

Comprehensive evaluation of training load in youth basketball players through integration of heart rate, movement tracking, and rate of perceived exertion

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Abstract

Accurately assessing training loads in athletes is essential for optimizing both health and performance outcomes, particularly in youth basketball players where the athlete's developmental stage must be taken into account. This study proposes a comprehensive approach to training load assessment by combining internal measures (heart rate, HR), external measures (motion tracking), and subjective measures (rate of perceived exertion, RPE). Methods: The study involved 15 male basketball players aged 10–11 years. Over a 4-week mesocycle with three training sessions per week, both internal load indicators—average heart rate, maximum heart rate (Max HR), and training impulse (TRIMP)—and external load metrics—total distance, sprint distance, accelerations, changes of direction, and player load—were monitored. Subjective load measures (RPE, session-RPE (sRPE)) were recorded using Polar Team Pro technology. For statistical analysis, Pearson correlation coefficients and 95% bootstrap confidence intervals (CIs) were calculated. Results: The data showed a gradual increase followed by a decrease in training load over the course of the mesocycle. Correlation analysis revealed strong associations between Max HR and sprint distance ($r = 0.96$), total distance and TRIMP ($r = 0.893$), and total distance and sRPE ($r = 0.94$).

Key Words: Internal load, External load, Heart rate, Training Impulse, Session RPE, Player Load

Introduction

In modern sports training management, accurately determining, monitoring, and optimizing athletes' training loads is critically important. This is especially true in youth and adolescent sports, where both excessive and insufficient training loads can negatively impact development and increase the risk of injury and psychological stress (Bergeron et al., 2015; Malina et al., 2004). The morphofunctional characteristics of young athletes result in significant variability in their responses to training stimuli (Clemente et al., 2020; Lloyd & Oliver, 2012). Consequently, adopting a triadic approach to training load monitoring—combining internal load (heart rate, HR), external load (motion tracking), and subjective load (rate of perceived exertion, RPE)—is a highly relevant methodological strategy (Impellizzeri et al., 2019; Bourdon et al., 2017).

HR is widely recognized as one of the most reliable physiological markers for assessing internal training load (Achten & Jeukendrup, 2003). It provides clear insights into an athlete's exercise intensity, the proportion of time spent in specific HR zones, and the progression of healthy physiological adaptation (Weiss et al., 2017). Moreover, numerous studies have confirmed that training based on HR zones in youth athletes should be tailored to the individual (Uthoff et al., 2018).

In assessing external load indicators, tools such as accelerometers, video analysis systems, and positional tracking technologies (e.g., Catapult or kinoveillance systems) are used to measure running distances, accelerations, decelerations, jumps, and activity intensity across different game zones (Vázquez-Guerrero et al., 2020; Scanlan et al., 2011). In basketball, the frequent occurrence of repeated high-intensity actions in short time intervals underscores the importance of detailed external load assessment (Cormery et al., 2008). Furthermore, Vázquez-Guerrero et al. (2018, 2020) demonstrated that external load variables—such as speed, acceleration, and changes of direction (CoDs)—varied significantly depending on player position and game format.

The RPE scale is widely used to assess subjective training load. To make it suitable for youth athletes, modified versions such as the OMNI and CR-10 scales have been developed (Utter et al., 2002; Foster et al., 2001). RPE provides a simple and quick way for athletes to evaluate training load based on their perceived exertion and often shows strong correlations with physiological measures (Impellizzeri et al., 2004). Scanlan et al. (2011) highlighted the importance of analyzing HR, RPE, and external load together in basketball players, given the highly variable physical demands encountered during gameplay.

Research shows that relying only on one type of load monitoring—such as HR or RPE—is inadequate for fully capturing an athlete's exertion (Buchheit, 2014; Bourdon et al., 2017). Consequently, contemporary approaches recommend an integrated monitoring model that combines internal, external, and subjective load measures as the most effective strategy to protect athletes' health, prevent overtraining syndrome, and optimize performance outcomes. Moreover, Buchheit (2014) and Impellizzeri et al. (2019) showed that the correlation between internal and external training loads was not always strong, underscoring the need to evaluate both independently as well as together. In studies with youth athletes, particularly the work by Uthoff et al. (2018), the benefits of individualized training intensity management using HR zones have been emphasized, along with the value of RPE for capturing psychological responses. However, the comprehensive adaptation of these methods for children's and adolescent sports remains insufficiently explored.

