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Workload Monitoring of Throwing Sport Athletes

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Abstract

Background: Throwing events involve the full use of the kinetic chain. Therefore, monitoring training loads is crucial to optimizing athlete adaptation while minimizing the risk of fatigue and long-term injury.
Aims: This study aimed to determine external load using work calculations and compare them to current session internal workload metrics such as heart rate and rate of perceived exertion. Furthermore, it aimed to monitor workload over a nine-week period.
Methods: Internal training load was evaluated using modes of heart rate monitoring and rate of perceived exertion. External training load was calculated as the product of throw distances and implement weight. Acute to chronic workload ratio was calculated by dividing the acute workload by the chronic workload
Results: Twenty-five throwing athletes (age: 19 (3); height: 1.82 (0) meter; mass: 93 (19) kilogram) completed 11 (7) throws in a single field session during which throwing work was calculated (Throw distance: 40.87 (17.54) meter; session-rating of perceived exertion: 198 (269) arbitrary units; Total work: 8719.37 (13960.6) Joule; Average work: 726.61 (1877.92) Joule). Correlations ($p<0.05$) were found between session rating of perceived exertion and average work ($r=0.433$), session duration and total ($r=0.433$), and average workload ($r=0.523$). Negative correlations existed between average heart rate and total work ($r=-0.435$), average work ($r=-0.442$), and duration. ($r=-0.483$). Workloads and acute to chronic workload ratio differed over the 9 weeks ($p=0.025$).
Conclusion: Relationships were reported between calculated average work, s-RPE, session duration, and average heart rate, indicating that monitoring the duration of training sessions will be of value while changing the implement weight in the sessions.

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INTRODUCTION

Throwing events, such as shot put, discus, javelin, and hammer throw, requires explosive strength and the ability to generate high rates of force development to achieve maximum velocity and distance of the implement (Waller et al., 2014; Zaras et al., 2021). These events rely on the effective use of the kinetic chain, where power generated from the lower extremities is sequentially transferred through the upper body to propel the implement. This process maximizes speed and distance, requiring strength, flexibility, coordinated muscle activation, and optimal biomechanics (Dinu et al., 2019; Meron & Saint-Phard, 2017). Kinematically, throw-like movements emphasize distance with sequential body segment rotations, while push-like movements focus on precision with simultaneous segmental rotations (Trasolini et al., 2022).

Performance in throwing events is commonly assessed by the distance achieved, which reflects the athlete's ability to generate and transfer energy efficiently (Köhler & Witt, 2023). This performance is influenced by training load, which can be categorized into internal loads, such as physiological and psychological responses to stress, and external loads, such as the number of throws, distances thrown, and implement weight (Bourdon et al., 2017). Internal loads are assessed using heart rate, blood lactate, oxygen consumption, and RPE, while external loads provide objective data on the work performed (Halson, 2014). Monitoring both types of loads is essential to optimize

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training, enhance performance, and reduce the risks of overtraining, fatigue, and injury (Thornton et al., 2019).

Despite its importance, workload monitoring in throwing events is still underexplored. While studies on sports such as cricket and baseball have advanced understanding of workload management, there is limited application to throwing events. Using metrics like the Acute: Chronic Workload Ratio (ACWR), which compares short-term and long-term training loads, has effectively reduced injury risks caused by sudden workload spikes (Black et al., 2016). However, the lack of clear injury thresholds and performance optimization strategies for throwing sports remains a significant gap in the literature (Gabbett & Whiteley, 2017; Geantă & Ardelean, 2021).

This study aims to address these gaps by systematically tracking the workloads of throwing athletes over nine weeks. It will compare internal workload metrics, such as heart rate and RPE, with external measures, such as the number of throws, distances achieved, and implement weights (Black et al., 2016; Hulin et al., 2013). The goal is to identify the "sweet spot" of training intensity that maximizes performance gains while minimizing the risk of injury and overtraining (Black et al., 2016; Halson, 2014). By combining internal and external data, the study offers a more comprehensive understanding of the stress placed on throwing athletes and guides their training programs (Bourdon et al., 2017; Thornton et al., 2019).

