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Training Load and Physiological Responses in Algerian Youth Swimmers: A Descriptive Analysis

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Abstract:

This study examined the external (training volume, duration, intensity) and internal (physiological) effects of high-performance training on elite youth swimmers, focusing on inter- and intra-individual variability in cardiovascular responses. Eleven competitive swimmers under 17 years (5 males, 6 females), all with notable national or international achievements, participated. Heart rate was continuously monitored during all training sessions using the validated Polar OH1 optical sensor, and data were analyzed via the Intervals.icu platform to assess responses across varying intensities. Descriptive statistics and Shapiro–Wilk tests guided the selection of parametric or non-parametric analyses for workload indicators, including training duration, moving time, and heart rate–derived measures. Results revealed substantial variability both within and between athletes, with most parameters showing non-normal distributions, indicating dynamic and individualized physiological stress responses. External load measures alone were insufficient to capture true training demands, as sessions of similar duration produced markedly different heart rate responses. Integrating internal and external load monitoring provides meaningful insights for individualized training prescription, optimized load management, and the development of high-level youth athletes, supporting evidence-based approaches in elite swimming programs.

Keywords: Monitoring; Descriptive Analysis ;Training Load; Competitive youth Swimmers .

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1. Introduction:

In the broader field of sports performance and particularly in high demand disciplines like competitive swimming precise and continuous monitoring of training load has emerged as an indispensable tool for optimizing athlete development and minimizing risks (Torres et al., 2025; Barry et al., 2024). status, implement targeted individual adaptations, and substantially mitigate risks of excessive fatigue, overtraining, injury, and maladaptation (Barry et al., 2024). Such meticulous oversight is crucial for young swimmers, whose physiological systems are still adapting to the stresses of training and competition, thereby necessitating dynamic adjustments in their regimens to foster optimal development (Armstrong et al., 2022; Mihăilescu et al., 2021). the systematic synthesis of research focusing on both internal and external training load monitoring methods in adolescent athletes is essential for understanding their relationship with physical qualities, injury rates, and overall illness prevalence (Dudley et al., 2023;Dudley et al., 2023).

In contemporary training methodologies that emphasize evidence-based, objective and quantifiable metrics such as heart rate variability, session duration and volume, training frequency, and internal load measures offer novel insights into athletes' capacity to tolerate accumulated training stress across acute, meso-, and chronic cycles, thereby facilitating proactive modifications that promote enduring performance enhancements Barry et al., 2024). (Buchheit M, 2025;Morais et al., 2021; Ruf et al., 2022). This metric holds special relevance in swimming, where the distinctive physiological requirements of aquatic exercise alter cardiovascular responses relative to land-based activities, thus demanding specialized interpretive frameworks (Barry et al., 2024; Bulte et al., 2025).heart rate variability has emerged as a prominent non-invasive index of autonomic nervous system function, yielding critical information on athletes' recovery states and adaptations to training-induced stressors (Esco et al., 2025;Collette et al., 2018 ; Dabal et al., 2023)

Competitive swimming exemplifies discipline where performance is highly sensitive to workload management, due to its unique biomechanical, metabolic, and neuromuscular demands in an aquatic environment. Swimmers must optimize energy systems, cardiorespiratory function, technical efficiency, rhythm, coordination, and pacing all influenced by training intensity and volume (Pyne & Sharp, 2014; Fernandes et al., 2024) With multiple daily sessions and substantial

hours across microcycles and mesocycles, even minor load variations can lead to progression, plateau, like overreaching. This intricate interplay between training stimulus and physiological response necessitates robust and individualized monitoring protocols to ensure optimal developmental trajectories (Fortunati et al., 2025; Dudley et al., 2023).

Effective monitoring helps athletes stay within their optimal performance zone by providing the right amount of training stimulus to , while reducing the chances of experiencing decreased performance, developing illnesses or burning out, and musculoskeletal injuries. (Rios & Pyne, 2025). Wearable technologies and digital tools now enable accurate, real time data collection in water, as maximum average heart rates and session-specific training stress. Correctly interpreted, these metrics allow coaches to refine session design, balance intensity with recovery, and personalize plans based on age, maturation, competitive calendar, and history (Seshadri et al., 2021). This approach optimizes physiological adaptations, enhances psychological well-being, and fosters sustainable long term athletic development (Barry et al., 2024; Collette et al., 2018). Integrating these sophisticated techniques requires careful consideration of practical application and interpretation in real world settings, given time and resource constraints (Botonis et al., 2021; Dalamitros et al., 2023 ;Kanwal et al., 2025; Barry et al., 2024). For instance, proper workload management in swimming, with training volumes often reaching 15,000 meters per day, is essential to prevent both under-recovery and overtraining, which can manifest as short-term performance declines or chronic maladaptation (Barry et al., 2024). The absence of consistent guidelines for event-specific training in swimming highlights a potential disparity between current scientific understanding and actual training practices (Pollock et al., 2019). This gap underscores the necessity for research that bridges theoretical knowledge with practical application, especially concerning the optimal periodization and volume strategies required for sustained performance enhancement in young swimmers without compromising their long term health (Marinho et al., 2020).

