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Systematic Review

Measurement of Training and Competition Loads in Elite Rhythmic Gymnastics: A Systematic Literature Review

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Abstract: In the long-term performance development of rhythmic gymnasts aged 16–17, athletes enter a high-performance training phase, marked by increased training loads and preparation for international competitions. This study aimed to (1) provide an overview of methods used to capture external and internal training/competition loads in elite rhythmic gymnasts, and (2) identify measurements of external and internal training/competition loads and their responses during monitored periods. Conducted according to PRISMA guidelines, the systematic review included 6 studies out of the 815 initially identified. The most common methods for calculating external training load were hours or minutes per week. Internal measures varied and included objective methods such as heart rate monitoring and biochemical, hormonal, and hematological assessments from saliva and blood samples. Among subjective methods, session-RPE was most frequently used, along with other questionnaires examining recovery, well-being, sleep, and competition anxiety. The analyzed studies integrated diverse external and internal training load variables, delving into their impact on athlete's biochemical parameters, recovery, and well-being. Pre-competitive and competitive training periods were the focal points of measuring loads. The complex training structure of rhythmic gymnastics can complicate the calculation of training loads. Therefore, more studies are needed to explore the dose-response relationships between training load and training adaptations, fatigue, and recovery.

Keywords: high performance; female athletes; external load; internal load

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1. Introduction

Sports training is a deliberately organized and systematically conducted process designed to achieve specific exercise adaptation, encompassing morphological, physiological, biochemical, and psychological changes [1]. In a well-structured training regimen that follows the principle of progressively increasing the training load over time, aligned with the specific training period, the athlete's body undergoes adaptive mechanisms. These mechanisms involve cycles of super-compensation resulting from phases of training stimulation and fatigue, coupled with optimal recovery [2]. A thorough understanding of the relationship between training and performance, along with the continuous monitoring of training loads, is essential for an effective training process [3].

To induce and sustain adaptive changes and enhance performance capacity, taking peaking strategies into account, training must be meticulously planned and executed within a specific time frame. Traditionally, the training structure is organized into cycles of varying duration and training units, including macrocycles (multi-year, annual, semi-annual), mesocycles (several weeks), and microcycles (7–10 days). A macrocycle typically comprises three periods, each consisting of specialized mesocycles: the preparatory period, the competitive period, and the transition period, and is characterized by an initial emphasis on high training volume and a conversion to higher training intensity at a reduced volume as competition periods begin [2,4]. This classical model is modified based on the sports discipline, level of competition, and individual athlete conditions. For instance, in rhythmic gymnastics features eight distinct training periods, including three competitive periods [5]. The main alternative models offer reverse periodization featuring low volume high intensity training in preparatory period, and increase of volume with intensity maintained in competition period [6], and the block periodized model including training cycles of highly concentrated specialized workloads [7]. Athletes competing in multiple events throughout the year benefit from developing several performance peaks during the season and the number of competitions per season depends on the adopted competition strategy [8].

Scientists have described the concept of training load by categorizing it into external and internal components [9]. External load refers to quantifying the work performed by an athlete as outlined in the training plan, encompassing volume (training/competition time), frequency (sessions or competitions per day/week/month) and intensity (training mode) [9]. Internal load, on the other hand, pertains to the individual athlete's psychophysiological response. This response can be measured subjectively using tools like the rating of perceived exertion (RPE), session RPE (s-RPE), wellness questionnaires, and psychological inventories, or objectively through metrics such as heart-rate indices, oxygen uptake, blood lactate, biochemical/hematological assessments during exercise or training sessions [9]. The choice of method for measuring training loads depends on the specific sports discipline and the type of effort involved (strength, speed, endurance) [10]. In aesthetic sports like gymnastics or acrobatics, physical preparation determines the quality of technical elements judged, thus the number of elements of a given difficulty and type, or the time spent performing them in intensity zones related to energy sources, will influence the calculation of training load [10,11]. Combining internal and external load measures provides valuable insights into how an athlete copes with tasks included in the training plan [12,13]. Effective management and monitoring of loads are essential to assess the athletes' adaptation to acute and chronic training outcomes and optimize performance [14,15]. Researchers have noted variations in the number of scientific studies on the monitoring of training loads across different sports disciplines [16], and the use of different tools depending on the type of sport highlights the need for further exploration to determine practical methods for evaluating training effects [17].

Rhythmic gymnastics is an Olympic discipline featuring individual or group exercises that last between 1.15 to 1.30 min and 2.15 to 2.30 min, respectively. Elite gymnasts' routines are a masterful blend of asymmetrical movements involving body difficulties like jumps/leaps, balances, rotations/turns/pivots, dance steps, dynamic elements with rotation, pre-acrobatic elements, body waves, and apparatus technical difficulties [18]. Success in rhythmic gymnastics is attributed to various factors: selected anthropometric features (45%), flexibility (12.1%), explosive strength (9.2%), aerobic capacity (7.4%), body dimensions (6.8%), and anaerobic abilities (4.6%) in elite and non-elite gymnasts. Notably, aerobic capacity components are identified as the most important predictor of an elite rhythmic gymnast's performance score [19]. Furthermore, Olympic-level rhythmic gymnasts exhibit higher training volumes at all stages of sports development compared to those at the international level [20]. The above-mentioned components are included in the training sessions, which during the basic preparatory period comprise 65% light intensity and 35% moderate to very vigorous intensity exercises, corresponding to routine parts performed during this period [21]. As competitions approach, the number of repetitions per part of the routines and entire training routines increases [22]. Additionally, training loads during competitive periods should be individualized based on the varying psychophysiological tolerance of the loads and age of the athletes [23]. Regarding methods of measuring training loads, Antualpa et al. [24] found that an acute:chronic workload ratio (ACWR) of 1.2–1.4 is a safe approach to periodized training loads in youth rhythmic gymnasts. Douda et al. [25] suggested using the RPE to measure exercise intensity in highly trained rhythmic gymnasts. Heart rate and blood lactate concentrations are used to determine training adaptation in juniors [26–28].