Carefully managing workload is crucial to fostering positive performance adaptations while minimizing injury risks. Fluctuations in acute workload, such as sudden throw volume or intensity increases, have been strongly associated with injury risks, emphasizing the need for well-structured training schedules (Coyne et al., 2018; Gabbett & Whiteley, 2017). Off-field training, focusing on strength and aerobic capacity, also plays an essential role in preparing athletes to handle the physical demands of throwing events. By implementing effective workload monitoring and tapering strategies, athletes can improve performance while avoiding overuse injuries (Geantă & Ardelean, 2021). This study aims to fill the gap in workload monitoring for throwing events, providing insights into optimizing performance and preventing injuries. By systematically collecting and analyzing workload data, the research seeks to establish clearer guidelines for workload management, including practical applications for coaches and athletes. The findings will contribute to the limited knowledge of throwing sports, offering evidence-based strategies for improving athletic performance and reducing injury risks (Bourdon et al., 2017; Gabbett & Whiteley, 2017).

METHOD

Research Design

This study was composed of two independent yet related evaluations. A quantitative cross-sectional evaluation study primarily measured an athlete during a single session. Secondly, a longitudinal observation study that monitored the training loads experienced by throwing sport athletes was conducted over nine weeks by collecting the RPE. The study design aimed to assess the heart rate experienced during throwing sessions, RPE experienced, distances, and weight thrown during a single training session.

Participants

A sample of 25 throwing discipline athletes (age: 19 (3) years; height: 1.82 (0) m; mass: 93 (19) kg; experience: 5 (3) years) volunteered to participate in the study. The sample comprised 11 hammer-throwers (HT) (4 females, 7 males), 3 javelin (JT) (1 female, 2 males), 4 shot putters (SP) (3 females, 1 male), and 7 discus throwers (DT) (4 females, 3 males). All participants were injury-free for at least 6 months before data collection. Ethical approval to conduct this study was obtained from the Research Ethics Committee (REC-1821-2022), and all participants were given signed informed consent.

A purposive sampling method was used, with the research participants volunteering to participate in the study. The population and derived sample were youth throwing athletes from Free State province, specifically athletes who participate in discus, javelin, hammer throw, and shot-put at various age group levels. The sampled participants were thus subjected to the inclusion and exclusion criteria.

Instrumentation

Internal workload was evaluated using the following modes of heart rate monitoring and rate of perceived exertion. (1) Heart rate monitoring*:* Heart rate (HR) is a key indicator of physiological adaptation, exercise intensity, and workout effort. HR was measured to establish the physiological exertion experienced by athletes during sessions. During exercise, the HR goes up to the sympathetic system activation. Researchers wanted to monitor the amount of HR elevation experienced during throws. HR monitoring is included to monitor and evaluate the internal load experienced by the athletes. Athletes wore a standardized chest heart-rate monitor (Wahoo Tickr) during a training session to determine the peak and average heart rates reached during the session. The chest strap was connected via Bluetooth to the Wahoo Tickr application on a cellphone, and data were stored in the Wahoo data cloud. (2) Rate of Perceived Exertion: The Borg CR-10 scale was used to develop the RPE values questionnaire. This is an outcome measure scale used to know the exercise intensity prescription. It is used to monitor progress and exercise mode (Liu et al., 2023). Quantitating the training load involved multiplying the athlete's RPE (on a scale from 1–10) by the training session duration (in minutes). Session RPEs were then defined in arbitrary units (AU).

Procedures

Data collection took place at scheduled training sessions at the Mangaung Athletics Stadium. Heart rate monitoring was conducted during entire sessions, which lasted approximately 45–90 minutes, with monitoring occurring in only one session. Over the nine weeks, participants completed RPE questionnaires electronically.

Workload

The internal workload was evaluated using heart rate monitoring and RPE. The throwing sessions consisted of each athlete doing their normal warm-ups (which included jogging, stretching, and warm-up drills). All throws were measured to the nearest cm with a 100 m measuring tape as by the Word Athletic standards and recorded. Peak and average heart rates were collected using a standardized chest rate monitor (Wahoo Tickr, Atlanta, GA, USA) worn by athletes for an entire training session. Additionally, internal load was measured using the Borg CR 10 scale (Liu et al., 2023) as the intensity experienced by the participants after each session. RPE rating was recorded at the end of each week for the different training sessions performed during that specific week. Session RPE (s-RPE) was calculated as the product of RPE and session duration. External training load (work: product of force and distance) was calculated by measuring the athlete's thrown distance and then multiplying it by the weight (mass x 9.81 m.s-2). Total work was the sum of all the throws done in a throwing session. Average work is the total work divided by the number of throws performed.

