doi.org/10.1016/j.jsams.2008.09.015

Dellal, A., Diniz, C., Silva, D. A., Hill-Haas, S., Wong, D. P., Natali, A. J., De Lima, J. R. P., Filho, M. G. B. B., Marins, J. J. C. B., Garcia, E. S., & Karim, C. (2012). Heart rate monitoring in soccer: Interest and limits during competitive match play and training, practical application.

Journal of Strength and Conditioning Research, *26*(10), 2890–2906. https://doi.org/10.1519/JSC.0b013e3182429ac7

Drust, B., Atkinson, G., & Reilly, T. (2007). Future perspectives in the evaluation of the physiological demands of soccer. *Sports Medicine*, *37*(9), 783–805. https://doi.org/10.2165/00007256-200737090-00003

Dudley, C., Johnston, R., Jones, B., Till, K., Westbrook, H., & Weakley, J. (2023). Methods of Monitoring Internal and External Loads and Their Relationships with Physical Qualities, Injury, or Illness in Adolescent Athletes: A Systematic Review and Best-Evidence Synthesis. *Sports Medicine*. https://doi.org/10.1007/s40279-023-01844-x

Fleming, A., Walker, M., Armitage, M., Connor, M., & Beato, M. (2023). A Comparison of Training and Match Play External Load During a Congested In-Season Period in English League 2 Football. *Journal of Strength and Conditioning Research*, *37*(9), e527–e534. https://doi.org/10.1519/JSC.0000000000004458

Ford, P. R., Bordonau, J. L. D., Bonanno, D., Tavares, J., Groenendijk, C., Fink, C., Gualtieri, D., Gregson, W., Varley, M. C., Weston, M., Lolli, L., Platt, D., & Di Salvo, V. (2020). A survey of talent identification and development processes in the youth academies of professional soccer clubs from around the world. *Journal of Sports Sciences*, *38*(11–12), 1269–1278. https://doi.org/10.1080/02640414.2020.1752440

Foster, C., Florhaug, J. A., Franklin, J., Gottschall, L., Hrovatin, L. A., Parker, S., Doleshal, P., & Dodge, C. (2001). A New Approach to Monitoring Exercise Training. *Journal of Strength and Conditioning Research*, *15*(1), 109–115.

Hannon, M. P., Carney, D. J., Floyd, S., Parker, L. J. F., McKeown, J., Drust, B., Unnithan, V. B., Close, G. L., & Morton, J. P. (2020). Cross-sectional comparison of body composition and resting metabolic rate in Premier League academy soccer players: Implications for growth and maturation. *Journal of Sports Sciences*, *38*(11–12), 1326–1334. https://doi.org/10.1080/02640414.2020.1717286

Hannon, M. P., Coleman, N. M., Parker, L. J. F., Mckeown, J., Unnithan, V. B., Close, G. L., Drust, B., & Morton, J. P. (2021). Seasonal training and match load and micro-cycle periodization in male Premier League academy soccer players. *Journal of Sports Sciences*, *39*(16), 1–12. https://doi.org/10.1080/02640414.2021.1899610

Hill-Haas, S. V, Dawson, B., Impellizzeri, F. M., & Coutts, A. J. (2011). Physiology of Small-Sided Games Training in Football A Systematic Review. *Sports Medicine*, *41*(3), 199–220. https://doi.org/2165/11539740-000000000-00000

Hopkins, W. G., Marshall, S. W., Batterham, A. M., & Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Medicine and Science in Sports and Exercise*, *41*(1), 3–12. https://doi.org/10.1249/MSS.0b013e31818cb278

Houtmeyers, K. C., Jaspers, A., Brink, M. S., Vanrenterghem, J., Varley, M. C., & Helsen, W. F. (2021). External load differences between elite youth and professional football players: ready for take-off? *Science and Medicine in Football*, *5*(1), 1–5. https://doi.org/10.1080/24733938.2020.1789201

Impellizzeri, F. M., Jeffries, A. C., Weisman, A., Coutts, A. J., McCall, A., McLauren, S. J., & Kalkhoven, J. (2022). The 'training load' construct: Why it is appropriate and scientific. *Journal of Science and Medicine in Sport*, *25*(5), 445–448. https://doi.org/10.1016/j.jsams.2021.08.013

Impellizzeri, F. M., Marcora, S. M., Castagna, C., Reilly, T., Sassi, A., Iaia, F. M., & Rampinini, E. (2006). Physiological and performance effects of generic versus specific aerobic training in soccer players. *International Journal of Sports Medicine*, *27*(6), 483–492. https://doi.org/10.1055/s-2005-865839