During long-term performance development, rhythmic gymnasts aged 16–17 enter the high-performance training stage, characterized by a systematic increase in all load factors to meet the demands of the World Championships program or Olympic cycle [29]. Thus, the training of rhythmic gymnasts aged 16 and older is of particular interest in this review. A comparative analysis of the Continental Championship results during the 2017–2020 Olympic cycle revealed significant differences in performance scores across five continents, highlighting the need to clarify the determinants of success in this sports discipline [30].

From the perspective of rhythmic gymnastics coaches, "planning the training process" and "control over the training process and the state of gymnast's body" are among the most important professional activities for achieving success in this complex discipline [31]. However, Debien et al. [32] found that perception was the most commonly used strategy to monitor load among rhythmic gymnastics coaches, and valid tools for monitoring training loads were rare, which could limit the effective management of training loads in this discipline. Thus, the purpose of this systematic literature review was to (1) provide an overview of methods used to capture external and internal training/competition loads in elite rhythmic gymnasts, and (2) identify measurements of external and internal training/competition loads and their responses during monitored periods.

2. Materials and Methods

2.1. Study Design

The present review adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) criteria, which are recognized standards for selecting collecting, reading, and analyzing studies. Additionally, guidelines specific to systematic reviews in the field of sports sciences were followed [33,34].

2.2. Search Strategy

Up to March 2024, a comprehensive search was conducted across four scientific databases: MEDLINE, SportDiscus with full text, Academic Search Ultimate, and EBSCOhost. The search strategy involved combining terms such as "rhythmic gymnasts" or "rhythmic gymnastics" with terms like "training", "competition", "monitoring", "external load", "internal load", "workload", "volume", "intensity", "performance", "fitness", "fatigue", "recovery", "well-being", and "injury", using Boolean operators like 'AND' and 'OR.' Additionally, the search was complemented by manually examining the reference lists of retrieved studies [35]. Finally, Google Scholar or ResearchGate was utilized to locate full-text publications.

2.3. Inclusion Criteria

The present review included original full-text research studies, written in English and published in peer-reviewed academic journals prior to March 2024. These studies involved elite rhythmic gymnasts, operating at a high-performance competitive level, specifying the training period and measurement of training/competition load, in a cross-sectional, longitudinal or interventional designs. They also entailed statistical analysis elucidating the correlation between training/competition load and training response indicators (as reported subjectively by athletes or measured by health professionals), or differences in training load variables (dose-response) across training periods. Load is defined as "the sport and non-sport burden (single or multiple physiological, psychological, or mechanical stressors) as a stimulus that is applied to a human biological system (including subcellular elements, a single cell, tissues, one or multiple organ systems, or the individual). The load can be applied to the individual human biological system over varying time periods (seconds, minutes, hours to days, weeks, months, and years) and with varying magnitude (i.e., duration, frequency, and intensity)" [9].

2.4. Exclusion Criteria

Articles were excluded from the initial search (screened based on title and abstract) if the sample did not include elite rhythmic gymnasts; if article was not related to training/competition load measurements. Unpublished articles, conference papers, studies from meeting proceedings, dissertations, PhD thesis, case studies, and reviews were also excluded. Following this, from the remaining articles the full texts were analyzed, and articles were excluded if: participants were under the age of 16; reported only descriptive data of training load without studying its effects or training period was not given; did not report any indicators of external or internal load measured in accordance with the classification of the International Olympic Committee [9].

2.5. Data Extraction

Information extracted from the included full-text papers encompassed sample size and characteristics (age, height, weight, experience, competition level, and nationality), details on the competition program, monitoring period, and study duration, methods of measuring external and internal load, as well as the principal findings concerning the association between training/competition load and their outcomes (p-values, effect sizes). The extracted data was organized into tables, followed by a narrative synthesis of the results.

2.6. Assessment of Study Quality

The methodological quality of the articles underwent assessment using a modified version of the Downs and Black checklist [36], a tool recognized for evaluating methodological reporting quality across various study designs, widely utilized in sports science reviews [37,38]. Twelve items from the original scale were adapted to suit this review, encompassing reporting, external validity, internal validity (bias), and statistical power. Each item received a score of 1 (yes) or 0 (no or unable to determine), with a maximum score of 12, as previously employed [39]. Evaluation of each study was conducted by a single reviewer (K.S.-P.), with consultation from a second reviewer (T.P.-I.) if clarification was required for any article. The score achieved by each study was then converted into a 'Study Quality Percentage' by dividing by 12 and multiplying by 100. Study quality percentages were categorized as high (66.7% or higher), fair (between 50.0% and 66.6%), and low (<50.0%) [40].

3. Results

3.1. Literature Search Procedure

The outcomes of the systematic literature search are depicted in Figure 1's flowchart. Initially, 815 documents were identified. After the removal of duplicates, 634 records remained for title and abstract screening. A total of 620 records were removed based on initial screening criteria and 14 full-text articles were assessed for eligibility. Subsequently, eight full-texts that didn't meet the inclusion criteria were excluded. Ultimately, six pertinent studies were incorporated into this systematic review.