2. METHODS AND MATERIALS

2.1 Participants



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This research involved 12 athletes aged below 17 years who were members of a high-performance training program designed to prepare athletes for their country and the world. At the time of selection for participation in this study, only 11 of the 12 athletes attended the training sessions on a consistent basis. One swimmer was not able to compete in this study because of his frequent inability to attend training due to academic obligations as he prepared for the Baccalaureate examination. The participants (11) were all competitive swimmers eligible for competition based on their ability level, having secured 3rd place at the Algerian Winter Championship and a 1st place at the Algerian Summer Championship. Five of these eleven competed in the African Games 2025 hosted in Algeria; one of these 11 had competed in the most recent Islamic Games; and 4 of these swimmers qualified for the African Championship to be held in Angola in the near future. The number of training sessions varied according to the training phase and competition schedule, with athletes completing between one and four sessions per day based on their individual needs. Training was organized into pool-based sessions and strength/conditioning (bodybuilding) sessions, tailored to each swimmer. This structure was maintained consistently throughout the entire training cycle, spanning from 01 October 2025 to 04 June 2026, allowing for individualized load management and optimal performance development. Participation in the study was voluntary; athletes and their parents were provided with both the purpose and procedures of the study prior to beginning participation; and written consent was obtained prior to data collection in accordance with ethical practices within sports science research. All data collection procedures were carried out in compliance with established ethical standards for sports sciences.(Collette et al., 2018 ; Khene et al., 2023).

2.2 Materials

The Polar OH1 optical heart rate sensor, a reliable and validated device, was worn by the swimmers during every training session to continuously monitor their physiological responses (Sorgente et al., 2023). This sensor offers accurate heart rate data crucial for assessing internal training load and evaluating cardiovascular adaptations across various intensities, including those encountered during critical velocity training and polarized training regimens (Pla et al., 2018; Toubekis et al., 2011).

2.3 Study Design and Procedure

Following each training session, data were synchronized with the Polar platform. These data were then exported to the Intervals.icu platform to facilitate the retrieval of raw data in CSV format. This comprehensive dataset allowed for meticulous analysis of various physiological parameters, enabling a detailed understanding of training load distribution and individual athlete responses over the entire training cycle.

2.4 Statistical Analysis

Jamovi Statistical Software was used to perform data analysis. Descriptive statistics are expressed as means and standard deviations for all variables evaluated. Data distributions normality was assessed with the Shapiro Wilk test therefore, statistical analyses were conducted using either parametric or non-parametric tests based on the results of the normality assessment. Appropriate statistical comparisons were made for all analyses, with a significance value $p < 0.05$

3. Results

3.1 Moving Time

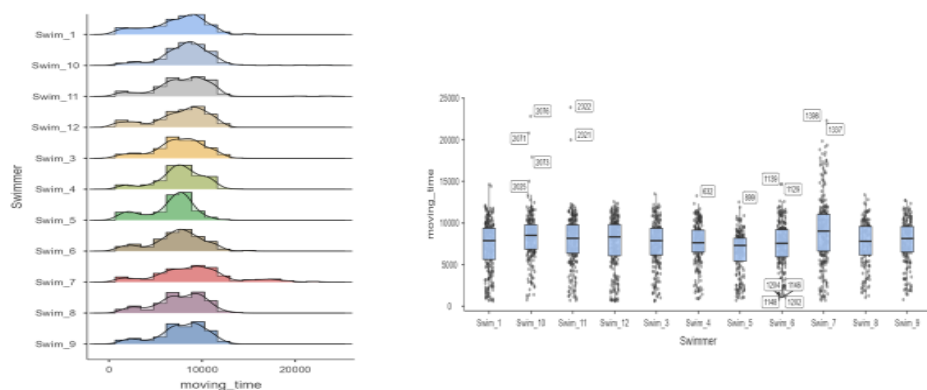
Definition : the total duration during which the athlete is actively performing movement during a training session, excluding rest periods, pauses, and inactive time.