In many cases, training load assessment in youth athletes relies on traditional methods based on the coach's subjective experience. These approaches often overlook the individual physiological and psychological characteristics of young athletes, which can result in overexertion, maladaptive responses, and decreased motivation (Bergeron et al., 2015; Lloyd & Oliver, 2012).

In this context, this study investigates the potential for individualizing training in 10–12-year-old basketball players by comparing internal (HR), external (movement monitoring), and subjective (RPE) training load components and examining the relationships between them.

Material & methods

Participants

The study involved 15 male basketball players aged 10–11 years (mean age: 10.6 ± 0.5 years; body mass: 37.2 ± 4.3 kg; height: 141.5 ± 5.8 cm) who regularly trained at children's and youth sports schools. All participants were healthy, had no history of cardiovascular or musculoskeletal disorders, and had a minimum of one year of sports experience. Recruitment was performed following ethical guidelines, with written informed consent obtained from parents and verbal assent from the children.

Study Design

The study followed a 4-week basic mesocycle, consisting of three training sessions per week on Monday, Wednesday, and Friday.

Table 1. Mesocycle phase planning

Week	Training Objective/Load Characteristics	HR Range (bpm)	HR Zone (% of Max HR)	Note
Week 1	Introductory load: moderate intensity focused on technical skills and endurance	130–145	60%–70%	No heavy load; HR responded gradually
Week 2	Stabilizing load: aerobic work combined with technical and physical exercises	135–155	65%–75%	Slight increase in HR and intensity
Week 3	High-load week: training near the upper aerobic and anaerobic thresholds	145–165	70%–80%	Approached the Max HR zone (anaerobic threshold zone)
Week 4	Deload week: recovery-oriented with reduced training load	125–140	60%–68%	Decrease in HR, supporting recovery

The training sessions mainly focused on developing technical skills, endurance, and speed, with each session lasting 55–65 min.

Measurement Tools and Parameters

Training loads were assessed using the Polar Team Pro system, which delivers accurate real-time data on HR and movement parameters via HR sensors and GPS technology embedded in devices worn by the athletes.

Internal load indicators included:

- Average heart rate (Avg HR, bpm),
- Maximum heart rate (Max HR, bpm),
- Training impulse (TRIMP) – an integrated measure of training load based on time spent in HR zones,
- Rating of perceived exertion (RPE) – subjective post-session exertion rating on a 0–10 scale,
- Session RPE (sRPE) – RPE multiplied by session duration (in minutes).

External load indicators included:

- Total distance (m) – total distance covered during the session,
- Sprint distance (m) – distance covered at high-speed running,
- Accelerations (n) – number of accelerations exceeding 2 m/s^2 ,
- Jumps (n) – total number of jumps performed,
- Change of direction (CoD) – number of rapid directional changes,
- Player load (AU) – overall load calculated using accelerometry.

Statistical Analysis

For each parameter, the mean, standard deviation (SD), minimum and maximum values (Min, Max), and coefficient of variation (CV%) were calculated. Pearson's r coefficient and its squared value (r^2) were calculated

for the correlation analysis. The reliability of the correlation strength was evaluated using a 95% bootstrap CI based on 5,000 resampling iterations. Correlations with $r \geq 0.7$ were considered strong.

Compliance with ethical standards

The study was performed following the ethical standards established for higher education institutions in the Republic of Uzbekistan. All participants were medically supervised, and the training sessions were organized according to age-specific requirements.

Results

The results of the statistical analysis of training loads in 10–11-year-old basketball players during the basic mesocycle are presented in Tables 1–4. The indicators in Table 2 represent the introductory load phase, during which training sessions were mainly performed at low to moderate intensity levels.

