REVIEW ARTICLE

https://doi.org/10.6063/motricidade.30042

The relationship between training load, physical performance and physiological adaptations in Rugby football players: a systematic review

Eduardo Paiva[1], Sérgio Valentim[1], Tiago Reis[1], José Eduardo Teixeira[2,3,4,5], Luís Branquinho[1,2,6], Álvaro Fortunato[7], Pedro Forte[1,4,5,7]*

ABSTRACT

Applying appropriate training loads in accordance with the defined objectives promotes optimal physical and physiological adaptations, reduces the likelihood of illness and injury and, therefore, increases the possibility of success during Rugby. The aim of this review was to compile and systematise the information in the literature on the association between training load variables (internal and external) and performance outcomes in Rugby. As such, the main objective will be to conduct a systematic review of the published literature to identify the physical and physiological performance variables in Rugby sport to monitor the training load. Following the preferred reporting item for systematic reviews and meta-analyses (PRISMA) and PICOS approach, the search was adapted and conducted systematically only in the PubMed database, which, in itself, also restricts the search spectrum of the paper, thus conferring a limitation to the present academic work. The search was conducted in PubMed throughout the possible temporal spectrum since there is still little robustness in the literature about rugby sports performance. Articles were selected by pre-defined selection criteria, including observational, randomised clinical and clinical trial studies. After further screening, and based on the inclusion criteria of the papers, the result of the analysis of the relevance of the studies, the final set of analysis resulted in 16 articles. From the studies compiled in this review, there seems to be a strong correlation between the perceived exertion (RPE) and the prescription and definition of the training load applied in Rugby athletes. The RPE reflects the most used and analysed variable throughout all the studies. Several articles reflect a strong relationship between the training load, the inter-individual capacity of each athlete and their tolerance to the load (player load).

KEYWORDS: team sports; workload; player load; perceived exertion.

INTRODUCTION

Rugby is a high-intensity intermittent sport that requires physical and physiological prowess and force during collisions and hits. Low-intensity runs and rest intervals are typically included between fast runs as a team invasion sport aims to conquer space (Cunniffe, Proctor, Baker, & Davies, 2009; Cunningham et al., 2018; Dubois et al., 2017). The literature has recently focused on understanding how to mimic these physical and physiological aspects of the game in rugby training (Memmert, 2021; Reilly & Gilbourne, 2003).

Rugby players must be able to demonstrate great levels of strength and power in order to succeed in practice (Chavarro-Nieto, Beaven, Gill, & Hébert-Losier, 2023; Cormier, Freitas, & Seaman, 2021). Rugby players are exposed to a wide range of different sorts of training to be able to participate in high-level tournament scenarios (Weaving, Marshall,

[1]Department of Sports, Instituto Superior de Ciências Educativas do Douro – Penafiel, Portugal.
[2]Research Centre in Sports Sciences, Health and Human Development – Vila Real, Portugal.
[3]Department of Sport Sciences, Instituto Politécnico de Guarda – Guarda, Portugal.
[4]Department of Sport Science, Instituto Politécnico de Bragança – Bragança, Portugal.
[5]Sport Physical Activity and Health Research & Inovation Center – Rio Maior, Portugal.
[6]Instituto Superior de Ciências Educativas do Douro – Penafiel, Portugal.
[7] Research Center for Active Living and Wellbeing, Instituto Politécnico de Bragança – Bragança, Portugal.
Corresponding author: Rua Vitorino da Costa, 96 – CEP: 4560-708 – Penafiel, Portugal. E-mail: pedromiguel.forte@iscedouro.pt

Conflict of interest: nothing to declare.
Funding: Instituto Superior de Ciências Educativas do Douro and Fundação Portuguesa para a Ciência e Tecnologia, I.P. (project UIDB04045/2021).
Received: 03/08/2023. Accepted: 07/05/2023.