Table 1. Individual Descriptive Statistics of Swimmers Moving Time During Training Sessions

Swimmer	moving_time	Mean	Standard deviation	Minimum	Maximum	Shapiro-Wilk W	Shapiro-Wilk p
Swim_1	295	7299	2947	628	14637	0.96	< .001
Swim_3	255	7496	2668	616	13504	0.971	< .001
Swim_4	262	7548	2452	925	13265	0.96	< .001
Swim_5	226	6578	2510	712	12517	0.927	< .001
Swim_6	285	7301	2750	798	14670	0.972	< .001
Swim_7	280	9023	4059	713	22289	0.971	< .001
Swim_8	177	7542	2688	1054	13394	0.969	< .001
Swim_9	222	7787	2603	804	12713	0.956	< .001
Swim_10	245	8329	2795	766	22814	0.929	< .001
Swim_11	272	7880	2972	713	23880	0.933	< .001
Swim_12	282	7585	2982	627	12571	0.932	< .001

The variance in moving time between swimmers, even though all and all competed using identical techniques or drills during their competitive training sessions, indicates significant amounts of time difference between swimmers. Mean move times range from 6578 moves (Swimmer Five) to 9023 moves (Swimmer Seven)

respectively; most swimmers exhibit move times clustered approximately between 7300 and 7900 moves, reflecting the accumulation of evaluated training. Means are considered a range of between 2452 (Swimmer Five) and 4059 (Swimmer Seven) moves; the standard deviation of made times across all swimmers was quite large compared to the average time that swim time lasted swimmers made relatively low numbers of moves exceptionally high numbers of moves were made by Swimmer Seven, Swimmer Ten, and Swimmer Eleven in some cases, indicating that training frequently exceeded the maximum number of times allowed in competitive swims by large margins. Scores on the Shapiro Wilk test indicated that all scored lower than 0.001 indicative of extreme (not normal or Gaussian).



adaptation in youth competitive swimmers

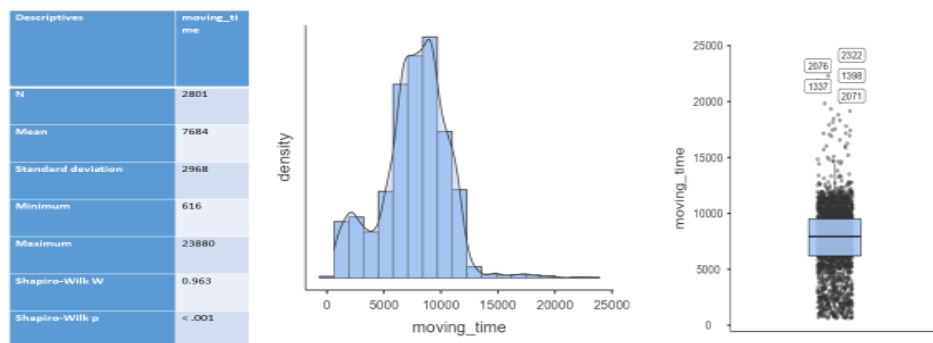


Figure. 2. Global Descriptive Statistics of Swimmers Moving Time During Training Sessions

The moving time data show a clear non-normal distribution, with a mean of 7,684 units and a large standard deviation (2,968 units), indicating substantial variability in training volume. The histogram reveals a pronounced right-skewed pattern, with most sessions clustered between 5,000 and 10,000 units and a long tail reflecting occasional very high training durations. Boxplot analysis confirms the presence of numerous upper outliers exceeding 20,000 units, likely corresponding to intensified training phases or exceptional workload sessions. The Shapiro Wilk test ($W = 0.963$, $p < 0.001$) confirms significant deviation from normality. These findings highlight marked heterogeneity in training duration and emphasize the need for individualized monitoring to optimize load management, control fatigue, and support long-term adaptation in competitive swimmers under 17 years of age.

3.2 Max heartrate

Definition : The highest heart rate value reached by an athlete during a training session or exercise bout (Faff, 2007).

All swimmers exhibited moderate inter-individual variability in the maximum heart rate (HRmax) as measured by descriptive statistics. The mean value of HRmax ranged from 162 bpm (Swim_6) to 179 bpm (Swim_4) between swimmers. These values reflect the differences in the exposure to high-intensity training and the cardiovascular fitness/ability of each swimmer within a similar training context. The standard deviations revealed a range of 13.3 to 20.6 bpm for the peak HR across swim sessions and indicated differences in how individuals respond to high



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intensities (e.g., peak heart rate) over time. The lower HR values (106 -132 bpm) indicate the occurrence of lower intensity training, while the highest HR observed (211 bpm) represents data indicative of intense training stimulus. The results of the Shapiro-Wilk test demonstrated significant departures from the normal distribution in all cases ($p < .001$).