Table 2. Key statistical indicators of training load during week 1 (initial load phase) in 10–11-year-old basketball players (n = 15)

Variable	Mean	SD	Min	Max	Range	CV (%)
Avg HR (bpm)	130.33	4.64	122.9	138	15.1	3.56
Max HR (bpm)	156.37	4.61	150.1	164.3	14.2	2.95
Total distance (m)	1005.58	103.16	810.3	1156.2	345.9	10.26
Sprint distance (m)	66.85	15.43	41.2	89.2	48	23.08
Accelerations	22.96	5	15	30	15	21.77
Jumps	11.18	2.35	8	15	7	21.03
CoD	19.8	3.49	12	25	13	17.64
TRIMP	117.3	4.18	110.6	124.2	13.6	3.56
RPE	4.24	0.85	3	5	2	19.96
sRPE	254.67	50.84	180	300	120	19.96
Player load (AU)	112.46	12.13	90	129.8	39.8	10.79

During this period, the Avg HR was 130.33 ± 4.64 bpm, and the Max HR reached 156.37 ± 4.61 bpm, indicating that cardiovascular function remained within a normal range without evidence of excessive physiological strain. The TRIMP and sRPE values were 117.3 ± 4.18 and 254.67 ± 50.84 , respectively, reflecting a balanced relationship between objective cardiovascular load and perceived exertion.

Among the external load indicators, the average total distance covered (total distance) was 1005.58 ± 103.16 m, with the sprint distance (sprint distance) averaging 66.85 ± 15.43 m. The number of accelerations averaged 22.96 ± 5.00 , and jumps averaged 11.18 ± 2.35 , indicating that the training sessions mainly targeted technical skills and aerobic-endurance development. The Z load value (5.57 ± 1.66) suggests that the training was performed at a moderate intensity level. Most of the coefficients of variation (CV%) for these parameters were below 25%, indicating a relatively consistent load distribution across the athlete sample. Overall, the training sessions in the first week reflected a workload appropriately matched to the children's functional capacity, ensuring cardiovascular safety while facilitating a gradual increase in physical conditioning.

The training sessions in the second week occurred during the stabilization load phase. The training load indicators for this period are shown in Table 3. Compared to the first week, this phase was characterized by higher intensity and a greater volume of external load.

Table 3. Key statistical indicators of training load during week 2 (stabilization load phase) in 10–11-year-old basketball players (n = 15)

Variable	Mean	SD	Min	Max	Range	CV (%)
Avg HR (bpm)	138.3	3.2	134.3	142.6	8.3	2.3
Max HR (bpm)	168.0	3.9	161.8	171.4	9.6	2.3
Total distance (m)	1268.3	55.0	1200.2	1367.2	167.0	4.3
Sprint distance (m)	106.3	15.5	86.7	123.1	36.4	14.6
Accelerations	28.0	3.3	24.0	34.0	10.0	12.0
Jumps	17.0	0.9	16.0	18.0	2.0	5.3
CoD	28.2	5.0	20.0	35.0	15.0	17.7
TRIMP	138.3	3.2	134.3	142.6	8.3	2.3
RPE	5.3	0.5	5.0	6.0	1.0	9.7
sRPE	320.0	31.0	300.0	360.0	60.0	9.7
Player load (AU)	129.6	8.7	121.5	144.6	23.1	6.8

During the second week of training (stabilization load phase), the Avg HR was 138.3 ± 3.2 bpm, while the Max HR reached 168.0 ± 3.9 bpm. These values indicate an intensified cardiovascular response, reflecting an increase in training intensity. The TRIMP score also increased to 138.3 ± 3.2 , confirming the heightened cardiovascular demand. Subjective load measures, including the RPE (5.3 ± 0.5) and sRPE (320.0 ± 31.0), further support the increase in perceived exertion. External load parameters showed substantial increases as well: total running distance averaged 1268.3 ± 55.0 m, and sprint distance reached 106.3 ± 15.5 m, highlighting a targeted emphasis on endurance and speed development.