Impellizzeri, F. M., Marcora, S. M., & Coutts, A. J. (2019). Internal and External Training Load: 15 Years On. *International Journal of Sports Physiology and Performance*, *14*(2), 270–273. https://doi.org/10.1123/ijspp.2018-0935

Impellizzeri, F. M., Rampinini, E., Coutts, A. J., Sassi, A., & Marcora, S. M. (2004). Use of RPE-based training load in soccer. *Medicine and Science in Sports and Exercise*, *36*(6), 1042–1047. https://doi.org/10.1249/01.MSS.0000128199.23901.2F

Impellizzeri, F. M., Rampinini, E., & Marcora, S. M. (2005). Physiological assessment of aerobic training in soccer. *Journal of Sports Sciences*, *23*(6), 583–592. https://doi.org/10.1080/02640410400021278

Jeffries, A. C., Marcora, S. M., Coutts, A. J., Wallace, L., McCall, A., & Impellizzeri, F. M. (2022). Development of a Revised Conceptual Framework of Physical Training for Use in Research and Practice. *Sports Medicine*, *52*(4), 709–724. https://doi.org/10.1007/s40279-021-01551-5

Johnson, D. M., Cumming, S. P., Bradley, B., & Williams, S. (2022). The influence of exposure, growth and maturation on injury risk in male academy football players. *Journal of Sports Sciences*, *40*(10), 1127–1136. https://doi.org/10.1080/02640414.2022.2051380

Kelly, D. M., Strudwick, A. J., Atkinson, G., Drust, B., & Gregson, W. (2020). Quantification of training and match-load distribution across a season in elite English Premier League soccer players. *Science and Medicine in Football*, *4*(1), 59–67. https://doi.org/10.1080/24733938.2019.1651934

Lakens, D. (2022). Sample Size Justification. In *Collabra: Psychology* (Vol. 8, Issue 1). University of California Press. https://doi.org/10.1525/collabra.33267

Lloyd, R. S., & Oliver, J. L. (2012). The youth physical development model: A new approach to long-term athletic development. *Strength and Conditioning Journal*, *34*(3), 61–72. https://doi.org/10.1519/SSC.0b013e31825760ea

Malone, J. J., Di Michele, R., Morgans, R., Burgess, D., Morton, J. P., & Drust, B. (2015). Seasonal training-load quantification in elite English Premier League soccer players. *International Journal of Sports Physiology and Performance*, *10*(4), 489–497. https://doi.org/10.1123/ijspp.2014-0352

Malone, J. J., Murtagh, C. F., Morgans, R., Burgess, D. J., Morton, J. P., & Drust, B. (2015). Countermovement jump performance is not affected during an in-season training microcycle in elite youth soccer players. *Journal of Strength and Conditioning Research*, *29*(3), 752–757. https://doi.org/10.1519/JSC.0000000000000701

Martín-García, A., Gómez Díaz, A., Bradley, P. S., Morera, F., & Casamichana, D. (2018). Quantification of a professional football team's external load using a microcycle structure. *Journal of Strength and Conditioning Research*, *32*(12), 3511–3518. https://doi.org/10.1519/jsc.0000000000002816

Maughan, P. C., MacFarlane, N. G., & Swinton, P. A. (2021). Quantification of training and match-play load across a season in professional youth football players. *International Journal of Sports Science and Coaching*, *16*(5), 1169–1177. https://doi.org/10.1177/17479541211000328

McBurnie, A. J., Dos'santos, T., Johnson, D., & Leng, E. (2021). Training management of the elite adolescent soccer player throughout maturation. In *Sports* (Vol. 9, Issue 12). MDPI. https://doi.org/10.3390/sports9120170

McKay, A. K. A., Stellingwerff, T., Smith, E. S., Martin, D. T., Mujika, I., Goosey-Tolfrey, V. L., Sheppard, J., & Burke, L. M. (2022). Defining Training and Performance Caliber: A Participant Classification Framework. *International Journal of Sports Physiology and Performance*, *17*(2), 317–331. https://doi.org/10.1123/ijspp.2021-0451

Morgans, R., Di Michele, R., & Drust, B. (2018). Soccer match play as an important component of the power-training stimulus in premier league players. *International Journal of Sports Physiology and Performance*, *13*(5), 665–667. https://doi.org/10.1123/ijspp.2016-0412