Table 2. Individual Descriptive Statistics of Swimmers Maximum Heart Rate Values

Swimmer	max_heart rate	Mean	Standard deviation	Minimum	Maximum	Shapiro-Wilk W	Shapiro-Wilk p
Swim_1	295	173	18.7	106	202	0.928	< .001
Swim_3	255	172	15.1	115	195	0.9	< .001
Swim_4	262	179	14.1	132	211	0.969	< .001
Swim_5	226	168	20.6	120	211	0.975	< .001
Swim_6	285	162	16.6	112	190	0.924	< .001
Swim_7	280	166	14.3	110	204	0.964	< .001
Swim_8	177	167	17.4	109	197	0.936	< .001
Swim_9	222	169	19.9	120	205	0.961	< .001
Swim_10	245	166	14.7	108	205	0.967	< .001
Swim_11	272	165	13.3	110	194	0.943	< .001
Swim_12	282	175	15.3	114	199	0.899	< .001

According to the density plots and boxplots of maximum heart rate in youth competitive swimmers, there is marked inter-individual variability in cardiovascular responses during high-intensity training, despite most swimmers exhibiting peak values clustered between 160 and 180 bpm, which indicates generally comparable maximal effort levels across the group. Several swimmers show right-skewed distributions and very high peak values, with maximum heart rates exceeding 200 bpm, likely reflecting near-maximal efforts and/or the influence of fatigue, recovery status, or different phases of the training cycle. Although median values are similar among swimmers, the large differences in variability and dispersion highlight substantial individual differences in tolerance and responsiveness to high-intensity workloads. These visual patterns are consistent with the descriptive statistical findings.

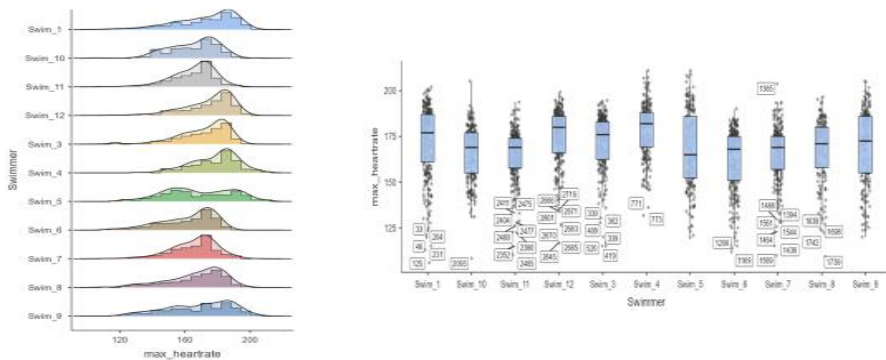


Figure. 3. Distribution and Descriptive Analysis of Swimmers Maximum Heart Rate Values

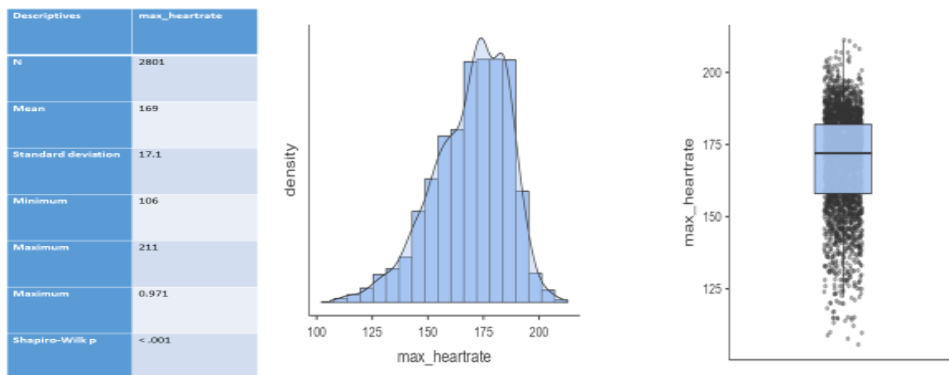


Figure. 4. Global Descriptive Statistics of Swimmers Maximum Heart Rate Values

Across 2,801 sessions, maximum heart rate (max hearttrate) averaged approximately 169 bpm with moderate variability (SD = 17 bpm) and ranged from 106 to 211 bpm. The distribution is unimodal and roughly symmetrical, but slightly negatively skewed (skew = -0.97) due to a few unusually low values. Most measurements cluster between 155 and 185 bpm, as shown by the histogram and density plot, while the boxplot confirms a stable median despite occasional low- and high-end outliers. Although the Shapiro Wilk test indicates a significant deviation from normality ($W = 0.971$; $p < .001$), visual inspection suggests that the distribution is sufficiently normal for many large-sample parametric analyses, with transformations or robust methods considered if strict normality is required. 'max_hearttrate' shows moderate variability, slight left skew, and occasional



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extreme values, consistent with physiological responses to variable-intensity training and competition.