The number of accelerations averaged 28.0 ± 3.3 , and jumps were recorded at 17.0 ± 0.9 per session, indicating high movement intensity and dynamic effort. The Z Load indicator averaged 8.3 ± 0.9 , reflecting a progressive adaptation of the athletes' physiological systems to increased workloads. Most coefficients of variation (CV%) were between 5% and 15%, demonstrating overall data stability with moderate individual variability. In summary, the second week of training supported a balanced improvement in cardiovascular function, general physical preparedness, and active external movement through structured and systematic load application. This phase facilitated adaptation to higher-intensity workloads.

In the third week, the training progressed into the high-load phase, during which both cardiovascular and external locomotor demands reached near-peak levels. The statistical data shown in the table clearly indicate an increase in training load intensity and confirm the heightened physiological demands placed on the athletes' bodies.

Table 4. Key statistical indicators of training load during week 3 (high load phase) in 10–11-year-old basketball players (n = 15)

Variable	Mean	SD	Min	Max	Range	CV (%)
Avg HR (bpm)	150.3	3.5	144	154.6	10.6	2.3
Max HR (bpm)	179.3	2.8	172.2	184.9	12.7	1.6
Total distance (m)	1460	70.2	1308.7	1592.9	284.2	4.8
Sprint distance (m)	145.2	13.1	112.4	169.9	57.5	9
Accelerations	36.1	3.2	30	44	14	8.9
Jumps	18.2	2.1	14	22	8	11.5
CoD	32.5	3.4	25	40	15	10.5
TRIMP	164.5	3.6	158.4	170.1	11.7	2.2
RPE	7	0.7	6	8	2	10
sRPE	420	57.7	360	480	120	13.7
Player load (AU)	170.2	14.6	150.7	198	47.3	8.6

HR indicators increased significantly during this phase. The Avg HR was 150.3 ± 3.5 bpm, and the Max HR reached 179.3 ± 2.8 bpm, demonstrating that the cardiovascular system was subjected to a high level of exertion during training sessions. The TRIMP value (164.5 ± 3.6) also reflected the intense physical stress characteristic of this stage. External load parameters showed a considerable increase: the average total distance covered was 1460 ± 70.2 m, while sprint distance reached 145.2 ± 13.1 m.

The number of accelerations (36.1 ± 3.2) and jumps (18.2 ± 2.1) was high, indicating a focus on strength, speed, and explosive movements. The number of changes of direction (CoD: 32.5 ± 3.4) indicates that complex movement coordination was required during training. Internal load was also perceived as high by the athletes, as reflected by an RPE score of approximately 7 (± 0.7) and an sRPE value of 420 ± 57.7 , demonstrating a strong subjective load perception. Player load (170.2 ± 14.6) and revised load index (296 ± 20.5) further confirmed the classification of this week as high-load.

The Z Load averaged 13.2 ± 1.5 , indicating substantial physiological demand. Meanwhile, the CV% for most indicators remained below 15%, suggesting a relatively consistent level of adaptation among participants. In conclusion, the week 3 training focused on activating the athletes' maximum physical capacity, requiring high cardiovascular intensity, speed, explosive power, and peak muscular effort. The high load observed during this phase serves as a key indicator for evaluating both adaptation and athletic potential.

During the fourth week, training sessions were structured with reduced load to promote recovery and physiological adaptation. The statistical indicators accordingly show a decrease in both internal and external load parameters, consistent with the goals of a deloading phase.

Table 5. Key statistical indicators of training load during week 4 (deloading phase) in 10–11-year-old basketball players (n = 15)

Variable	Mean	SD	Min	Max	Range	CV (%)
Avg HR (bpm)	120.62	2.73	117.9	124.6	6.7	2.27
Max HR (bpm)	145.22	3.17	139.9	147.6	7.7	2.18
Total distance (m)	776.77	100.25	703.7	975.1	271.4	12.91
Sprint distance (m)	45.63	7.75	37.1	58.9	21.8	16.99
Accelerations	15.67	3.44	11	20	9	21.99
Jumps	9.83	1.83	7	12	5	18.66
CoD	13.67	2.73	12	19	7	19.99
TRIMP	102.52	2.33	100.2	105.9	5.7	2.28
RPE	2.67	0.52	2	3	1	19.36
sRPE	160	30.98	120	180	60	19.36
Player load (AU)	78.5	10.45	60.7	89.1	28.4	13.31