Earle, Nevill, & Abt, 2014; Weaving, Jones, Marshall, Till, & Abt, 2017). Sports scientists must be able to employ legitimate and trustworthy methods to assess an individual's load during all types of training, though, given the inter-individual diversity in responses to any prescribed training session (Branquinho et al., 2022). This will help to optimise and personalise the training process (Impellizzeri et al., 2022; Weaving et al., 2014). Until now, given the high frequency and variety of collisions and impacts inherent to rugby, there are several limitations that make comprehensive monitoring difficult (Lovell, Sirotic, Impellizzeri, & Coutts, 2013; Williams et al., 2017).

The training load can theoretically be divided into internal (physiological) and external (physical) loads, revealing information on dose-response (Teixeira et al., 2021a; 2022a). The work done during practice or competition, regardless of internal variables, is referred to as the external load (Impellizzeri et al., 2022; Staunton, Abt, Weaving, & Wundersitz, 2021). However, another line of thinking emphasises the necessity of including the frequency, intensity, and duration of activities (for example, sprinting, accelerations, decelerations, and collisions) performed by players during these modes (that is, the external load) in the measurement of physical and physiological demands of training (Teixeira et al., 2021a). External load induces multiple physiological and mechanical responses (Colquhoun, 2014; Impellizzeri et al., 2022; Weaving et al., 2017). The internal training load represents the players' biomechanical, physical, and physiological responses to training or competition stimuli (McLaren et al., 2018). Internal load is typically assessed using perceptual measurements, load models derived from heart rate (HR), or intensity zones measured by HR associated with duration. The internal training load represents the players' biomechanical, physical, and physiological responses to training or competition-related stimuli. The internal load is typically assessed using perceptual measurements, load models derived from HR-based measures, or HR intensity zones associated with duration (Akubat, Patel, Barrett, & Abt, 2012; Stagno, Thatcher, & van Someren, 2007).

Independent of the player's internal characteristics, the load of an external workout represents the physical load that the athlete finds and is frequently measured by factors such as exposure time (total exposure time or elapsed time), speed, distance, volume of movement, or intensity (Campos-Vazquez et al., 2015; Garnica-Caparrós & Memmert, 2021; Memmert, 2021). Aiming to improve player and team performance in competition while lowering the risk of illness, injury, and unfavourable training reactions, training tactics have been introduced in team sports (Bourdon et al., 2017; Teixeira et al., 2021a). Training is timed to coincide with the major contests in order to accomplish these goals (Fox, Stanton, Sargent, Wintour, & Scanlan, 2018). To effectively prescribe and monitor training loads requires understanding and accounting for what are internal and external loads (Reilly & Gilbourne, 2003; Teixeira et al., 2022b). The relationship between internal and external training loads represents the nature of the imposed training stimulus and the resulting player responses (Akubat, Barrett, & Abt, 2014; Scanlan, Fox, Borges, Dascombe, & Dalbo, 2017; Yeomans et al., 2018). So, managing the players' physical capacity and fitness will be possible with the proper prescription and control of the training load (Teixeira et al., 2021a). When properly controlled, it can enhance the physical fitness of rugby players, including their strength, speed, endurance, and agility (Ramirez-Campillo et al., 2023). On the other hand, an excessive or improperly balanced training load might raise the risk of injury if individual characteristics are not considered (Gabbett, 2016). It should also be progressively raised over time to accommodate adaptations and lower the chance of damage.

The scientific community has been increasing the number of studies on rugby players, especially regarding the training load (Killen, Gabbett, & Jenkins, 2010). Upon that, it is important to summarise the variables most used to assess this concept in rugby players. Thus, the aim of this review was to compile and systematise the information in the literature on the association between training load variables (internal and external) and performance outcomes in Rugby. As such, the main objective will be to conduct a systematic review of the published literature to identify the physical and physiological performance variables in Rugby players to monitor the training load.