3.3 average_hearttrate

Definition : The mean heart rate of an athlete over the duration of a training session or exercise period (Persson et al., 2024).

Table 3. Individual Descriptive Statistics of Swimmers' Average Heart Rate Values

Swimmer	average_hearttrate	Mean	Standard deviation	Minimum	Maximum	Shapiro-Wilk W	Shapiro-Wilk p
Swim_1	295	126	15.8	86	166	0.984	0.002
Swim_3	255	125	13.9	90	153	0.975	< .001
Swim_4	262	135	14.5	96	172	0.982	0.002
Swim_5	226	124	13.7	90	163	0.983	0.008
Swim_6	285	117	15.8	83.1	148	0.97	< .001
Swim_7	280	121	13.6	91	150	0.98	< .001
Swim_8	177	118	14.9	78	149	0.972	0.001
Swim_9	222	119	13.3	91	167	0.983	0.009
Swim_10	245	118	11.9	88	153	0.995	0.653
Swim_11	272	121	13	91	150	0.98	< .001
Swim_12	282	126	12.2	90	157	0.99	0.057

Among swimmers, various descriptive statistics were calculated for heart rates and average heart rates varied moderately from swimmer to swimmer with mean heart rates ranging from 117 bpm for Swim_6 to 135 bpm (Swim_4). Despite the fact that the swimmers follow the same training program, it is evident that they train at different levels of intensity as evidenced by their heart rate means. Also, Heart rate standard deviation's between swimmers have some similarity (11.9 to 15.8 bpm) but indicate that each swimmer is experiencing a similar but individualised cardiovascular response each time they swim. Heart rates of the swimmers ranged from the level of rest (78 and 96 bpm) to a level of max (172 bpm) showing that each swimmer performed low- and high-intensity work throughout the course of their training. Analysis using the Shapiro–Wilk test demonstrated that there were no swimmers with normal distribution of heart rates, yet two swimmers showed an acceptable level of normality ($p = 0.653$) while Swim_12 was marginally acceptable on the Shapiro- Wilk test (0.057). the heart rate results demonstrated that each swimmer is responding on an individual basis to their training and that heart rate monitoring is an important component in determining a swimmer's

training load and an athlete's cardiovascular response to training.

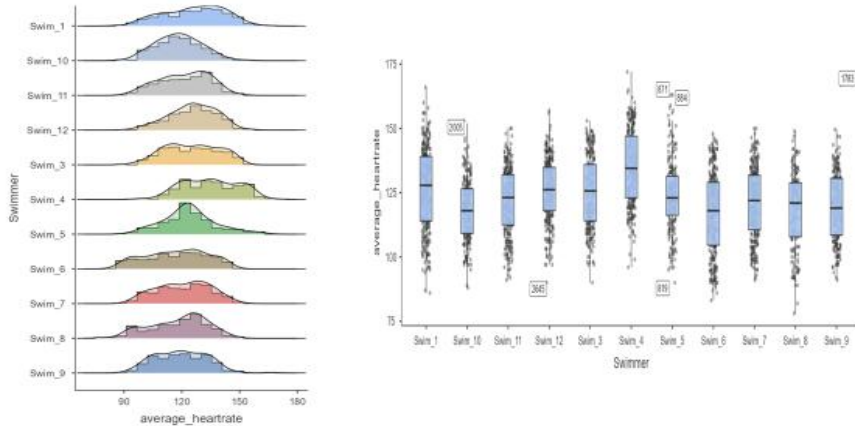


Figure 5 Distribution and Descriptive Analysis of Swimmers' Average Heart Rate Values

Individual heart rate distributions, shown through ridgeline plots and boxplots, reveal moderate inter-individual variability in cardiovascular responses among swimmers. Most swimmers display unimodal, approximately symmetric distributions with mean heart rates between roughly 115 and 130 bpm, reflecting the predominance of moderate-intensity sessions. Some swimmers, however, exhibit wider spreads and slight positive skewness, indicating occasional workouts with unusually low or high cardiovascular demand. Boxplot comparisons show that Swim_4 has higher median heart rates and interquartile ranges than the other swimmers, suggesting greater average training intensity, while the remaining swimmers' distributions are largely similar. between-swimmer variability is comparable to or exceeds within-swimmer variability, supporting assumptions of



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normality and homogeneity of variance for group-level analyses..