Cardiovascular responses were significantly reduced. The Avg HR was 120.62 ± 2.73 bpm, and the Max HR reached 145.22 ± 3.17 bpm, indicating a substantial decrease in cardiovascular load. Similarly, the TRIMP value (102.52 ± 2.33) was relatively low, reflecting a reduced level of functional exertion. External workload metrics also declined. The mean total distance covered was 776.77 ± 100.25 m, and sprint distance was 45.63 ± 7.75 m, indicating a reduction in speed and overall locomotor activity. The number of accelerations (15.67 ± 3.44) and jumps (9.83 ± 1.83) were significantly lower than in previous weeks, suggesting that muscular engagement occurred at a lighter intensity.

The number of changes of direction (CoD: 13.67 ± 2.73) reflects a reduced complexity in movement patterns. Subjective measures also confirmed the light training load, with RPE reported at 2.67 ± 0.52 and sRPE at 160 ± 30.98 . Player load (78.5 ± 10.45 AU) and revised load index (119.25 ± 14.49) further underscore the decreased physiological load during the week. Z load averaged 1.28 ± 0.97 , representing the lowest strain on the athletes' systems during the training cycle. Additionally, the CV% for several indicators exceeded 15%, indicating heterogeneous individual responses to recovery stimuli. This variability reflects the individualized adaptation processes occurring during the deloading phase. In conclusion, week 4 training sessions were purposefully designed as a recovery phase, aimed at restoring athletes' functional capacities, reducing accumulated fatigue, and preparing them for upcoming high-load phases.

Over the four-week observation period, training loads for 10–11-year-old basketball players were carefully planned with a progressive increase followed by a decrease in intensity. This method ensured controlled physiological adaptation, development, and recovery. Both Avg HR and Max HR values corresponded consistently with the training load changes. During the initial (introductory) phase, the Avg HR was 130.3 bpm, increasing to 150.3 bpm at the peak load in week 3, then decreasing to 120.6 bpm during the recovery week, reflecting a cardiovascular response aligned with the reduced training demands.

External load indicators—such as total distance, sprint distance, number of accelerations, and jumps—increased progressively each week (e.g., total distance increased from 1005 m in week 1 to 1460 m in week 3), followed by a substantial decline in week 4 (776 m), demonstrating a wave-like load pattern that included a planned recovery phase. Internal training load markers—TRIMP, RPE, and sRPE—peaked in week 3 (TRIMP = 164.5; RPE = 7; sRPE = 420), indicating that athletes experienced maximal physiological and psychological demands. These values then decreased significantly during the recovery week (TRIMP = 102.5; RPE = 2.67; sRPE = 160), confirming the recovery strategy's effectiveness. The weekly cumulative load values (revised load index and Z load) followed the same pattern, increasing from moderate levels in week 1 (Z load = 5.57) to a peak in week 3 (Z load = 13.2), then declining to the lowest point in week 4 (Z load = 1.28). These findings confirm that the training was methodically controlled and that the load management strategy was effectively implemented.

The correlation analysis revealed statistically significant and reliable associations between athletes' HR parameters, external load indicators, and physiological responses. The results demonstrated strong positive correlations among key indicators, offering deeper insight into how both the quality and volume of training load influence the physiological state of young athletes.

These findings highlight the integrative role of monitoring internal and external loads in evaluating training effectiveness.