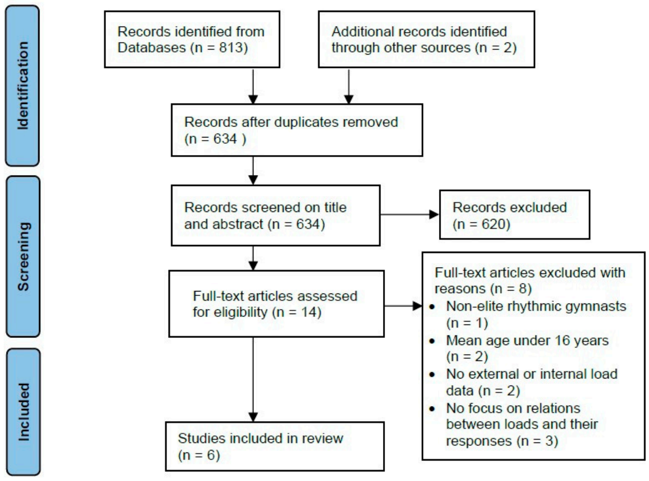

Figure 1. Flow diagram of the literature search procedure [33].

3.2. Critical Appraisal of Sources of Evidence and Risk of Bias

Each of the six included studies underwent quality assessment using the modified Downs and Black checklist [36], with the results detailed in Table 1. Notably, all six studies exhibited a low risk of bias. No articles were excluded due to issues with the quality of research reporting. Additionally, three studies calculated the effect size [41–43].

Table 1. Modified Downs and Black checklist for study quality assessment of the included studies (N = 6).

Included Studies	Criteria													
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	Total Score	Study Quality
Roupas et al. (2012) [44]	1	1	0	1	1	1	0	0	1	1	1	0	8	high
Silva & Paiva (2016) [45]	1	1	0	1	1	1	0	1	1	1	1	0	9	high
Debien et al. (2019) [46]	1	1	1	1	1	0	0	0	1	1	1	0	8	high
Debien et al. (2020) [41]	1	1	1	1	1	0	0	0	1	1	1	1	9	high
Fernandes et al. (2022) [22]	1	1	1	0	1	1	0	0	1	1	1	1	9	high
de Jesus Silva et al. (2022) [43]	1	1	1	1	1	1	0	0	1	1	1	1	10	high

Scoring: 'yes' = 1, 'no' = 0, 'unable to determine' = 0; Criteria: 1. Is the hypothesis/aim/objective of the study clearly described? 2. Are the main outcomes to be measured clearly described in the Introduction or Methods section? 3. Are the characteristics of the participants included in the study clearly described? 4. Are the main findings of the study clearly described? 5. Does the study provide estimates of the random variability in the data for the main outcomes? 6. Have actual probability values been reported (e.g., 0.035 rather than <0.05) for the main outcomes except where the probability value is less than 0.001? 7. Were the subjects asked to participate in the study representative of the entire population from which they were recruited? 8. Were those subjects who were prepared to participate representative of the entire population from which they were recruited? 9. If any of the results of the study were based on "data dredging", was this made clear? 10. Were the statistical tests used to assess the main outcomes appropriate? 11. Were the main outcome measures used accurate (valid and reliable)? 12. Did the study have sufficient power to detect a clinically important effect where the probability value for a difference being due to chance is less than 5%?

3.3. Characteristics of Studies

In this systematic review, a total of 153 senior elite female rhythmic gymnasts were included (Table 2). Examination of the athletes' countries of origin revealed that two studies featured samples of various nationalities [44,45], while four studies included Brazilians [41–43,46]. Among the six studies, five focused on training load outcomes, predominantly investigating group exercises, with one study addressing both individual and group exercises [45]. One study [44] focused on competition load outcomes. However, in two studies, the type of competitive routine was not explicitly stated [44,45]. Due to limited information provided in the Methods sections, additional source materials were consulted. Upon comparison of the number of study samples and competition participants, it was determined that both individual and group exercise representatives were included in these two studies [47,48].

Table 2. Study and participant characteristics.

Reference (Year of Publication) Study Design	Sample Size	Nationality	Age (Years)	Height (cm)	Weight (kg)	Experience (Years)	Modality
Roupas et al. (2012) [44] Pre- and post- intervention with CG	RGs = 51 CG = 27	Eight European countries	16.96 ± 2.67 18.33 ± 3.33	165.84 ± 6.09 162.67 ± 5.76	49.26 ± 6.13 53.71 ± 7.72	9.16 ± 3.6 -	Individual and Group
Silva & Paiva (2016) [45] Cross sectional intervention	RGs = 67 GYM1 = 33 GYM2 = 34	North America, South America, Europe, Asia, Oceania	18.7 ± 2.7 19.7 ± 3.1 17.8 ± 2.2	- 166.0 ± 1 167.0 ± 1	- 47.6 ± 4.8 49.1 ± 5.0	11.5 ± 3.2 12.4 ± 3.2 16.7 ± 3.0	Individual and Group
Debien et al. (2019) [46] Prospective single cohort study	RGs = 8	Brazilian	20 ± 2.5	165.0 ± 4	53 ± 3.93	14.3 ± 2.4	Group
Debien et al. (2020) [41] Prospective single cohort study	RGs = 8	Brazilian	20.5 ± 2.5	165.0 ± 4	53.38 ± 3.93	14.3 ± 2.4	Group
Fernandes et al. (2022) [42] Prospective single cohort study	RGs = 10 Starters = 5 Reserves = 5	Brazilian	- 17.8 ± 0.8 17.4 ± 0.5	- 160.0 ± 1 160.0 ± 5	- 49.6 ± 3.4 50.6 ± 2.9	9.9 ± 2.4 - -	Group
de Jesus Silva et al. (2022) [43] Cross sectional intervention (pre- and post-assessment without CG)	RGs = 9	Brazilian	17.7 ± 1.1	165 ± 5	49.7 ± 4.2	9.44 ± 2.8	Group