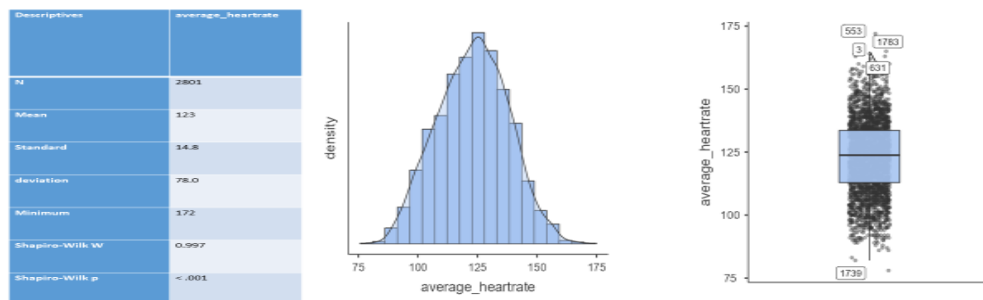


Figure 6. Global Descriptive Statistics of Swimmers Average Heart Rate Values

Across 2,801 sessions, average heart rate (average heartrate) had a mean of approximately 123 bpm with moderate variability (SD = 14.8 bpm) and ranged from 78 to 172 bpm, reflecting diverse cardiovascular demands during training. The distribution is unimodal, nearly symmetric, and most values cluster between 110 and 135 bpm, with only a few mild low- and high-end outliers, as shown by the histogram, kernel density plot, and boxplot. Although the Shapiro–Wilk test indicated a statistically significant deviation from normality ($W = 0.997$, $p < .001$), visual inspection confirms average heartrate demonstrates a stable central tendency, relatively tight spread, minimal skew, and occasional mild outliers, making it a reliable indicator of typical cardiovascular load during training sessions.

3.4 HR_load (Heart Rate Load) :using Banister's TRIMP

Definition: The computation of cardiovascular load as a result of a workout through measurement of time participated in the workout with the relative intensity of that workout. This is achieved by measuring the individual's heart rate response during each workout in addition to comparing the results from one workout with another (Banister's TRIMP method provides a means of evaluating the internal training load for each session of an athletic individual) (Morton et al., 1990).

$$\text{TRIMP} = D \times \Delta\text{HR} \times e^{(b \times \Delta\text{HR})}$$

The descriptive statistics of heart rate based training load (hr_load) reveal clear inter individual variability among the swimmers, with mean values ranging from 47.5 units (Swim_6) to 73.2 units (Swim_4), indicating differences in internal training stress despite participation in a similar training program.

Standard deviations were relatively high across all swimmers (24.6–37.8 units), reflecting substantial within-athlete variability and fluctuations in session intensity.

Minimum hr_load values were consistently low (1–3 units), whereas maximum values varied widely, reaching an extreme of 233 units for Swim_7, suggesting occasional exposure to very high cardiovascular stress.

The Shapiro–Wilk test demonstrated significant deviations from normality for all swimmers ($p < .01$), confirming non-normal distributions of hr_load. Overall, these findings emphasize the heterogeneous nature of internal training load responses and support the need for individualized monitoring and training load management in youth competitive swimmers

Table 4. Individual Descriptive Statistics of Swimmers’ Heart Rate–Based Training Load

Swimmer	hr_load	Mean	Standard deviation	Minimum	Maximum	Shapiro-Wilk W	Shapiro-Wilk p
Swim_1	295	58.2	35.9	2	168	0.951	< .001
Swim_3	255	61.6	30.7	2	138	0.983	0.003
Swim_4	262	73.2	35.3	3	161	0.984	0.004
Swim_5	226	50.5	30.4	2	140	0.962	< .001
Swim_6	285	47.5	28	2	107	0.954	< .001
Swim_7	280	63.5	37.8	2	233	0.925	< .001
Swim_8	177	51.6	30.5	1	128	0.964	< .001
Swim_9	222	51.5	29.8	3	156	0.961	< .001
Swim_10	245	50.9	24.6	2	154	0.965	< .001
Swim_11	272	55.8	28.5	2	180	0.977	< .001
Swim_12	282	61.2	33.8	1	139	0.971	< .001