Mujika, I., Halson, S., Burke, L. M., Balagué, G., & Farrow, D. (2018). An integrated, multifactorial approach to periodization for optimal performance in individual and team sports. *International Journal of Sports Physiology and Performance*, *13*(5), 538–561. https://doi.org/10.1123/ijspp.2018-0093

Murtagh, C. F., Brownlee, T. E., O'Boyle, A., Morgans, R., Drust, B., & Erskine, R. M. (2018). Importance of speed and power in elite youth soccer depends on maturation status. *Journal of Strength and Conditioning Research*, *32*(2), 297–303. https://doi.org/10.1519/JSC.0000000000002367

Newans, T., Bellinger, P., Drovandi, C., Buxton, S., & Minahan, C. (2022). The Utility of Mixed Models in Sport Science: A Call for Further Adoption in Longitudinal Data Sets. *International Journal of Sports Physiology and Performance*, *17*(8), 1289–1295. https://doi.org/10.1123/ijspp.2021-0496

Oliva-Lozano, J. M., Gómez-Carmona, C. D., Fortes, V., & Pino-Ortega, J. (2022). Effect of training day, match, and length of the microcycle on workload periodization in professional soccer players: A full-season study. *Biology of Sport*, *39*(2), 397–406. https://doi.org/10.5114/biolsport.2022.106148

Owen, A. L., Djaoui, L., Newton, M., Malone, S., & Mendes, B. (2017). A contemporary multi-modal mechanical approach to training monitoring in elite professional soccer. *Science and Medicine in Football*, *1*(3), 216–221. https://doi.org/10.1080/24733938.2017.1334958

Parr, J., Winwood, K., Hodson-Tole, E., Deconinck, F. J. A., Hill, J. P., Teunissen, J. W., & Cumming, S. P. (2020). The Main and Interactive Effects of Biological Maturity and Relative Age on Physical Performance in Elite Youth Soccer Players. *Journal of Sports Medicine*, *2020*, 1–11. https://doi.org/10.1155/2020/1957636

Pass, J., Nelson, L., & Doncaster, G. (2022). Real world complexities of periodization in a youth soccer academy: An explanatory sequential mixed methods approach. *Journal of Sports Sciences*, *40*(11), 1290–1298. https://doi.org/10.1080/02640414.2022.2080035

Radnor, J. M., Oliver, J. L., Waugh, C. M., Myer, G. D., Moore, I. S., & Lloyd, R. S. (2018). The Influence of Growth and Maturation on Stretch-Shortening Cycle Function in Youth. *Sports Medicine*, *48*(1), 57–71. https://doi.org/10.1007/s40279-017-0785-0

Roca, A., & Ford, P. R. (2020). Decision-making practice during coaching sessions in elite youth football across European countries. *Science and Medicine in Football*, *4*(4), 263–268. https://doi.org/10.1080/24733938.2020.1755051

Ryan, D., Lewin, C., Forsythe, S., & McCall, A. (2017). Developing World-Class Soccer Players: An Example of the Academy Physical Development Program From an English Premier League Team. *Strength and Conditioning Journal*, *40*(3), 2–11. https://doi.org/10.1519/SSC.0000000000000340

Salter, J., De Ste Croix, M. B. A., Hughes, J. D., Weston, M., & Towlson, C. (2021). Monitoring practices of training load and biological maturity in uk soccer academies. *International Journal of Sports Physiology and Performance*, *16*(3), 395–406. https://doi.org/10.1123/IJSPP.2019-0624

Silva, H., Bio, F., Nakamura, Y. F., Castellano, J., & Marcelino, R. (2023). Training Load Within a Soccer Microcycle Week-A Systematic Review. *Strength and Conditioning Journal*, *45*(5), 568–577. https://doi.org/10.1519/SSC.0000000000000765

Szigeti, G., Schuth, G., Revisnyei, P., Pasic, A., Szilas, A., Gabbett, T., & Pavlik, G. (2022). Quantification of Training Load Relative to Match Load of Youth National Team Soccer Players. *Sports Health*, *14*(1), 84–91. https://doi.org/10.1177/19417381211004902

Torres-Ronda, L., Beanland, E., Whitehead, S., Sweeting, A., & Clubb, J. (2022). Tracking Systems in Team Sports: A Narrative Review of Applications of the Data and Sport Specific Analysis. *Sports Medicine - Open*, *8*(15). https://doi.org/10.1186/s40798-022-00408-z

Towlson, C., Salter, J., Ade, J. D., Enright, K., Harper, L. D., Page, R. M., & Malone, J. J. (2020). Maturity-associated considerations for training load, injury risk, and physical performance in youth soccer: One size does not fit all. *Journal of Sport and Health Science*, 0–32. https://doi.org/10.1016/j.jshs.2020.09.003