Legend: RGs—rhythmic gymnasts, CG—control group, GYM1—gymnasts with the highest competition scores, GYM2—gymnasts with the lowest competition scores. Note: All values are presented as Mean ± SD.

3.4. Methods Used to Measure External Training/Competition Loads

Training loads were assessed throughout all training periods, encompassing competitions (Table 3). Across five of the six articles, external load was quantified in terms of hours per week or minutes per week, along with training frequency [42,46]. Moreover, it was measured by the duration of various exercise types (such as ballet, conditioning, technical drills, flexibility exercises, simulated presentations, and competitions) within a week [46], as well as the duration of daily sessions and types of exercises performed [43]. Additionally, one study evaluated the ACWR [41], while another examined the competitive routine executed under competition conditions [44].

3.5. Methods Used to Measure Internal Training/Competition Load

Internal measures of training load encompassed both objective and subjective tools. Objective assessments included biochemical, hormonal, and hematological evaluations utilizing saliva [43,44] and blood samples [43]. Heart rate monitoring was employed [43], and training stimuli were categorized into relative intensity zones based on the effect of time and heart rate [49]. Subjective methods relied on athlete-reported data through questionnaires. The Total Quality Recovery scale (TQR) [50] was utilized in two studies [41,46], while s-RPE [14] was calculated as the product of session duration (minutes) and RPE in four studies [41–43,46]. Strain and monotony calculations were also employed [42,46]. Additionally, a well-being questionnaire [51] was utilized in one study [42], while the Epworth Sleepiness Scale (ESS) [52], Pittsburgh Sleep Quality Index (PSQI) [53], and Sport Competition Anxiety Test Form A (SCAT-A) [54] were utilized in another study [45] (Table 3).

3.6. Training/Competition Load and Biochemical/Hormonal/Hematological Parameters

The investigation into the effects of acute and chronic exercise, as well as negative energy balances, on salivary adiponectin, resistin, and visfatin levels, along with their association and interaction with salivary cortisol and insulin levels, revealed several significant findings. Rhythmic gymnasts undergoing 43 ± 7.79 h per week of training during the competitive period, complemented by data of body mass index and body fat % assessments, exhibited higher adiponectin levels compared to the control group. However, official performance during competition resulted in increased salivary insulin levels and decreased salivary adiponectin and visfatin levels, with no changes observed in salivary resistin levels among the rhythmic gymnasts [44]. During a single day of moderate-intensity training sessions lasting 8.21 h and 59 min, with breaks for meals, rest, and diuresis, undertaken by rhythmic gymnasts in the pre-Olympic intensified training period, significant alterations were observed in various physiological parameters. These included elevations in total leukocytes, lymphocytes, neutrophils, monocytes, platelets, aspartate aminotransferase, lactate dehydrogenase, thyroid-stimulating hormone, and ferric reducing ability of the plasma, as well as significant reductions in red blood cells, hematocrit, hemoglobin, and salivary cortisol. Following 24 h of rest, significant increases were noted in creatine kinase and lactate dehydrogenase levels [43] (Table 3).

3.7. Training Load and Recovery, Well-Being, Sleep, and Competition Anxiety

Two studies delved into internal training loads utilizing s-RPE measurements and recovery assessments. The initial study [46] demonstrated noteworthy variations in daily internal load, weekly internal load, strain, monotony, and recovery throughout preparatory, competitive, and competition periods. A significant negative correlation emerged between daily internal training load and recovery. The subsequent study [41], which scrutinized internal training load and recovery over a 43-week pre-Olympic season divided into eight training periods, unveiled significant fluctuations in weekly internal training loads (four increases and two decreases), s-RPE (two increases and three decreases), Total Weekly Training Duration (three increases and two decreases), TQR score (one increase and one decrease), ACWR (two increases and one decrease) between adjacent periods. Notably, most increases in training load variables were observed during competitive periods. Furthermore, a small to moderate negative correlation between TQR scores and weekly internal training load and s-RPE was identified. Throughout all examined training periods, athletes exhibited poor recovery during 50.9% of the season, with ACWR evident in 18.1% of the season.

One study scrutinized training load, general well-being, monotony, and strain among starters and reserves over 25 weeks, spanning three training periods: a general preparatory period (GPP), a specific preparatory period (SPP), and a pre-competitive period (pre-CP). Results indicated significantly higher internal training load (s-RPE) in SPP and pre-CP, along with higher strain in both periods, among starters compared with reserves. Starters exhibited notably lower monotony values in GPP compared to pre-CP, exhibited notably lower monotony values in SPP compared to pre-CP. However, no significant disparities were found in general muscle soreness, fatigue, sleep quality, stress level, and mood between starters and reserves. Furthermore, training load specific to particular training periods did not differentiate gymnasts' general well-being and its domains [42].