$$W = F \times d$$

Acute: Chronic Workload

Participants completed the Weekly Training Load Monitoring Questionnaire at the end of each week to identify their weekly training load and RPE of sessions. A total summary of the number of sessions, total duration of the training, and average RPE for the week was compiled. The chronic workload value was the average of the 4-week workloads. The ACWR was then calculated by dividing the acute and chronic workloads (Black et al., 2016; Griffin et al., 2020).

Analysis Plan

The distribution of the data was assessed (Shapiro-Wilk). All data were non-parametric and presented as median (Interquartile range). Spearman's Correlations were computed to evaluate the relationships between internal and external training loads. Non-parametric tests (One-way ANOVA) were run to compare weekly workloads and ACWR over the 9 weeks. The Statistical Program for the Social Sciences (SPSS version 27, IBM) was used for statistical procedures with a significance level of $p<0.05$.

Scope and/or limitations

Sporting activities always risk delayed onset muscle soreness or muscle fatigue. Although these risks existed, participants were not expected to exert themselves beyond their usual training intensity. The risks involved were minimal, as participants should have been accustomed to their training level, and the research focused on monitoring their normal training load.

RESULTS AND DISCUSSION

Results

Throwing Session Data

Summary data (median (IQR)) for throwing sessions are reported in Table 1. Within their training session, HT athletes completed (10 (4)) throws, achieving an average distance of 49.64 (10.34) m. Secondly, JT athletes performed 14 (5) throws, attaining an average distance of 39.02 (5.69) m. SP athletes performed the highest number of throws (15 (9.25)) but reached the lowest distance (10.26 (0.51) m). Lastly, DT athletes performed 11 (6.5) throws, achieving an average distance of 40.30 (12.53) m. The average work performed was the highest for HT (2609.01 (1533.11) J) and the lowest for JT (254.37 (59.46) J). The highest s-RPE and work values were reported by HT (399 (202) AU), with DT achieving the lowest values (130 (58.5) AU). Average heart rates range between 127-145 bpm, and the peak heart rate is between 152-171 bpm during the throwing session (Table 1).

Table 1. Summary Data of 25 Throwing Athletes' Throw Metrics, s-RPE, Calculated Work, Average and Peak Heart Rates for a Single Throwing Session

	Combined Group (n=25)	Hammer Throw (n=11)	Javelin Throw (n=3)	Shot Put (n=4)	Discus Throw (n=7)
Number of throws	11 (7)	10 (4)	14 (5)	15 (9.25)	11 (6.5)
Implement mass(kg)	0.8 (3.4)	5 (0)	0.6 (0.1)	4 (0)	1 (0.75)
Average throw distance (m)	40.87 (17.54)	49.64 (10.34)	39.02 (5.69)	10.26 (0.51)	40.30 (12.53)
Maximum throw distance (m)	44.62 (18.66)	53.25 (9.86)	42.6 (4.87)	10.80 (0.73)	44.62 (13.78)
s-RPE (AU)	198 (269)	399 (202)	198 (46)	110 (143.75)	130 (58.5)
Total work (J)	8719.37 (13960)	19273.7 (12866)	1498.58 (1481.89)	8006.85 (2620.48)	5534.97 (3474.04)
Average work (J)	726.61 (1877.92)	2609.02 (1533.11)	254.37 (59.46)	417.40 (111.95)	495.89 (261.79)
Average heart rate (bpm)	132 (20)	124 (18.5)	135 (18)	144.5 (13.5)	133 (19.5)
Peak heart rate (bpm)	162 (6)	163 (3.5)	163 (14.5)	163.5 (11.5)	156 (14.5)
Duration (min)	35 (35)	56 (20)	33 (3.5)	20.5 (20.25)	16 (19)

Workload Correlation Matrix

A correlation matrix was calculated between calculated work, workload, and physiological exertion (Table 2). The s-RPE was correlated to the average work (r=0.433; p=0.031). The training session duration and total workload correlate (r= 0.433; p=0.026) with the average workload (r=0.523; p=0.007). Negative correlations exist between average HR and total work (r = -0.435; p=0.030), average work (r= -0.442; p=0.027), and duration (r= -0.483; p=0.014).