Vanrenterghem, J., Nedergaard, N. J., Robinson, M. A., & Drust, B. (2017). Training Load Monitoring in Team Sports: A Novel Framework Separating Physiological and Biomechanical Load-Adaptation Pathways. *Sports Medicine*, *47*(11), 2135–2142. https://doi.org/10.1007/s40279-017-0714-2

Wrigley, R., Drust, B., Stratton, G., Scott, M., & Gregson, W. (2012). Quantification of the typical weekly in-season training load in elite junior soccer players. *Journal of Sports Sciences*, *30*(15), 1573–1580. https://doi.org/10.1080/02640414.2012.709265

Figures:

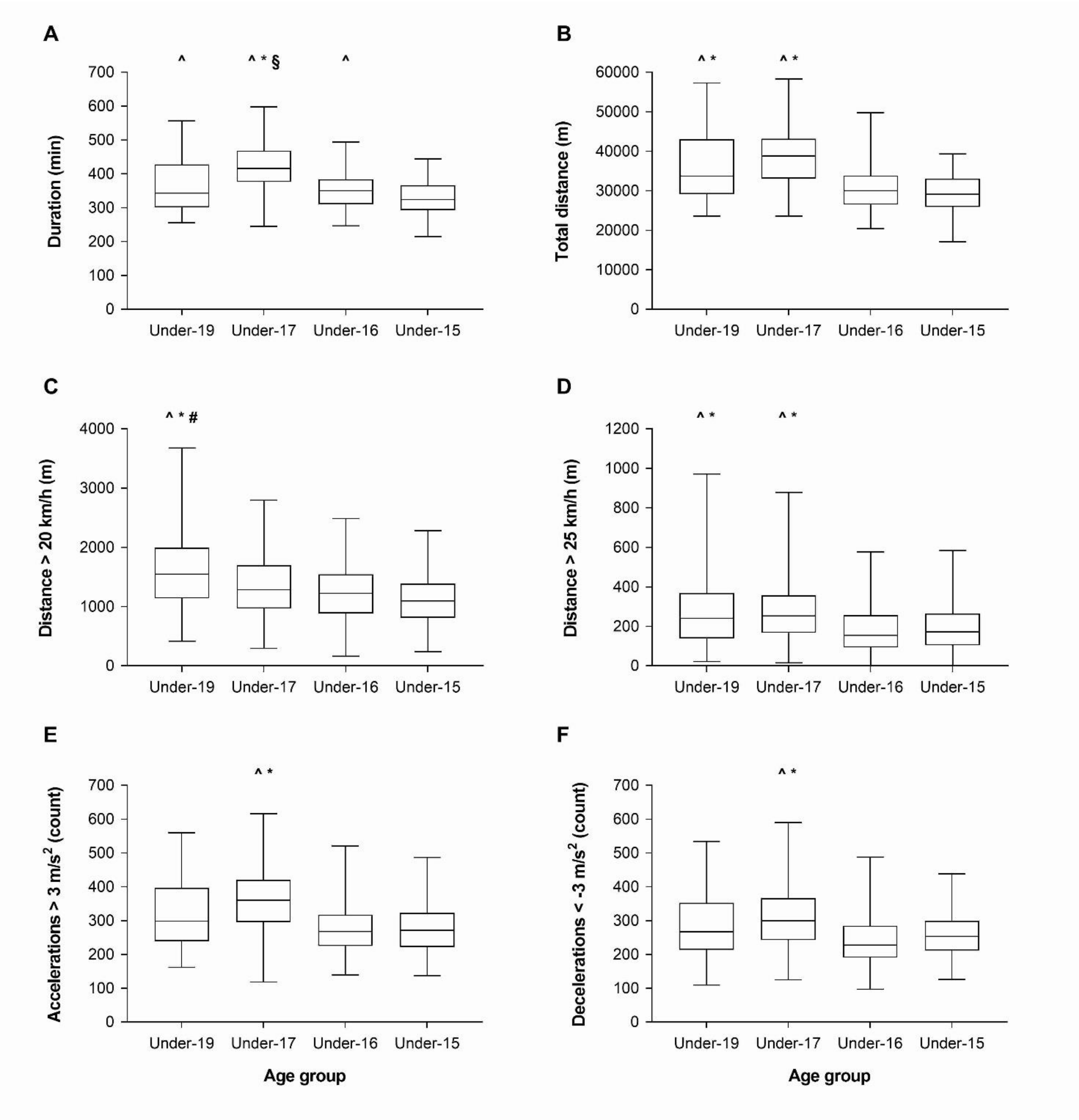

Figure 1: Weekly external loads in Italian Serie A youth soccer players during competitive microcycles. (A) duration, (B) total distance, (C) distance > 20 km/h, (D) distance > 25 km/h, (E) accelerations > 3 m/s^2, (F) decelerations < -3 m/s^2. Box and whiskers graphs display median, lower and upper quartiles, and min and max values. Statistically significant differences ($p < 0.05$) across age groups are reported as follows: ^ significantly higher than under-15; * significantly higher than under-16; # significantly higher than under-17; § significantly higher than under-19.