METHODS

Literature search strategy

An adaptation based on the preferred reporting items for systematic reviews and meta-analyses (PRISMA) guidelines and the population-intervention-comparators-outcomes (PICOS) were used to conduct this systematic review (Ardern et al., 2022; Tricco et al., 2018). The literature search was based on PubMed/Medline with the keywords: "Training Load", "Rugby", "Observational Studies", "Randomized Clinical Trials", and "Clinical Trial Studies". The eligibility criteria were defined in agreement with: (1) *population*: male and female rugby players; (2) *intervention and comparison*: relationship between training load, physical performance and physiological adaptations in Rugby football; (3) study design: experimental and quasi-experimental trials (e.g., randomised controlled trial, cohort studies, or cross-sectional studies). According to the search strategy, studies from January 2000 to March 2023 were included for relevant publications. Based on this, data extraction was organised into: (1) reference; (2) variables and study; (3) study purpose; (4) main conclusions.

Data extraction: training load variables

For a given external load, both the magnitude and type of internal load can vary between players due to differences in individual characteristics that result in multiple physical conditions and fatigue effects and ultimately varying training outcomes (Gabbett, Whyte, Hartwig, Wescombe, & Naughton, 2014; Impellizzeri, Rampinini, Coutts, Sassi, & Marcora, 2004; Teixeira et al., 2021b). Understanding these dose-response relationships is therefore important to balance the promotion of adaptations and minimise negative outcomes, such as injury (Colby, Dawson, Heasman, Rogalski, & Gabbett, 2014). To ensure accurate and appropriate prescribing and training monitoring, it is important that practitioners use valid methods to quantify the internal and external loads placed on players in all training modes. There are numerous measures to quantify training load – internal and external – including heart HR-based methods (Akubat et al., 2014; Weaving et al., 2014), subjective perceived exertion (RPE) (Kelly, Strudwick, Atkinson, Drust, & Gregson, 2016), global positioning systems (GPS) (Colby et al., 2014; Lovell et al., 2013; Weaving et al., 2014), and accelerometers (Gómez-Carmona, Pino-Ortega, Sánchez-Ureña, Ibáñez, & Rojas-Valverde, 2019). Methods that use HR to quantify internal load include the training impulse (TRIMP) and the individualised TRIMP (iTRIMP) (Teixeira et al., 2021a; 2022a). While methods used to determine high-speed distance include and individualise methods with interpolation of 15Hz and 10Hz GPS sampling frequencies (Abt & Lovell, 2009; Aughey, 2011; Delaney, Duthie, Thornton, & Pyne, 2018).

A player load is an arbitrary unit derived from instantaneous three-dimensional measurements of acceleration rates of change (i.e., player load ™: reliability, convergent validity, and influence of unit position during treadmill running - PubMed). Its utility as a marker of training load has been established against criterion measures of both external loads (distances covered) and internal training loads (heart rate, subjective perceived exertion ratings in training environments (Scott, Lockie, Knight, Clark, & Janse de Jonge, 2013; Scott & Lovell, 2018; Teixeira et al., 2021a).

Selection criteria

The papers considered for inclusion in this review met the following criteria: (1) observational studies, randomised clinical trials" and clinical trial studies. The with at least one week of training monitoring; (2) studies with screening procedures based on internal and/or external load measures; (3) studies with training load quantification of gross and temporal demands in complete/full training sessions (with or without match-play load); (4) studies with at least one week of training load monitoring; and (5) studies with screening procedures based on internal and/or external load measures. Article disclosed sample and screening techniques; (6) original paper published in a peer-reviewed publication; (7) complete text available in English; and (8) (e.g., data collection, study design, instruments, and the outcomes).