Another study explored factors contributing to high performance, encompassing, among other factors, external load measures like training volume and frequency, and internal load measures such as sleep duration, sleep quality, and pre-competitive anxiety in the competitive period preceding the competition. Various factors including body composition, sleep, pre-competitive anxiety, and dietary intake were assessed before an international competition, following a training regimen of 36 ± 7.6 h per week. Correlations between training load and performance indicated positive associations with the number of daily training hours, weekly training hours, and sleep duration, while negative correlations were observed with ESS, PSQI, and SCAT-A. Regression analysis, incorporating training load, revealed that performance was explained by 73% due to daily training hours, ESS, PSQI, age, energy availability, sleep duration, and protein relative to body size [45] (Table 3).

Table 3. Summary of results from studies investigating external and internal training/competition loads in elite rhythmic gymnasts.

Reference (Year of Publication) N of Participants	Duration/Training Period/ Type of Competition	External Load Measures	Internal Load Measures	Summary of Main Findings
Roupas et al. (2012) [44] RGs = 51 CG = 27	Competitive "Kalamata 2010 Rhythmic Gymnastics World Cup"	Training: 43.68 ± 7.79 h/week Training prior to competition: 45.41 ± 7.88 h/week "Official performance of the tournament"	Biochemical/hormonal assessment	RGs in comparison to CG showed higher adiponectin ($p < 0.05$) and lower visfatin levels. The RGs' acute intensive anaerobic exercise led to increased salivary insuline levels ($p < 0.001$), reduced salivary adiponectin ($p < 0.001$) and visfatin levels ($p < 0.05$). Diurnal variation of salivary cortisol was lost.
Silva & Paiva (2016) [45] N = 67 GYM1 = 33 GYM2 = 34	-/ Competitive Before FIG World Cup and International Tournament in Portugal 2011	Total: 36.6 ± 7.6 h/week GYM1: 40.1 ± 7.7 h/week 6.8 ± 1.2 h/day GYM2: 33.2 ± 5.7 h/week 5.8 ± 1.0 h/day	ESS [52] PSQI [53] SCAT-A [54]	Training hours per week and per day significantly differentiated GYM1 and GYM2 ($p < 0.001$). The mean sleep duration during the week was 8 h 10 min ± 1 h 30 min. 56.7% of gymnasts slept less than eight hours; 67% of gymnasts had mild daytime sleepiness. GYM1 showed significantly lower "daytime sleepiness" than GYM2 ($p = 0.001$) but poorer quality of sleep than GYM2 ($p = 0.038$). Both groups showed moderate levels of precompetitive anxiety but GYM1 demonstrated significantly lower values of SCAT-A than GYM2 ($p = 0.002$). Performance was positively correlated with number of daily training hours (r = 0.680, $p = 0.000$), number of hours of training/week (r = 0.678, $p = 0.000$), sleep duration (r = 0.339, $p = 0.005$) and negatively with ESS (r= −0.454, $p = 0.000$), PSQI (r= −0.242, $p = 0.042$), SCAT-A (r= −0.374, $p = 0.002$). Performance was explained in 73% by daily training hours, ESS, PSQI, sleep duration, and age, energy availability, and protein according to body size (F = 26.519, $p < 0.001$).

Table 3. *Cont.*

Reference (Year of Publication) N of Participants	Duration/Training Period/ Type of Competition	External Load Measures	Internal Load Measures	Summary of Main Findings
Debien et al. (2019) [46] N = 8	Total of 37 weeks	Training weekly *: 6 × 230–250 min and 4 × 210 min in afternoon containing weekly: Ballet: 390 min; Conditioning: 420 min; Technical drills: 1200 min; Flexibility exercises: 100 min	s-RPE [14] daily, weekly TQR scale [50]	CP showed higher mean of daily and weekly internal load and strain, and lower monotony than PP and CW ($p < 0.005$). CW showed the worst recovery and highest monotony scores ($p < 0.005$). Daily ITL negatively correlated with TQR (r = −0.333; 90% CI [−0.374; −0.295]; $p < 0.001$; N = 1678)
	PP: 11 weeks (from 1th to 11th week) CP: 16 weeks (from 12th to 37th week)	Training weekly *: 7 × 90–240 min in the morning and 4 × 200–210 min in the afternoon containing weekly: Ballet: 240 min; Conditioning: 140 min; Technical drills: 1750 min; Flexibility exercises: 20 min; Simulated presentations: 120 min		
	CW: 15th, 22nd, 25th, 29th, 37th	Training weekly *: 6 × 30–170 min in the morning and 3 × 70–140 min in the afternoon containing weekly: Ballet: 100 min; Conditioning: 30 min; Technical drills: 940 min; Competition: 290 min; 7th day: Travel, light warm-up at airports		
Debien et al. (2020) [41]	43 weeks	Total weekly training duration	s-RPE [14] TQR scores [50]	Changes in weekly ITL, s-RPE, Total weekly training duration, TQR score, ACWR were observed across analyzed training periods ($p < 0.05$; ES from 0.12 to 6.31) Weekly ITL and s-RPE were inversely correlated with recovery (N = 328; r = −0.17; 90% CI = −0.26, −0.08; $p = 0.002$; N = 328; r = −0.32; 90% CI = −0.40, −0.23; $p < 0.001$, respectively.)
	BPP (1th–4th week) SPP (5th–9th week)	2255 ± 39 min 2263 ± 207 min 2054 ± 257 min		
	pre-CP (10th–18th week) CP1 (19th–22nd week)Varied period (23rd–27th week) CP2 (28th–30th week) CP3 (31th–40th week) TP (41th–43rd week)	2168 ± 198 min 1183 ± 152 min 1583 ± 68 min 1718 ± 164 min 1801 ± 136 min ACWR		