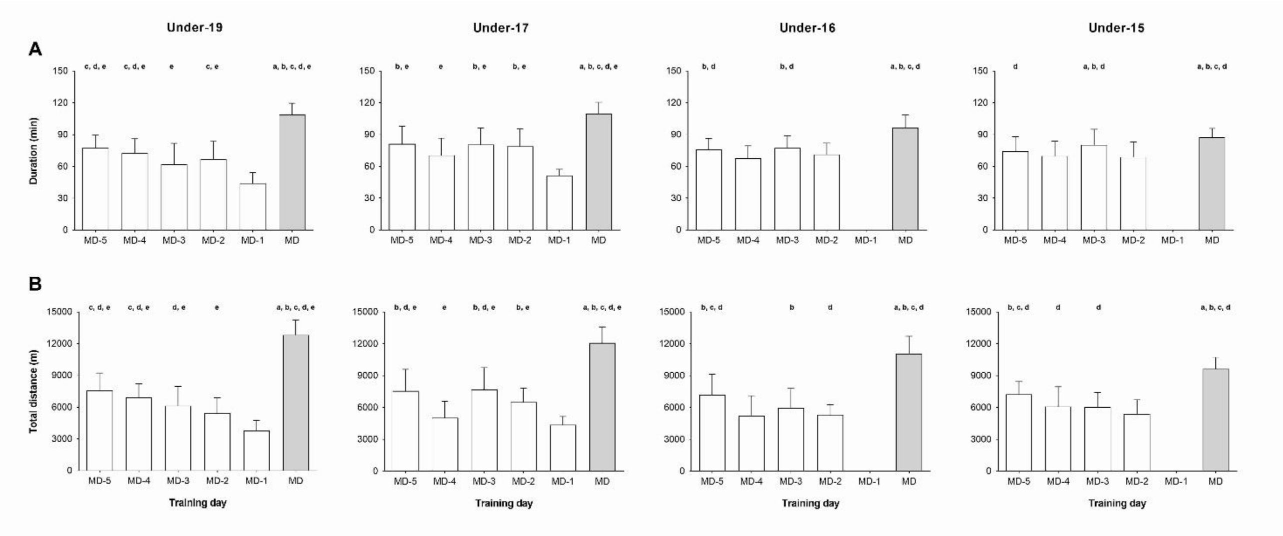

Figure 2: Microcycle periodisation of external training and match loads in Italian Serie A youth soccer players during a competitive season. (A) duration, (B) total distance. Vertical bars display mean ± standard deviation (SD) for each age group. White bars represent training days (i.e., MD-5, MD-4, MD-3, MD-2, MD-1) and grey bars represent match day (MD). Statistically significant differences ($p < 0.05$) across training days are reported as follows: a significantly higher than MD-5; b significantly higher than MD-4; c significantly higher than MD-3; d significantly higher than MD-2; e significantly higher than MD-1; f significantly higher than MD.