Table 2. Spearman's Correlations between Total Work, Average Work, Session-Rating of Perceived Exertion, Rating of Perceived Exertion, Session Duration, Average Peak Heart Rates

	Total work	Average work	s-RPE	RPE	Session duration	Average heart rate
Average work	0.829**					
s-RPE	0.361	0.433*				
RPE	-0.082	0.074	0.506**			
Session duration	0.443*	0.523**	0.942**	0.271		
Average heart rate	-0.435*	-0.442*	-0.490*	-0.032	-0.485*	
Peak heart rate	-0.019	0.028	-0.233	-0.155	-0.090	0.561**

* p< 0.05
** p< 0.01

Weekly Workload

The workload, using s-RPE, was monitored over nine weeks. The average weekly workload for the sample was 4353.18 AU. The weekly median workloads for the sample are reported in Figure 1.

Weekly workloads were different over the nine weeks (p=0.025). Specifically, workloads in week 1 (5365 (3231.25) AU) were different (p=0.001). Week 1 has the highest workload, which decreases until week 3. From week 4, there is a spike again, but the workload plateaus for five weeks. In the final week, the workload has one final decline when the season comes to an end, indicating tapering of the season.

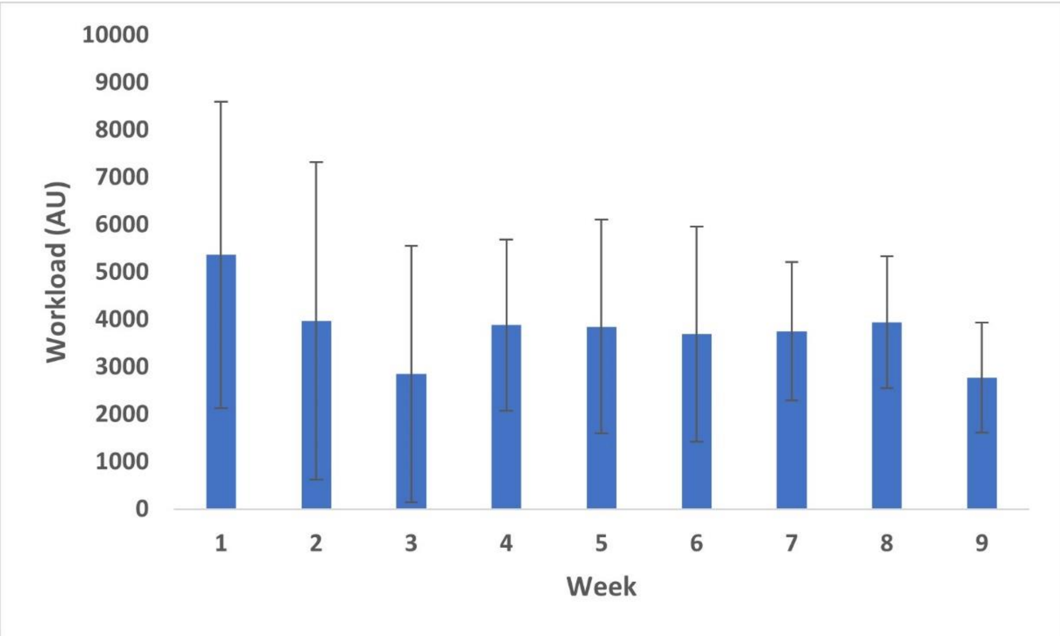

Figure 1. Weekly Workloads (s-RPE) of 25 Throwing Athletes Performed over a Nine-Week Preparatory Phase (Bars Represent Median and Interquartile Range)

Acute: Chronic Workload Ratio

The average ACWR is 0.36 for the 25 throwing discipline athletes over the 9 weeks. Figure 2 reports the ACWR over the 9-week observation period. Weeks 1-3 were omitted from the analysis due to chronic workload accumulation. From week 4 (0.24 (0.10) AU), it has a slight incline towards week 7 (0.27 (0.09) AU), where it then starts to decline again to week 9 (0.20 (0.11) AU). ACWR were different over the 9-week period (p =0.025). Post-hoc analysis revealed that weeks 7 and 9 were different (p=0.010).