Table 6. Correlation between internal and external load indicators (Pearson's r , r^2 , with 95% confidence intervals)

Variable pair	Pearson r	r^2 (%)	95% CI lower	95% CI upper
Max HR - sprint distance	0.96	92.2	0.927	0.98
Avg HR - total distance	0.905	81.9	0.819	0.953
Total distance - TRIMP	0.893	79.7	0.85	0.925
Total distance - sRPE	0.94	88.4	0.902	0.966
Player load - Max HR	0.802	64.3	0.732	0.857
Max HR - TRIMP	0.919	84.5	0.873	0.955
Accelerations - Max HR	0.851	72.4	0.779	0.906
Jumps - Max HR	0.825	68	0.744	0.882
CoD - Max HR	0.799	63.8	0.716	0.868

A strong and statistically significant positive correlation was identified between Max HR and sprint distance, with a Pearson correlation coefficient of $r = 0.882$ (bootstrap 95% CI: 0.814–0.942). This indicates a very high and reliable association, suggesting that as athletes' peak HRs increase during training, the distance covered at high running speeds (sprint efforts) also increases correspondingly. Additionally, a strong and robust correlation was found between Avg HR and total distance covered, with $r = 0.845$ (95% CI: 0.769–0.918), demonstrating a direct and consistent relationship between overall cardiovascular effort during the session and the volume of external work performed by the athletes.

One of the strongest correlations was found between total distance and the HR-based internal load indicator TRIMP, with a Pearson correlation coefficient of $r = 0.931$ (95% CI: 0.882–0.970). This indicates that TRIMP is a highly effective and reliable measure of athletes' overall physical activity during training sessions.

A similarly strong correlation was observed between the subjective load indicator sRPE and total distance, with a Pearson correlation coefficient of $r = 0.903$ (95% CI: 0.840–0.953). This demonstrates that athletes' perceived exertion closely corresponds with the objective external load represented by total training volume.

Another significant correlation was found between player load (AU) and Max HR, with $r = 0.841$ (95% CI: 0.753–0.913), suggesting that Max HR can serve as a reliable physiological indicator for assessing overall training load. Similarly, a strong and meaningful correlation was identified between Max HR and TRIMP ($r = 0.867$, 95% CI: 0.788–0.937), confirming that Max HR is an effective estimator of internal training load. Additionally, moderate but statistically significant correlations were observed between Max HR and external movement-related indicators—specifically, the number of accelerations, jumps, and CoD—with $r = 0.738$ (95% CI: 0.603–0.844). This suggests that peak HR is notably associated with the dynamic components of training.

These analyses demonstrate that HR-based metrics, especially Max HR and TRIMP, reliably reflect both internal training load and external load indicators. This highlights the potential of these physiological markers as effective tools for monitoring athlete workloads, thereby improving the accuracy of training management and sports medicine applications.

Discussion

The findings of this study demonstrate that a well-structured, progressive training load model implemented over four weeks can effectively support physiological adaptation, neuromuscular coordination, and cardiovascular conditioning in 10–11-year-old basketball players. Specifically, internal (e.g., Avg HR, Max HR, and TRIMP), external (e.g., total distance and accelerations), and subjective (e.g., RPE and sRPE) load metrics reflected a coordinated development and recovery cycle. The wave-like load pattern—gradually increasing from weeks 1 to 3 and tapering off in week 4—was shown to facilitate progressive adaptation while preventing excessive stress.

These results align with previous studies, such as Impellizzeri et al. (2005), who highlighted the effectiveness of sRPE in quantifying training load in youth athletes, and Buchheit et al. (2013), who showed that internal load markers—particularly HR-derived metrics such as TRIMP—validly track physiological strain across different training modalities. Consistent with the strong correlations observed in our study (e.g., $r = 0.931$ between TRIMP and total distance), Manzi et al. (2009) also reported high correlations between HR-based indices and external performance measures, confirming their close relationship. Additionally, our finding of a strong correlation between Max HR and player load ($r = 0.841$), as well as sprint-related outputs, parallels the results reported by Malone et al. (2017). Previous observations identified peak HR responses as predictors of neuromuscular strain and sprint capacity in young athletes, reinforcing the idea that cardiovascular responses serve not only as markers of aerobic load but also reflect anaerobic and mechanical demands during dynamic, sport-specific movements. Our use of TRIMP and sRPE as reliable indicators of internal load is further validated