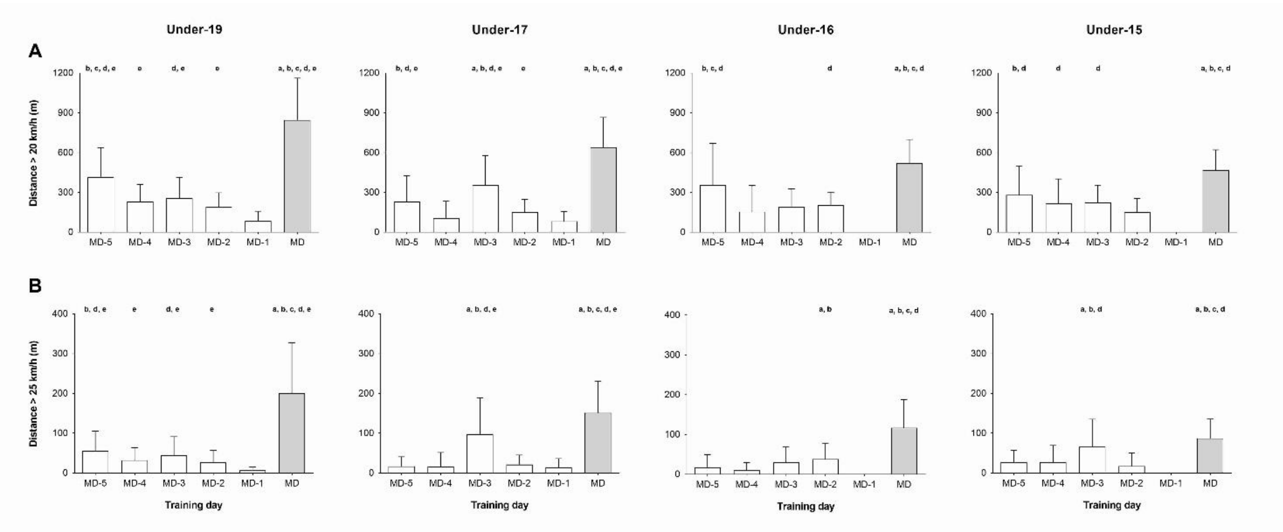

Figure 3: Microcycle periodisation of external training and match loads in Italian Serie A youth soccer players during a competitive season. (A) distance > 20 km/h, (B) distance > 25 km/h. Vertical bars display mean ± standard deviation (SD) for each age group. White bars represent training days (i.e., MD-5, MD-4, MD-3, MD-2, MD-1) and grey bars represent match day (MD). Statistically significant differences ($p < 0.05$) across training days are reported as follows: a significantly higher than MD-5; b significantly higher than MD-4; c significantly higher than MD-3; d significantly higher than MD-2; e significantly higher than MD-1; f significantly higher than MD-2.

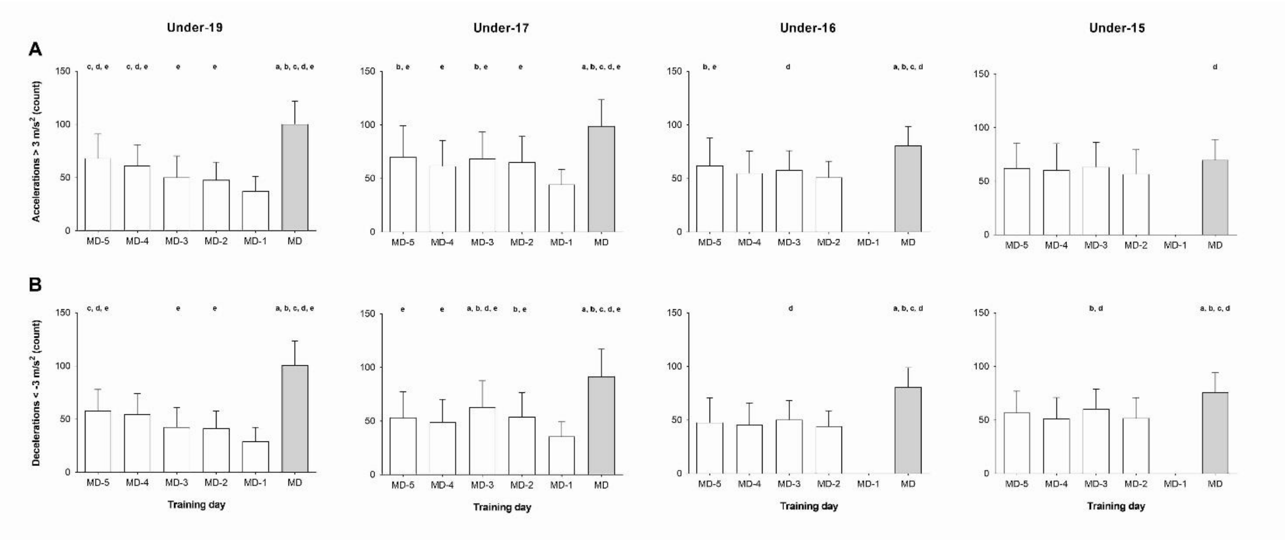

Figure 4: Microcycle periodisation of external training and match loads in Italian Serie A youth soccer players during a competitive season. (A) accelerations > 3 m/s^2, (B) decelerations < -3 m/s^2. Vertical bars display mean ± standard deviation (SD) for each age group. White bars represent training days (i.e., MD-5, MD-4, MD-3, MD-2, MD-1) and grey bars represent match day (MD). Statistically significant differences ($p < 0.05$) across training days are reported as follows: a significantly higher than MD-5; b significantly higher than MD-4; c significantly higher than MD-3; d significantly higher than MD-2; e significantly higher than MD-1; f significantly higher than MD-2.