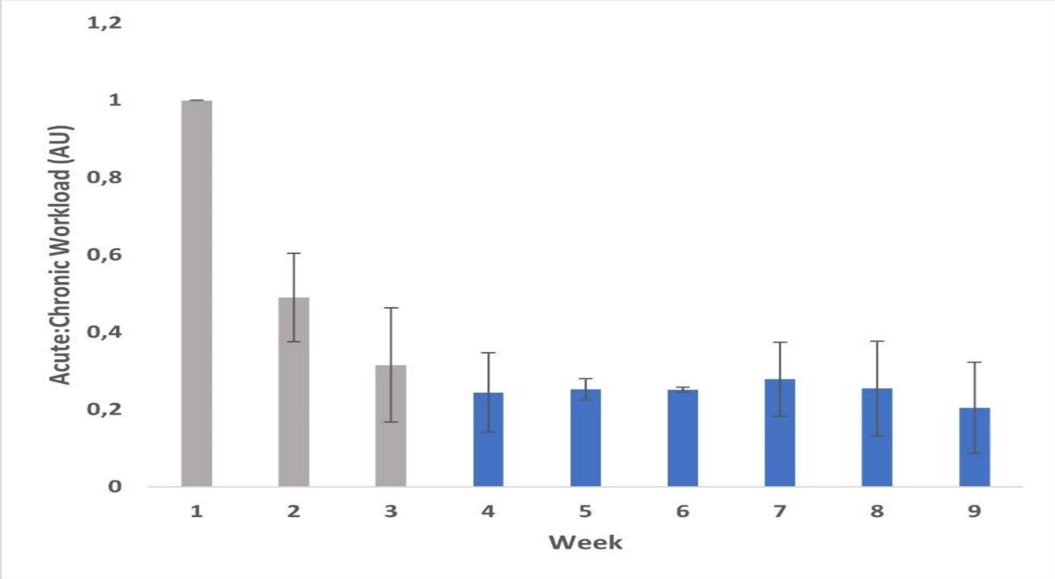

Figure 2. Acute to Chronic Workload Ratio of 25 Throwing Athletes Performed over a Nine-Week Athletic Season (Bars Represent Median and Interquartile Range)

Discussions

Implications

The study aimed to determine internal and external training loads experienced by throwing sport athletes during a single throwing session. Specifically, physical work was calculated along with s-RPE. Significant correlations were reported between the training session duration and total and average workloads. The results indicated that calculating physical work and heart rate during throwing sessions may effectively monitor training loads during throwing events. Additionally, the workload was monitored over a 9-week period prior to a national competition. In this monitoring period, tapering in workloads was observed toward the week of competition.

The primary aim of this study was to determine the external training loads during throwing sessions. A novel approach was used to calculate the physical work for each throw and session. This resulted in two key measures: total work (all throws) and average work (total work divided by the number of throws). Overall, athletes made 11 throws in their single training session, resulting in total work of (8719.37 (13960.6) J) and average work of (726.61 (1877.92) J). In the current study, work quantifies the effort to throw an implement, factoring in throw distance, and can account for variations in implement mass, number of throws, and performance.

Hammer throw and Shot put athletes showed the highest s-RPE, likely due to the heavier implements and longer training durations. According to Vickery, Dascombe, and Duffield (2017), including session duration in s-RPE calculations helps capture a significant portion of low-intensity training time in the overall load. Furthermore, s-RPE can be influenced by long sessions and repeated exercise bouts (Falk Neto et al., 2020). Subjective measures like s-RPE are often more sensitive and consistent than objective measures, and it is the most commonly used training load variable across sports, better reflecting the allostatic stress athlete's experience during mixed training sessions (e.g. tactical, skill, strength, and fitness) (Coyne et al., 2018). However, using RPE alone, combined with a number of throws, may not be precise enough to effectively monitor throwing loads for injury prevention or rehabilitation (Hoyne, 2022).