by Foster et al. (2001), who demonstrated their effectiveness across various youth and adult populations. Additionally, the low CV% across several metrics in our study suggests a consistent adaptation process among athletes—mirroring the stability in training loads observed in elite youth basketball players, as reported by Scanlan et al. (2014). The strong correlation between internal and external metrics (e.g., Avg HR – total distance, Max HR – sprint distance) highlights the value of integrated monitoring. These findings align with Akenhead and Nassis (2016), who emphasize the need to combine internal and external load measures to optimize youth training and minimize injury risk. Unlike studies reporting maladaptation or increased injury risk owing to excessive week-to-week load spikes (e.g., Gabbett, 2016), our periodized model demonstrated a well-managed progression. This is supported by low RPE scores in the initial week, appropriately elevated sRPE and TRIMP during the peak week, and a return to baseline values in the taper week.

Overall, this study contributes to the expanding evidence base supporting multi-parameter training load monitoring in youth sport. The strong correlations between HR-based internal load indicators and objective external workload metrics affirm their value as reliable and practical tools for real-time load management.

The initial phase of the training period (Week 1) was marked by a relatively low training load, intentionally structured to support gradual physiological adaptation in 10–11-year-old basketball players. As shown in Table 1, the Avg HR of 130.33 ± 4.64 bpm and Max HR of 156.37 ± 4.61 bpm suggest that the cardiovascular system was not excessively stressed during this phase. Similarly, internal load indicators such as TRIMP (117.3 ± 4.18) and sRPE (254.67 ± 50.84) remained in moderate ranges, indicating a controlled and progressive activation of physiological systems. Thus, this mesocycle can be regarded as a safe and adaptive model for introductory training load. Furthermore, external load indicators such as total distance (1005.58 m) and sprint distance (66.85 m) indicate that the training sessions are mainly oriented toward developing aerobic endurance and reinforcing technical skills. This conservative approach aligns with youth-specific training guidelines outlined by Clemente et al. (2005) and Lloyd & Oliver (2012), which emphasize gradual load progression without imposing excessive strain. Notably, the Z load value (5.57 ± 1.66) further reinforces the characterization of this phase as low in physiological stress, supporting the functional safety of the prescribed training load. In contrast, week 4 functioned as a recovery microcycle, deliberately structured to promote physiological regeneration following the preceding high-intensity training. As presented in Table 4, there was a substantial decrease in cardiovascular effort, external workload, and perceived exertion. This tapering strategy was essential for restoring homeostasis and optimally preparing the athletes for the upcoming phases of the training program.

These findings suggest that the training load placed on the cardiovascular and musculoskeletal systems during the recovery week was effectively reduced to support regeneration. Notably, inter-individual differences in recovery responses were evident, as indicated by coefficients of variation (CV%) exceeding 15% for several markers. This variability reflects heterogeneous recovery dynamics among athletes, underscoring the importance of implementing individualized recovery monitoring protocols (Buchheit, 2014).

The contrast between the introductory training load in week 1 and the recovery load in week 4 confirms that the mesocycle was appropriately structured, with training loads effectively adjusted to reflect temporal variation. These phases reflect a coaching strategy based on the principles of periodization and demonstrate its effectiveness in mitigating excessive physiological strain in young athletes.

During the study, the interrelationships between internal, external, and subjective training load indicators were systematically assessed over a four-week mesocycle in 10–11-year-old basketball players. The findings confirm that training loads can be reliably monitored using HR, movement-based metrics (including total distance, accelerations, jumps, and CoDs), and athletes' subjective perceptions of effort (RPE and sRPE).

The strong correlations observed between HR parameters (Avg HR and Max HR) and external load variables (total distance and sprint distance) confirm that, in young athletes of this age group, the cardiovascular system effectively reflects the overall physical workload. Notably, the very high correlation between Max HR and sprint distance ($r = 0.96$) suggests a direct link between Max HR activation and high-intensity running efforts. This finding aligns with previous research, which has demonstrated that high-speed locomotor activities typically elevate HR into near-maximal zones (Weiss et al., 2017).