Tables:

Table 1. Overview of the training micro-cycles analysed across the youth academy squads of an Italian Serie A team.

Age-group	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Under-19	Off	MD-5	MD-4*	MD-3	MD-2*	MD-1	MD
Under-17	Off	MD-5	MD-4*	MD-3	MD-2*	MD-1	MD
Under-16	Off	MD-5	MD-4*	MD-3	MD-2*	Off	MD
Under-15	Off	MD-5	MD-4*	MD-3	MD-2	Off	MD

Off: day off; MD: match-day; MD-x: training session with respect to the distance prior to the next competitive match; *: training session with a gym session (i.e., strength and power) performed in addition to pitch-based training.

Table 2. Linear mixed models' details according to the research objective.

Objective	**Dependent variables (levels)**	**Fixed effects (levels)**	**Random effects**
To quantify accumulated weekly training loads across academy age groups during the competitive microcycles	External load measures (duration, total distance, distance covered at different speed zones, accelerations and decelerations) Internal load measures (time spent at different heart rate zones, sRPE, sRPE-TL)	Age group effect (under-19, under-17, under-16, under-15) Player position effect (central defender, wide defender, central midfielder, wide midfielder, attacker) Age group x player position interaction	Individual player
To examine the periodisation of daily training loads within the competitive microcycles across academy age groups	External load measures (duration, total distance, distance covered at different speed zones, accelerations and decelerations) Internal load measures (time spent at different heart rate zones, sRPE, sRPE-TL)	Age group effect (under-19, under-17, under-16, under-15) Training day effect (MD-5, MD-4, MD-3, MD-2, MD-1, MD) Age group x training day interaction	Individual player

sRPE: session rating of perceived exertion; TL: training load; MD: match day.

Table 3. Weekly internal loads in Italian Serie A youth soccer players during competitive microcycles.

	Under-19	Under-17	Under-16	Under-15
Time spent > 85% HRmax (min)	35.6 ± 28.5	48.8 ± 33.4	40.8 ± 28.2	64.4 ± 28.9 $^{*\,\#\,\S}$
Time spent > 90% HRmax (min)	10.3 ± 12.6	15.4 ± 17.0	12.2 ± 14.6	26.3 ± 17.0 $^{*\,\#\,\S}$
sRPE (AU)	4.3 ± 0.5 $^{\wedge\,\#}$	3.9 ± 0.5	4.4 ± 0.5 $^{\wedge\,\#}$	4.0 ± 0.6
sRPE-TL (AU)	1690.9 ± 444.2 $^{\wedge}$	1722.5 ± 409.0 $^{\wedge}$	1575.3 ± 316.8 $^{\wedge}$	1353.1 ± 264.4

Data are mean ± standard deviation (SD). HR: heart rate; sRPE: session rating of perceived exertion; TL: training load; AU: arbitrary units. HR measures represent the weekly sum of the training sessions, with the exclusion of matches (i.e., no HR data recorded during matches).

Significant between-group differences ($p < 0.05$) are reported as follows: $^{\wedge}$ significantly higher than under-15; * significantly higher than under-16; $^{\#}$ significantly higher than under-17; § significantly higher than under-19.

Table 4. Microcycle periodisation of internal training and match loads in Italian Serie A youth soccer players during a competitive season.