The papers that were excluded using the following exclusion criteria: (1) Studies that examined training loads for team sports or football codes other than rugby (such as football/soccer, futsal, Australian football or Gaelic football) were excluded; (2) studies that monitored only match-play load; (3) studies that quantified training load based on field-based tests and laboratory tests; (4) studies that included less than a week of monitoring; (7) other research areas and non-human participants; (8) articles with poor quality in the description of study sample and screening procedures (e.g., data collection, study cohort intervention, etc.); The search was limited to original articles published online until March 2023. Duplicated articles were identified and eliminated prior to the application of the selection criteria (inclusion and exclusion). Titles and abstracts were initially selected and excluded according to selection criteria. The selection of full texts was based on a selection to determine the final status: inclusion or exclusion. Disagreements were resolved through discussion between two authors or via a third researcher if required. Secondary-sourced articles considered relevant and with the same screening procedures were added.

RESULTS

Figure 1 illustrates the process of searching, screening, and defining the keywords used to search the scientific papers. The search resulted in a set of 114 articles, of which only 96 articles were selected after the selection criteria application, where, a posteriori, after selecting the search variables "Observational Studies", "Randomized Clinical Trials", and "Clinical Trial Studies", only 19 articles resulted. Three duplicates were eliminated, making the final set of 16 articles.

Table 1 shows the data extraction from articles under analysis, variables under study, objectives and conclusions.