Table 3. *Cont.*

Reference (Year of Publication) N of Participants	Duration/Training Period/ Type of Competition	External Load Measures	Internal Load Measures	Summary of Main Findings
Fernandes et al. (2022) [42] N = 10 Starters = 5 Reserves = 5	Duration of 25 weeks for 2020 OG GPP: 7 weeks SPP: 12 weeks pre-CP: 5 weeks	225 training sessions with average of 9 ± 1.7 session per week lasted between 4–5 h each with weekly duration of 2014 ± 450 min	s-RPE [14] Well-being questionnaire [51] **	The starters displayed significantly higher ITL in SPP than reserves (p = 0.03; ES= −1.60; Δ%= −22.4) and pre-CP (p = 0.02; ES= −1.71; Δ%= −33.9) and higher values of strain in SPP and pre-CP (p = 0.04; ES= −1.52; Δ%= −23.3 and p = 0.05; ES= −1.45; Δ%= −29.1). For starters the value of monotony was lower in GPP than pre-CP (p = 0.04; ES = 2.21; Δ% = 14.1) and for reserves in SPP compared to pre-CP (p = 0.04; ES = 1.76, Δ% = 20.9). Starters obtained lower values of s-RPE in GPP compared to SPP ($p < 0.05$; ES = 2.43, Δ% = 26.3) and pre-CP (p = 0.01; ES = 1.91; Δ% = 47.4). No significant intra/inter groups differences of general well-being and its' domains were observed in analyzed periods ($p > 0.05$) and classified as normal.
de Jesus Silva et al. (2022) [43]	Pre-Olympics intensified training period	A day with two separate training sessions of 8 h 21 min (and 59 min of intervals for meals, rest and diuresis), consisted of warm-up, low intensity Jogging: 5 min; ballet (bar, center, and floor): 59 min; flexibility exercises (trunk and lower limbs): 15 min; resistance training exercises, such as squats, sit-ups, and trunk elevations: 46 min; technical-driven training exercises (body difficulties and repetitions of isolated elements, dance steps, risks, exchanges, and collaborations: 38 min, practicing routine parts, with and without music: 5 h 38 min.	s-RPE [14] HR Biochemical/ hormonal/ hematological assessment	The average HR remained 129 ± 11.3 bpm (64% maximum HR), average s-RPE was 3.2 ± 0.4, both corresponded with moderate-intensity training. The day of training induced elevation of total leukocytes (p = 0.001, ES = 4.5), lymphocytes (p = 0.003, ES = 2.0), neutrophils (p = 0.001, ES = 4.0), monocytes (p = 0.006, ES = 1.5), platelets (p = 0.009, ES = 0.3), aspartate aminotransferase (p = 0.007, ES = 1.2), lactate dehydrogenase ($p < 0.05$), thyroid-stimulating hormone (p = 0.008, ES = 9.5), ferric reducing ability of plasma (p = 0.001, ES = 1.3), and reduction of red blood cells (p = 0.001, ES = 1.0), hematocrit (p = 0.001, ES = 1.3), hemoglobin (p = 0.001, ES = 0.5), salivary cortisol (p = 0.001, ES = 2.8); after 24 h rest increase in creatine kinase (p = 0.001) and lactate dehydrogenase (p = 0.001)

Legend: N—number of study participants, RG—rhythmic gymnastics, RGs—rhythmic gymnasts, CG—control group, FIG—Fédération International de Gymnastique, h/week—hours per week, h/day—hours per day, GYM1—gymnasts with the highest competition scores, GYM2—gymnasts with the lowest competition scores, ESS—Epworth Sleepiness Scale, PSQI—Pittsburgh Sleep Quality Index, SCAT-A—Sport Competition Anxiety Test form A, s-RPE—session Rating of Perceived Exertion, TQR—Total Quality Recovery, ACWR—Acute-to-Chronic Workload Ratio, OG—Olympic Games, PP—preparatory period, BPP—basic preparatory period, GPP—general preparatory period, SPP—specific preparatory period CP—competitive period, pre-CP—precompetitive period, TP—transitional period, CW—competition weeks, ITL—Internal Training Load, r—correlation coefficient, CI—confidence interval, p—significance, ES—effect size, HR—heart rate. * Summation of external load made by the authors of the present study; ** The original study was not cited. Authors carried out the same procedure as used in Antualpa et al. [55].

4. Discussion

The aim of this systematic review was to consolidate the methodologies employed in measuring external and internal training/competition loads among elite rhythmic gymnasts, along with identifying the corresponding measurements and their responses during monitoring periods. As far as our knowledge extends, this review represents the inaugural attempt at systematically assessing the techniques utilized for gauging training loads in high-performance rhythmic gymnasts. The review's findings underscore a scarcity of research evaluating the efficacy of tools for monitoring external and internal training loads among elite rhythmic gymnasts during the high-performance training phase. The included studies utilized various measurements of external and internal training/competition loads to examine biochemical/hormonal/hematological parameters, recovery, well-being, sleep, and competition anxiety.

The scientific papers reviewed in this study exhibited a range of study design, including three interventional [43–45] and three prospective single cohort studies [41,42,46]. Samples comprised both individual and group rhythmic gymnasts, with participant numbers ranging from 8 to 67. The number of training periods assessed varied from one to eight, with all studies focusing on pre-competitive or competitive periods.