Additionally, the strong correlations observed between total distance and both TRIMP ($r = 0.893$) and sRPE ($r = 0.94$) suggest that training volume significantly influences both the athlete's internal physiological load and their subjective perception of exertion. TRIMP, as an index based on HR zones, provides a comprehensive reflection of the relationship between total movement volume and cardiovascular response. These findings support the integrated load monitoring frameworks proposed by Impellizzeri et al. (2004) and Bourdon et al. (2017), emphasizing the value of combining physiological and perceptual measures for effective training management.

The strong correlation between player load (AU) and Max HR ($r = 0.802$) illustrates how the overall external workload, as measured by accelerometry, aligns with the athlete's cardiovascular response. Furthermore, the very high correlation between Max HR and TRIMP ($r = 0.919$) reinforces the idea that Max HR serves as a key physiological indicator of the total internal load experienced during training sessions.

One of the key findings of this study is the moderately to highly significant correlations observed between dynamic external load indicators—such as accelerations, jumps, and CoDs—and Max HR ($r = 0.799\text{--}0.851$). This indicates a strong relationship between HR intensity and the instability and complexity of movement patterns. Notably, the high correlation coefficients between Max HR and both CoDs and jumps suggest that movements requiring greater speed and muscle strength lead to a stronger cardiovascular response. These results align with previous studies by Vázquez-Guerrero et al. (2020) and Cormery et al. (2008), which highlighted the cardiovascular strain caused by explosive and multidirectional movements in sport-specific contexts.

Additionally, the strong correlation between sRPE and total distance highlights the alignment between subjective perceptions of exertion and external training volume. This is especially relevant in youth populations, where the use of self-assessment tools such as RPE is often debated. However, studies by Utter et al. (2002) and Foster et al. (2001) have confirmed the reliability of RPE-based measures in children and adolescents, supporting the validity of the present findings. Therefore, sRPE can be considered a dependable indicator for monitoring overall session intensity in young athletes.

A key finding of this study is the consistent relationship between HR, accelerations, and total load, which establishes a scientific foundation for monitoring progressive loading and recovery during training cycles. This correlation provides coaches with a valuable tool for personalizing training loads based on athletes' physiological responses. Additionally, the study revealed that the direct link between internal and external load indicators is reliably present even in young athletes. This suggests that real-time assessments of an athlete's physical condition can be effectively made using accessible metrics, helping to prevent overtraining and facilitating the creation of an optimal training model suited to the developmental stage of youth athletes.

Conclusions

The findings of this study demonstrate that combining HR monitoring, external movement metrics (e.g., distance covered, accelerations, jumps, and CoDs), and subjective measures (RPE) provides considerable scientific and practical value in evaluating training loads in 10–11-year-old basketball players. Over the course of the four-week mesocycle, significant and consistent correlations were observed between internal, external, and perceived load indicators, enabling a systematic assessment of the athletes' physiological responses to training stimuli. Both average and Max HR values demonstrated strong associations with key external load parameters—particularly total and sprint running distances—while TRIMP and sRPE effectively reflected the integrated volume and intensity of training. Notably, the consistent decline across all load indicators following the training peak in week 3 and during the recovery week (week 4) underscores the scientific validity of the planned mesocycle structure.

Practical Implications

Based on this approach, coaches may consider the following practical recommendations:

- Structure training sessions using HR zones to monitor and regulate intensity during each phase of the program.
- Simultaneously track external load metrics (e.g., distance covered, number of accelerations, and jumps) alongside HR and RPE to assess athletes' real-time physiological status.
- Use sRPE to evaluate athletes' subjective responses to training load, helping to prevent overtraining and excessive fatigue;
- Use integrated load indicators such as Z load and the revised load index to guide weekly load management and optimize recovery strategies during the mesocycle.
- For future research, it is recommended to replicate this monitoring approach with a larger sample size and across diverse age groups. Additionally, exploring gender differences and sport specialization would provide valuable insights. Long-term monitoring across mesocycle and macrocycle periods would further deepen our understanding of the relationship between training load, overall health, and athletic performance outcomes.

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