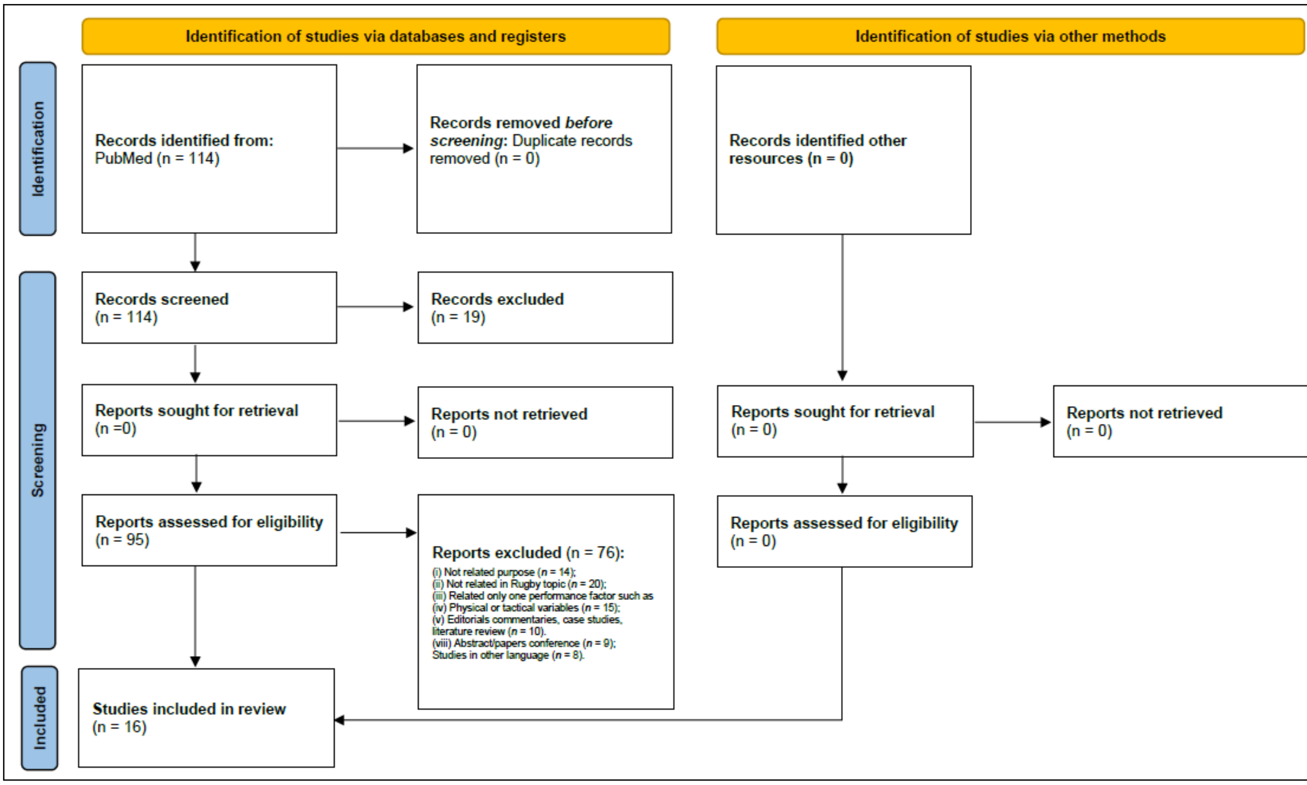

Figure 1. The Preferred Reporting Item for Systematic Reviews and Meta-analyses (PRISMA) flow diagram.

From the studies compiled in this review, there is a strong correlation between the perceived exertion (RPE) for training prescription and planning in Rugby athletes. The RPE showed the variable that has been used and examined the most throughout all the research.

DISCUSSION

The aim of this study was to mine the information in the literature on the association between training load variables (internal and external) and performance outcomes in Rugby players. In summary, the findings of the studies included in this review indicate that monitoring the internal and external loads of training enables an approximation of the ideal training load that may be applied throughout the periodisation of a season or sport phase, primarily through the subjective perception of individual effort and the teams collectively. This work allowed us to identify the prominently used variables to assess rugby players' training load: RPE, HR and GPS metrics.

From all the studies gathered it was found that the most commonly used study variables for determining training load are RPE and HR-based measures (Akubat et al., 2014; Haddad, Stylianides, Djaoui, Dellal, & Chamari, 2017; Weaving et al., 2014). Several studies have already related a strong correlation between HR and RPE during exercise and sports practice (Impellizzeri et al. 2004; 2022). Some studies also contend that the individual correlation between RPE and various distance-derived measures tracked by GPS technology, in addition to the correlation between HR and RPE, establishes parameters for evaluating the relationship between the external training load and the intensity of training sessions, particularly with regard to the distances and intensities at which those distances are travelled (expressed in speed and acceleration) (Colby et al., 2014; Lovell et al., 2013; Weaving et al., 2014). The current results show that both total distance and distance travelled at high speed significantly affect RPE in Rugby training sessions (Abt & Lovell, 2009; Aughey, 2011; Delaney et al., 2018).

It is also relevant to understand how different types of training (fitness, technical and tactical) influence the interpretation of these training load analysis methods (Weaving et al., 2014). Weaving et al. (2017) suggest considering combinations of methods for the different loads, internal and external, in order to obtain more reliable results. However, more studies will be needed to establish a relationship between combinations of methods and types of load (external and

Table 1. Data extraction of the reviewed studies in accordance with relationships between weekly internal and external load.