The most prevalent method for calculating external training load, reported in five [41,42,44–46] of the six papers, was hours per week or minutes per week, consistent with common practice in rhythmic gymnastics [56,57]. However, some papers lacked detailed information on exercise volume without specifying intensity and training characteristics. Notably, two studies [44,46], encompassing one day of two training sessions, and 37 weeks, respectively, provided detailed training characteristics, including exercise modalities and duration and the second of the mentioned studies [46] showed differentiation of modality and duration of exercises across analyzed training periods. Only one study measured the ACWR using rolling averages to compare current training load:acute load in relation to longer-term training load:chronic load [58] across a 43-week pre-Olympic Season [41]. This analysis revealed substantial increases during two competition periods and a moderate decrease during transitional period, with an average value of 1.09 ± 0.52 across seasons, reaching its peak during 34th week (training period: Competitive 3, ACWR = 2.69 ± 0.25). A value of ACWR ≥ 1.5 is considered one of the factors related to the risk of injury [59] and occurred 55 times during the pre-Olympic Season in the elite group of gymnasts. Other external training load measurements included the execution of competitive routines under competition conditions ("Kalamata 2010 Rhythmic Gymnastics World Cup"), as observed in one study [44] assessing short-term intensive anaerobic exercise, judged based on difficulty and execution quality [60]. Studies examining elite rhythmic gymnasts during competition regarding load are scarce, yet they offer insights into athletes' responses to intense training demands throughout the season and how they manage competition pressures [61].

Reviewed literature presented the results of both "objective" and "subjective" methods applied to measure internal training load with dominance observed in the frequency of use of subjective methods (1/6 studies and 4/6 studies, respectively; one study [43] used methods from both categories).

Among the objective methods employed for internal training load measurements, two studies utilized biochemical/hormonal/hematological assessments. Saliva samples were collected to examine the chronic and acute effects of exercise on salivary adiponectin, resistin, and visfatin levels, along with their association and interaction with salivary cortisol and insulin levels. In elite rhythmic gymnasts, it was observed that salivary adiponectin increased while salivary visfatin decreased after an intensive pre-competitive training period and negative energy balance. Conversely, after acute intensive anaerobic exercise (competitive performance), both salivary adiponectin and visfatin levels were suppressed [44]. The innovative methodology for measuring resistin, visfatin, and adiponectin levels from saliva has been previously reported [62]. In the broader context of negative energy balance and patterns of eating disorders observed among rhythmic gymnasts striving to maintain a thin body shape, combined with intense training and competition efforts, there may be potential health risks in the long term [63]. Therefore, monitoring training loads and controlling daily food intake during the annual training season are crucial responsibilities for coaches in aesthetic sports [64].

Another study collected blood samples from an elite group of rhythmic gymnasts during a pre-Olympics intensified training period to demonstrate the effects of typical training day on various biochemical and hematological parameters. Two moderate-intensity training sessions (duration of 8 h and 21 min) induced acute effects such as hemolysis, leucocytosis, muscle damage, perturbations in redox status, and inadequate fluid replacement, indicating potential health and performance risks for gymnasts. Significant decreases in salivary cortisol (stress marker) concentration were noted after two training sessions, likely influenced by the long training duration and circadian cycle [43,65]. In the same study, heart rate (HR) indices were also used to assess exercise intensity, with a mean HR of 129 ± 11.3 bpm (64.0% of the maximum HR) corresponding to the moderate intensity zone according to the American College of Sports Medicine intensity level category scale [49]. This widely used training control classification is based on the percent of the maximum HR and divided into five intensity zones ranging from "very light" to "near–maximal to maximal". The use of wireless devices facilitated the monitoring of HR during exercises [43,49]. The analysis of training loads among regional-level individual gymnasts during 10 training sessions in competitive periods demonstrated the average HR as an important indicator to control training intensity [66]. It was found to positively impact competitive performance score ($p < 0.01$) along with the number of competitive performance routine repetitions during training sessions ($p < 0.05$), providing valuable insights for rhythmic gymnasts regarding training intensity [67].

Subjective methods for measuring internal loads are sensitive to changes in well-being influenced by training stimuli and are recommended by researchers for implementation in training load monitoring [68]. Among these methods, the most frequently utilized was s-RPE [41–43,46], which evaluates the subjectively perceived intensity of training sessions by athletes, ranging from 0 (rest) to 10 (maximal) in response to the question "How was your workout?" [14]. This method has been previously validated in ballet, an integral part of rhythmic gymnastics training [69], as well as in several sports, confirming its validity, reliability, internal consistency, and ecological usefulness [70]. s-RPE was employed in an elite group of rhythmic gymnasts to monitor and compare the weekly profile of internal training loads across preparatory, competitive, and competition periods [46], across eight training periods including basic and specific preparatory, pre-competitive, competitive 1, varied, competitive 2 and 3, and transitional periods [41], to assess internal training load weekly among starters and reserves across general preparatory, specific preparatory, and pre-competitive periods [42], and to gauge the intensity of exercises during a day with two separate training sessions, resulting in a moderate mean s-RPE of 3.2 ± 0.4 [43]. In studies utilizing s-RPE [42,46], monotony as the ratio between weekly internal training loads and their standard deviation, and strain as the product of weekly internal training load and monotony, were calculated and compared across training periods to ascertain the effect of external load on these variables in rhythmic gymnasts. Additionally, differences between starters and reserves were identified. Fernandes-Villarino et al. [67] discovered a significant effect of s-RPE on performance scores in regional-level individual rhythmic gymnasts during competitive training periods, suggesting the utility of this tool for controlling internal training load in rhythmic gymnasts.