	Age-group	**MD-5**	**MD-4**	**MD-3**	**MD-2**	**MD-1**	**MD**
Time spent > 85% HRmax (min)	Under-19	15.2 ± 11.6 $^{b\,c\,d\,e}$	10.6 ± 10.3 $^{c\,d\,e}$	7.2 ± 8.1 $^{d\,e}$	4.3 ± 5.0	2.5 ± 3.8	-
	Under-17	16.1 ± 14.1 $^{b\,d\,e}$	8.6 ± 8.8 ^{e}	14.8 ± 11.7 $^{\S\,b\,d\,e}$	8.1 ± 8.3 ^{e}	5.2 ± 5.0	-
	Under-16	16.7 ± 13.8 $^{b\,c\,d}$	9.6 ± 9.6 ^{d}	11.1 ± 10.5 ^{d}	5.9 ± 6.1	-	-
	Under-15	24.8 ± 12.9 $^{*\,\#\,\S\,b\,c\,d}$	18.5 ± 12.7 $^{*\,\#\,\S\,d}$	16.6 ± 9.7 $^{\S\,d}$	10.3 ± 8.9 §	-	-
Time spent > 90% HRmax (min)	Under-19	5.7 ± 7.0 $^{b\,c\,d\,e}$	2.9 ± 4.6 $^{d\,e}$	2.0 ± 3.7 ^{e}	0.8 ± 1.6	0.4 ± 1.1	-
	Under-17	5.6 ± 7.9 $^{b\,d\,e}$	3.0 ± 4.9 ^{d}	4.4 ± 5.8 $^{b\,d\,e}$	2.2 ± 3.9	1.4 ± 2.6	-
	Under-16	6.2 ± 8.4 $^{b\,c\,d}$	2.9 ± 5.1 ^{d}	3.2 ± 5.3 ^{d}	1.3 ± 2.4	-	-
	Under-15	11.9 ± 8.7 $^{*\,\#\,\S\,b\,c\,d}$	8.3 ± 8.3 $^{*\,\#\,\S\,c\,d}$	5.9 ± 5.5 $^{\S\,d}$	3.3 ± 4.7	-	-
sRPE (AU)	Under-19	5.0 ± 1.0 $^{\wedge\,*\,\#\,b\,c\,d\,e}$	4.4 ± 1.0 $^{\wedge\,\#\,d\,e}$	4.2 ± 0.9 $^{d\,e}$	3.5 ± 0.7 ^{e}	2.5 ± 0.6	7.1 ± 0.9 $^{\wedge\,*\,a\,b\,c\,d\,e}$
	Under-17	3.9 ± 0.9 $^{b\,d\,e}$	3.7 ± 0.8 $^{d\,e}$	4.2 ± 0.8 $^{a\,b\,d\,e}$	3.3 ± 0.5 ^{e}	2.5 ± 0.5	6.9 ± 1.1 $^{\wedge\,*\,a\,b\,c\,d\,e}$
	Under-16	4.6 ± 1.0 $^{\#\,b\,d}$	4.2 ± 0.8 ^{d}	4.4 ± 0.9 ^{d}	3.8 ± 0.7 $^{\wedge\,\#\,\S}$	-	5.9 ± 0.9 $^{\wedge\,a\,b\,c\,d}$
	Under-15	4.3 ± 1.1 $^{\#\,b\,d}$	3.9 ± 0.9 ^{d}	4.3 ± 1.0 $^{b\,d}$	3.5 ± 0.8	-	5.2 ± 0.9 $^{a\,b\,c\,d}$
sRPE-TL (AU)	Under-19	389.5 ± 86.7 $^{\wedge\,\#\,b\,c\,d\,e}$	326.3 ± 92.8 $^{\wedge\,c\,d\,e}$	267.9 ± 110.9 $^{d\,e}$	236.5 ± 80.1 ^{e}	112.4 ± 38.3	776.9 ± 141.8 $^{\wedge\,*\,a\,b\,c\,d\,e}$
	Under-17	323.5 ± 113.6 $^{b\,d\,e}$	261.1 ± 85.3	344.5 ± 98.4 $^{b\,d\,e}$	261.2 ± 75.6 $^{\S\,e}$	129.7 ± 33.3	764.4 ± 167.2 $^{\wedge\,*\,a\,b\,c\,d\,e}$
	Under-16	352.4 ± 103.8 $^{b\,d}$	284.7 ± 77.7	342.7 ± 95.8 $^{b\,d}$	275.6 ± 68.2 §	-	576.4 ± 130.4 $^{\wedge\,a\,b\,c\,d}$
	Under-15	323.9 ± 101.9 $^{b\,d}$	284.0 ± 93.1 ^{d}	349.8 ± 110.7 $^{\S\,b\,d}$	242.7 ± 82.4	-	454.0 ± 94.7 $^{a\,b\,c\,d}$

Data are mean ± standard deviation (SD). sRPE: session rating of perceived exertion; TL: training load; AU: arbitrary units.
No HR data were recorded during MD sessions.
Between-group differences are reported as follows: [^] significantly greater than under-15 ($p < 0.05$); [*] significantly greater than under-16 ($p < 0.05$); [#] significantly greater than under-17 ($p < 0.05$); [§] significantly greater than under-19 ($p < 0.05$).
Significant between-day differences ($p < 0.05$) are reported as follows: [a] significantly higher than MD-5; [b] significantly higher than MD-4; [c] significantly higher than MD-3; [d] significantly higher than MD-2; [e] significantly higher than MD-1; [f] significantly higher than MD.