Reference (Year)	Research purpose	Methodology (Device Specification)	Training Variables	Main Conclusion
Coutts, Reaburn, Piva and Rowsell (2007)	Identify indicators of non-functional excess in Rugby athletes when performing intensive training loads.	Medgraphics® CPX-D Gas Analysis System (Parkway, MN, USA)	External training load, VO_2max, Aerobic speed max, HR_{max}, vertical jump, sprints and body mass.	Positive physical changes in endurance and power performance were observed after the application of intensive training loads.
Grainger, Neville, Ditroilo and Comfort (2020)	Assessing the magnitude of change and association with variation in training load on markers of performance and well-being.	OptoJump optical measuring system (Microgate, Bolzano, Italy)	Counter movement jump, Speed in the horizontal supine, general well-being.	The effect of training load on performance may vary according to the type of stimulus, as may be administered based on tests for both upper and lower body
Hulin et al. (2018)	How changes in direction influence the playerload variables when controlling the total distance traveled. And the relationship of collisions to playerload.	10 Hz GPS (Catapult, Optimeye S5, Melbourne, Australia).	Accelerations, changes of direction, collisions, total distance (meter) and Player load	Large increase in player load when direction changes intensify. The player load variables should be used with caution when collisions are measured.
McLaren, Smith, Spears and Weston (2017)	Investigate different applications of subjective effort perception in team sports.	CR10®, CR100® scale	Variable player load, direction changes intensify. Player load variables should be used with caution when measuring collisions.	Different Subjective Perceptions of Exertion can provide a more detailed quantification of the internal training load.
McLaren et al. (2018)	Comparison of differentiated training loads between fitness and Rugby athletes during an 8-week pre-season.	Optojump Next (Version 1.3.20.0, Microgate, Bolzano, Italy)	RPE	The results support the collection of different types of subjective perceived exertion and the use of individual response.
Parmley, Jones, Sawczuk and Weaving (2022)	Evaluation and analysis of the differences in external training load between micro-cycles and their respective variation between micro-cycles, players, and head coaches.	10 Hz GPS (Catapult S5, Catapult Innovations, Melbourne, Australia)	Total distance (meters), average speed, distance at maximum speed, distance at relative maximum speed, sprint distance, acceleration distances, and relative acceleration distances.	There is variability in the training loads applied, making variation in the variables of maximal speed (total maximal speed time) and sprints most evident.
Scantlebury et al. (2018)	Level of agreement between the coach's intended (pre-session) and observed (post-session) intensity by by the athlete RPE during different intensities.	Optojump Next (Version 1.3.20.0, Microgate, Bolzano, Italy)	CMJ, DWB, PRS	There appears to be little difference between the RPE observed by the coach and that of the athlete over the training load applied in the study.
Scantlebury et al. (2020)	Identification of external load variables and their influence on the internal response. Relationship between intentional and perceived training intensity.	10 Hz GPS (Catapult sprint 5.17, Catapult Innovations, Melbourne, Australia)	RPEs, Distance (meters), Sprints/runs at lower intensity, Sprints/runs at higher intensity, Player load	Analysing perceived exertion, made it impossible to further analyze the internal response to different training loads (light, moderate, intense).
Suarez-Arrones et al. (2016)	Relationship between repeated high-intensity activity and internal training load in Rugby players during international matches, and comparison between the two game halves	10 Hz GPS (SPI Pro X, GPSports Systems, Canberra, Australia)	Distance (meter), speed, HR_{max}	This study provides evidence that a pronounced reduction in high-intensity and high-intensity repetition activities and an increase in internal training load in seven-a-side rugby during the second half of international games.
Weaving et al. (2014)	Effect of training mode on relationships between training load measures in professional Rugby players.	CR10® scale; Polar HR straps (T14, Polar, Oy, Finland); 15-Hz GPS (SPI Pro XII, GPSports, Canberra, Australia)	RPEs, Body load, Sprints, Total impact.	Using only a single measure of internal or external training load may lead to an underestimation of training dose. A combination of internal and external load measurements is needed for greater accuracy.

Continue

Table 1. Continuation.