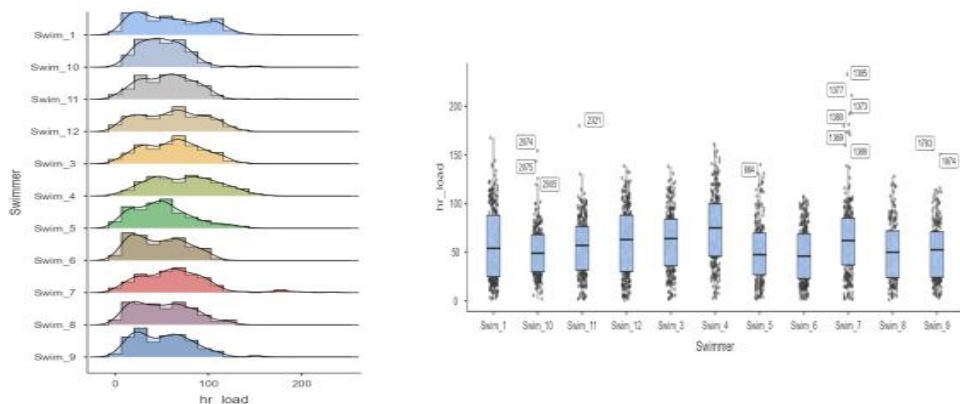


Figure 7. Distribution and Normality Assessment of Swimmers’ Heart Rate–Based Training Load

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The density plots and boxplots illustrate the distribution of heart rate load (hr_load) for each swimmer and reveal pronounced inter-individual variability in internal training load. Most swimmers show distributions centered between approximately 40 and 70 units, while the shape and spread of the distributions vary considerably across individuals. Several swimmers exhibit right-skewed distributions, indicating occasional training sessions associated with markedly higher cardiovascular load. The boxplots confirm the presence of numerous upper outliers, particularly for Swim_7, who demonstrates the highest variability and extreme hr_load values exceeding 200 units, reflecting very demanding training sessions. In contrast, swimmers such as Swim_6 and Swim_10 display lower median values and narrower interquartile ranges, suggesting more consistent and moderate internal loads. The observed skewness and outliers are consistent with the statistical evidence of non-normal distributions.

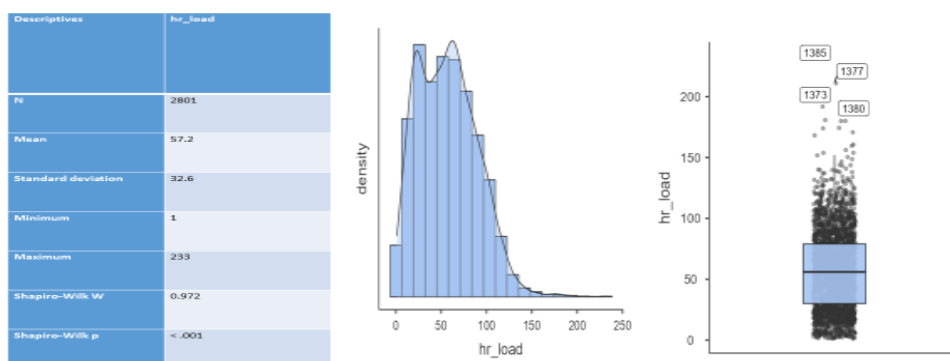


Figure 8 Global Descriptive Statistics of Swimmers' Heart Rate-Based Training Load

The histogram and density plot show that heart rate load (hr_load) values are mainly concentrated between approximately 30 and 80 units, with a clearly right-skewed distribution. While most training sessions fall within a moderate internal load range, a long tail toward higher values is observed, indicating occasional sessions with very high cardiovascular stress. The boxplot confirms the presence of several upper outliers, with extreme hr_load values exceeding 200 units.

The descriptive statistics support these visual observations. Across 2,801 observations, the mean hr_load was 57.2 units, with a relatively large standard deviation (32.6 units), reflecting substantial variability in internal training load. The wide range between the minimum (1 unit) and maximum (233 units) further

highlights heterogeneous training demands. The Shapiro–Wilk test revealed a significant deviation from normality ($W = 0.972$, $p < .001$).