Athletes' perceived effort during the session is reflected in their maximum HR. Shot put (145 ± 16 bpm), and Javelin throw (141 ± 19 bpm) athletes had the highest average HRs, while Javelin (171 ± 16 bpm) and Hammer throw (165 ± 9 bpm) athletes reached the highest maximum HR. Exercises that require core stabilization and significant coordination between the upper and lower body can cause a natural Valsalva manoeuvre, which raises the HR (Falk Neto et al., 2020). This is reflected in the higher maximal HRs seen by JT and HT athletes due to the more physically demanding throwing mechanics.

Workload Correlations

A correlation matrix was created between the various internal and external load metrics to assess the usefulness of the calculated work during the sessions. Based on previous studies, correlations between workload metrics were expected (Benson & Connolly, 2020; Casamichana et al., 2013; Day et al., 2004; de Salles et al., 2009; Haddad et al., 2017; Hiscock et al., 2015; Sweet et al., 2004). This study found a significant correlation between an athlete's s-RPE and the average work, suggesting that average work could be a practical metric in throwing sports. While RPE is useful for measuring training load, for intermittent activities, or for those with varying technical difficulty, outcome measures used in calculations may offer additional benefits (Casamichana et al., 2013; Haddad et al., 2017).

The current study also found correlations between session duration, average work, and total work. Hermassi (2015) noted that the body's workload is lower when power output, similar to throw work in the current study, is maintained and exercise duration is short. However, they also found that alternating intense exercise bouts with rest or lower intensity can reduce the physiological limitations on performance. Burnley & Jones (2018) observed that increasing power output, work interval duration, or recovery interval power output while keeping recovery time constant decreases exercise tolerance. This suggests that longer recovery periods between throws lead to longer training sessions, resulting in higher s-RPE. Additionally, the 3-5 minutes rest periods between throws allow better recovery, lowering HR during recovery (DeWeese et al., 2015). Longer recovery also enables more intense performance, which increases the total work done.

Negative correlations were found between average HR and total workload, average workload, s-RPE, and session duration. Heart rate monitoring is based on the principle that heart rate is linearly related to steady-state work rate (Borresen & Ian Lambert, 2009). The principle of s-RPE is well suited for steady-state exercise and high-intensity interval cycling, as the athletes' RPE ratings strongly correlate with average HR and acute HR changes (Green et al., 2006). RPE is more influenced by resistance load than exercise volume, meaning athletes often find more repetitions with a lighter load easier than fewer repetitions with a heavier load (Sweet et al., 2004). Athletes may experience lower RPE as session duration increases due to HR stabilization. In contrast, shorter sessions with less recovery between high-intensity bouts can result in higher RPE and HR (Benson & Connolly, 2020).

The correlations suggest that both average and total work are related to the s-RPE athletes perceive. Longer sessions involving more work are likely to increase both session duration and s-RPE, as athletes perceive greater effort over longer periods. HR monitoring in these sessions could lead to misinterpretation, as HR may stabilize during longer sessions when the body adapts. In contrast, shorter sessions often have higher HR due to limited recovery between throws.

Weekly Monitoring

A secondary aim of the study was to monitor workloads over a 9-week preparation phase. The average workload over the 9 weeks was 4353.18 AU, peaking in week 1 (5669.66 AU) and declining until week 3. A spike occurred in week 4 (4223.08 AU), followed by a decrease in workload from week 5, with a final drop in week 9 (3209.20 AU) at the end of the season. The ACWR was calculated, with the average range for week 4-9 being 0.20 – 0.27 AU. Weeks 1-3 were excluded from the analysis due to chronic workload accumulation. From week 4 (0.24 (0.10) AU), there was a slight increase until week 7 (0.27 (0.09) AU), followed by a decline toward week 9 (0.20 (0.11) AU). ACWR varied over the 9 weeks ($p = 0.025$), with post-hoc analysis showing significant differences between weeks 7 and 9 ($p = 0.010$).

These findings align with previous studies showing that a 25-40% reduction in resistance training volume (sessions per week) while maintaining intensity improves throwing performance after two weeks in track and field athletes (Murach & Bagley, 2015). This suggests that tapering, which reduces training volume while keeping intensity the same or slightly higher, is key for strength- and power athletes. A 5-6% improvement in throwing distance may occur in competitive track and field athletes after a tapering period. Overall, tapering is effective for improving performance in strength and power, as well as in the performance of team sports athletes. Collegiate throwers can benefit from an overreaching week followed by a 3-week taper phase, where the training load is gradually reduced before a major competition (Bazyler et al., 2017), enhancing explosive ability and throwing performance.