The TQR Scale, which assesses recovery based on responses to the question "How do you feel about your recovery?" on a scale ranging from 6 to 20 points, was administered daily before the commencement of the first training session [41,46], with the value of $\geq$13 (reasonable recovery) indicated a minimally adequate recovery state [50] to monitor recovery across training and competition periods and to examine associations between internal training loads (s-RPE) and recovery in an elite group of rhythmic gymnasts. Accumulated and prolonged fatigue can precipitate overreach, overtraining, and decreased performance; hence, appropriate recovery time, encompassing both active and passive recovery strategies, should be integrated between exercises and sessions. It is imperative to systematically collect information about the recovery state and interpret it in an individualized manner [71,72].

The Hooper Index, a well-being questionnaire comprising four separately assessed parameters: fatigue, stress level, muscle pain (DOMS), and quality of sleep, rated on a scale from 1 (“very, very low”) to 7 (“very, very high”), has been widely utilized to evaluate the well-being [51,73] of elite athletes [74–76]. Adapted versions of the Hooper index [77] have been employed by Fernandes et al. [42], with modifications to the parameters, including fatigue, sleep quality, general muscle soreness, stress level, and mood, assessed using a 5-point Likert scale. This adaptation was utilized to monitor general well-being and its domains across general preparatory, specific preparatory, and pre-competitive periods in elite rhythmic gymnasts. Although no significant differences were observed between the analyzed periods, the daily questionnaire revealed notably lower overall well-being scores in rhythmic gymnasts aged over 13 compared to younger age groups (11.2 $\pm$ 0.9 and 10.2 $\pm$ 1.0-year-old groups) during intensified training period followed by tapering. This finding suggests that older gymnasts, closer to puberty, may be more sensitive to environmental changes resulting from training load manipulation, highlighting the utility of this tool as an internal measure to monitor loads in youth categories [55].

The ESS [52], consisting of self-administered responses to eight questions/situations regarding the likelihood of dozing off or falling asleep, rated on a 4-point scale (0–3) with the sum of the 8 items ranging from 0 (zero) to 24 points, and PSQI [53], comprising nineteen items assessing daytime sleepiness, sleep quality, and sleep disturbance over one month, with score range from 0 (zero) to 21 points, were utilized in elite rhythmic gymnasts just before an international competition preceded by intense training [45]. These assessments revealed poor pre-competitive sleep habits among elite rhythmic gymnasts, a finding particularly relevant considering the challenges posed by international competitions, such as long journeys, which can significantly impact sleep duration and quality, and may affect competitive performances [78]. Additionally, the SCAT-A [54], which assesses anxiety through 15 statements with responses categorized as rarely, sometimes, and often, was employed in the same study [45] to evaluate competitive anxiety, an especially pertinent measure for athletes in aesthetic sports like rhythmic gymnastics, who are particularly susceptible to anxiety [79]. Thus, monitoring competitive anxiety is crucial during pre-competitive and competitive periods, as high levels of competitive trait anxiety can detrimentally affect performance, and coping strategies should be incorporated by professional sports psychologists. These questionnaires were combined with external training data, such as the number of training sessions and hours per week, and hours per day, to elucidate performance scores. While nutrient deficiencies and body composition were also examined, their results were not included in this review, as the study [45] did not establish a direct relationship between training load and these parameters, with only relevant findings extracted.

The alternative measurements of training loads could be potentially adopted in rhythmic gymnastics. For example, the countermovement-jump test was recognized as a practical tool suitable to detect neuromuscular fatigue [80] and was widely used in monitoring athletes representing both individual and team sports [81]. Future research should consider the possibility of including this tool in monitoring loads in this sport discipline.

Limitations

This systematic review of literature on external and internal training/competitive load measurements among elite rhythmic gymnasts is subject to several limitations. Primarily, the variation in study designs, load measurement methods, and sample sizes hinders the synthesis and summary of main findings extracted from the included articles. Notably, the majority of analyzed studies focused on Brazilian rhythmic gymnasts, with only two studies involving international samples. Additionally, the inclusion criteria limited the review to English-language papers potentially excluding relevant studies published in other languages that could have contributed to a more comprehensive understanding of the research landscape in this field.

5. Conclusions

The present study marks the systematic overview of methods utilized to assess external and internal indicators of training load among elite rhythmic gymnasts, offering valuable insights into training periodization. The most common approaches for external training load calculation included hours or minutes per week, while internal load measurements showcased considerable diversity. Objective methods encompassed HR measurements and biochemical/hormonal assessments from saliva and blood samples, reflecting responses to training sessions and competitive engagements. Subjective methods, primarily s-RPE, were frequently utilized. Additionally, various questionnaires examined general well-being, recovery, sleep quality, and competitive anxiety. The analyzed studies integrated diverse external and internal training load variables, delving into their impact on athlete's biochemical parameters, recovery, and well-being. Pre-competitive and competitive training periods were the focal points of measuring loads, albeit with variations in the number and duration of training periods assessed across studies. Given the intricate nature of rhythmic gymnastics training, which encompasses technical and aesthetic elements across diverse training modalities, the calculation of training loads may pose challenges. Thus, further researches elucidating dose-response relationships between training load, adaptations, and fatigue and recovery, are needed and warranted.

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