4. DISCUSSION

This study aimed to characterize and examine the external and internal training loads in a group of elite youth swimmers, employing metrics such as session duration, moving time, heart rate responses, and heart rate-derived load indices. The findings reveal considerable inter- and intra-individual variability in all workload measures, underscoring the intricate and heterogeneous demands of training in elite swimming contexts. Specifically, the non-normal distribution of heart rate load across swimmers and sessions indicates that mean values alone may not fully capture the physiological stress, necessitating a deeper exploration of training load distributions (Zwaard et al., 2023). Analysis of training minutes and moving time indicated substantial dispersion and uniformly non-normal distributions, marked by right-skewness and extreme outliers. The mean values for session duration and moving time align with those commonly documented in competitive swimming programs, which emphasize extended aerobic sessions within weekly training regimens. Nonetheless, the elevated standard deviations and prevalent outliers suggest inconsistent training volume exposure, attributable to periodization, tapering, or competition preparation phases. These observations corroborate prior studies demonstrating that elite youth swimmers encounter highly variable external loads stemming from variations in training emphasis, stroke specialization, and competition schedules (Robertson et al., 2009; Pyne & Sharp, 2014). This variability highlights the shortcomings of depending exclusively on duration metrics, since sessions of comparable length can induce disparate physiological demands (Impellizzeri et al., 2019 ;Ari Tri Fitrianto, 2025). Mean maximum and average heart rates exhibited moderate variability, implying that the majority of sessions were performed at moderate-to-high aerobic intensities. These heart rate profiles correspond to those observed in adolescent competitive swimmers during organized training. instances of maximum heart rates surpassing 200 bpm signify exposure to near-maximal or maximal efforts, presumably linked to race-pace work or simulated competitions (Alexandre et al., 2012).

The heart rate load (hr_load) variable exhibited substantial inter- and intra-individual heterogeneity in internal training load, with a pooled mean of 57.2 units



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(SD = 32.6) across 2,801 sessions, ranging from a minimum of 1 to a maximum of 233 units, and pronounced right-skewness confirmed by Shapiro–Wilk tests ($W = 0.972$, $p < .001$) for all swimmers. Individual distributions varied markedly, with medians centered between ~40–70 units, numerous upper outliers, and extremes exceeding 200 units (e.g., Swim_7). This variability underscores that sessions of similar durations can induce markedly different internal stresses (Buchheit & Laursen, 2013; Impellizzeri et al., 2019), reinforcing the critical importance of integrating physiological markers, such as heart rate-derived loads, in training monitoring. These right-skewed, non-normal distributions align with prior research showing that internal load metrics capture sporadic high-stress sessions often masked by averages (Manzi et al., 2009), and emphasize distribution-based analyses to fully characterize heterogeneous demands (Zwaard et al., 2023). This is particularly relevant in youth sports where individual physiological responses to training can vary significantly, necessitating individualized approaches to training intensity and recovery (Kårström et al., 2023).

Across all variables, Shapiro–Wilk tests consistently indicated non-normal data distributions, justifying the use of non-parametric statistical approaches. From a practical perspective, this non-normality reflects the inherent complexity of elite training systems, where training stimuli are deliberately manipulated to induce adaptation (Issurin, 2010). These findings caution against the exclusive use of mean values for decision-making and emphasize the need for individualized load monitoring. For instance, the significant improvements in anthropometric measurements and swimming performance observed in adolescent swimmers further underscore the importance of tailored training volumes and intensities (Karabıyık et al., 2023). Such individualized approaches are crucial for optimizing adaptation and preventing maladaptation, overtraining, and suboptimal readiness to perform, particularly given the high physiological and psychological demands placed on adolescent elite athletes (Almási et al., 2021; Bulte et al., 2025).

For coaches and practitioners, combining external (minutes, moving time) and internal (heart rate-based) measures provides a more comprehensive representation of training demands. This integrated approach is particularly important in youth athletes, where excessive internal load may increase the risk of maladaptation or overtraining (Soligard et al., 2016).

Although the study benefits from a large number of training observations, it is limited by its descriptive nature and the absence of performance or recovery markers. Future research should explore the relationships between training load, competition performance, and wellness indicators, as well as longitudinal changes across training phases. Integrating perceptual measures such as session-RPE could further enhance the understanding of internal load responses in young swimmers. Further research should also consider the impact of various mediating factors, such as maturation, which can significantly influence the load-response relationship in adolescent athletes (Dudley et al., 2023).

5. CONCLUSION

This study provides a comprehensive description of external and internal training load characteristics in elite youth swimmers. The results demonstrate pronounced inter- and intra-individual variability across all workload indicators, including training duration, moving time, heart rate responses, and heart rate-based load. The consistent presence of non-normal data distributions highlights the heterogeneous and dynamic nature of training demands in high-performance swimming. The findings confirm that external load measures alone are insufficient to fully characterize training stress, as sessions of similar duration can elicit markedly different physiological responses. The integration of heart rate-derived variables offers valuable insight into internal load and cardiovascular strain, emphasizing the importance of a multidimensional monitoring approach. Notably, the occurrence of occasional high-load sessions underscores the need for careful load management, particularly in developing athletes.

This study supports the use of combined external and internal load monitoring strategies in youth elite swimming programs. Such an approach enables more individualized training prescription, improves training load interpretation, and contributes to long-term athlete development and performance sustainability. Future research should explore longitudinal relationships between training load, performance outcomes, and recovery indicators to further refine evidence-based training management in competitive swimming.



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