Para-athletes showed a maximum s-RPE of 4404 AU during the overloading phase, with a minimum of 1950 AU during tapering (Garcia-Carrillo & Ramirez-Campillo, 2020). These values were higher than those recorded by college throwers, who had 3250 AU during overload and 1000 AU during tapering (Bazyler et al., 2017). This aligns with the current study, showing higher workloads at the beginning of the season and lower workloads during the tapering.

Individual sports often have shorter competitive periods and specific training phases (Boullosa et al., 2020). This leads to extended loading phases before peaking after significant workload accumulation. To reduce injury risk and optimize performance, coaches use tapering strategies to decrease the workload before competition (Cabre et al., 2021). This study's acute workload dropped significantly in week 9, likely due to tapering before the Championship. Chronic workload peaked in week 4, reflecting the initial accumulation of training. From week 5, the chronic workload stabilized, indicating adaptation, while the acute workload fluctuated, showing changes in session duration and frequency during tapering. In sprinters, optimal performance is often achieved with an ACWR of 0.8-1.3 (Cabre et al., 2021), which is linked to lower injury risk. Most sprinters recorded their fastest times at lower ACWR values (Saylor, 2019). In contrast, cricket bowlers with an ACWR above 1.09 face a higher injury risk (Warren et al., 2018). These findings suggest that individualized load management is crucial across sports to minimize injury risk and optimize performance (Warren et al., 2018).

Research Contribution

The research contributes to understanding internal and external training loads in throwing athletes by quantifying physical work during training sessions using metrics like total work and average work, alongside session-Rating of Perceived Exertion (s-RPE). The study highlights significant correlations between session duration, workload, and physiological exertion, emphasizing the utility of these metrics in monitoring and managing training loads. Additionally, the investigation into workload variations over a 9-week preparatory phase, including tapering effects, provides valuable insights for optimizing training regimens and performance outcomes. The findings support the use of workload monitoring in enhancing athletic performance while minimizing injury risk, offering practical implications for training load management in throwing disciplines.

Limitations

The researchers only observed the implemented linear periodization followed by athletes. During this phase, athletes were observed during the competitive phase, where training tapering had started. Additionally, all athletes were from a single region. Moreover, using subjective measures such as sRPE in a questionnaire suggests that the results are speculative and that the researcher relied solely on the accuracy of the athlete's integrity to report accurate results. Previous studies evaluating sRPE and ACWR are limited in throwing events, making comparisons difficult. No data was collected on prior injuries, age, perceived muscle soreness, fatigue, mood, sleep quality, and psychological stressors, which are limitations of the current study.

Suggestions

Many studies have used different acute chronic ratios and categories, including workload ratio classifications and boundaries. Future studies should include a bigger sample size and data collection over a longer timeframe by collecting heart rates and performing work from multiple sessions rather than one session.

CONCLUSION

The current study's findings have indicated significant, meaningful relationships between internal and external load measures in throwing discipline athletes. Specifically, relationships were reported between calculated average work, s-RPE, session duration, and average heart rate. These relationships indicate that monitoring the duration of training sessions will be of value for coaches and athletes. More throws allow the coach and athlete to focus on technical aspects. As a result, the number of throws and mass of implement may be changed during sessions, ultimately increasing the athlete's work. As seen in the results, HR will decrease, and s-RPE will increase with the duration of sessions increasing. As such, coaches and athletes should focus on the duration of training sessions with various implementation weights in order to achieve peak performance. It will benefit coaches to monitor both RPE of athletes' training sessions to determine how athletes experience their training session, but calculating work for a session done will determine the actual load placed on the athlete's body during their throwing session. It is recommended that future studies include work in longitudinal studies to assess its effectiveness as a monitoring tool. Additionally, monitoring seasonal work and workload could be incorporated into ACWR calculations to monitor injury risk.

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AUTHOR CONTRIBUTION STATEMENT

JH was responsible for conceptualizing and designing the study, collecting data, and drafting the manuscript. AG contributed to the data analysis, interpretation of the results, and critical revision of the manuscript. CS also contributed to interpreting the results and revising the manuscript.

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