Reference (Year)	Research purpose	Methodology (Device Specification)	Training Variables	Main Conclusion
Weaving et al. (2017)	Investigate the effect of training types (conditioning and technical training) on training load relationships by analyzing training variables.	CR10® scale; Polar HR straps (T31 coded, Polar, Oy, Finland) 10 Hz GPS device (Optimeye X4, Catapult Inno vations, Scoresby, Victoria)	Heart rate, RPEs, Player load, accelerations, crashes, maximum speed and distance (meters)	Combination of the measurements of internal and external load variables is necessary for different types of training
Weaving et al. (2018)	Acute SLED with external loading associated with percent body mass of athletes on sprinting performance and athletes' power gains	15 Hz GPS (Optim Eye X4; Catapult Innovations, Melbourne, Australia)	Speed/Power	75% of the athletes' BW in the sled push can be an effective preload stimulus to improve subsequent sprint performance, provided adequate recovery time (8-12 minutes).
Weaving et al. (2018)	Understanding which and how many training variables will provide the best information for the subjective perception of effort when applying the training load.	CR10® scale; Polar heart rate straps (T14, Polar, Oy, Finland), 15 Hz (SPI Pro XII, GPSports, Canberra, Australia)	Distance (meters), Player load, RPE	Multiple training variables need to be removed to provide the most valid and accurate representation of the actual training load in professional rugby.
Weaving et al. (2019)	Assessment and identification of training load through the LOVO and PLSCA analysis methodology using GPS and MEMS technologies	GPS, MEMS, LOVO, PLSCA,	sRPE	LOVO PLSCA identified the cumulative distance at high speed (>7 ms-1) as the most important TL variable in influencing the performance of Rugby athletes.
Weaving et al. (2020)	Relative contribution of exercise duration and intensity to athlete training load.	15 Hz devices (SPI HPU GPSports, Canberra, Australia).	RPEs, Total distance (mts), Body load, Sprints, Player load.	The current use of training load measures that aggregate duration and intensity into a single day is unlikely to translate more than the duration of the session reliably.
Weaving et al. (2021)	Relative importance of external training load measurements to relate to musculoskeletal response at the collective and individual level.	GPS, MEMS, LOVO, PLSCA,	Total distance (meters), speed threshold.	Repeated measures have established relative importance of training load measures and investigated their relationship to collective musculoskeletal response. There is however, a lack of inf. regarding musculoskeletal responses.

CMJ: Counter-movement jumps; COD: Change of direction; CR-10: Borg category-ratio 10 scale; DWB: daily well-being questionnaire; HR: Heart rate; HR_{max}: maximum heart rate; PRS: perceived recovery status scale; RPE: Rating of perceived exertion; SLED: sled boosting effects; sRPE: session rating of perceived exertion.

internal) for different types of training. As well as to compare these combinations with the use of only one method (Teixeira et al., 2022b; Weaving et al., 2014).

The limitations of using only one method are also mentioned by Hulin, Gabbett, Johnston, and Jenkins (2018) regarding the quantification of training load through "*playerload" because no variable related to this method really* accurately quantifies the load generated by the shock between players. We would probably have to resort to a combination of methods to bridge the load quantification of these shocks (Teixeira et al., 2022b; Weaving et al., 2014). As mentioned, more studies on the effectiveness and optimisation of these combinations will be necessary, according to the specificity of Rugby (Colby et al., 2014; Cunniffe et al., 2009). Studies suggest that there are significant intra-individual correlations between the PSE method and other internal and external variables related to training load and intensity and that the crossing of these "*training load*" variables allows a more reliable validation of the RPE (Colby et al., 2014; Lovell et al., 2013; Weaving et al., 2014).

Since RPE represents the athlete's own perception of training *stress*, which may include both physical and psychological *stress*, the session RPE method can provide a valuable tool for analysing and diagnosing the internal training load (Teixeira et al. 2022a; 2022c). The RPE-based method for quantifying internal training load is simple and practical, however, to be used most reliably, it is necessary to follow correct standardised procedures and foster player education and instruction as well as familiarisation with the perceived exertion scales (Gabbett et al., 2014; Impellizzeri et al., 2004; Teixeira et al., 2021b). The RPE method, when crossed with HR monitoring and when both energy systems, anaerobic and aerobic, are activated significantly, as in Rugby, the method's dependability greatly increases (Reilly & Gilbourne, 2003; Weaving et al., 2017).

The quantification of the training load can be fundamental to analyse the periodisation of training during the training week to ensure that adequate physiological stimulus is provided, allowing adequate time for recovery before competition days (Graham & Greenham, 2018). In summary, based on the analysis of the studies analysed in this review, the RPE-based method seems to be a good indicator and the most reliable and easily applicable auxiliary variable in the sport context, particularly in team sports, and thus becomes a specific periodisation strategy for teams, and a way to analyse and monitor the overall internal training load in Rugby (Campos-Vazquez, Toscano-Bendala, Mora-Ferrera, & Suarez-Arrones, 2017; Weaving et al., 2017). However, meta-analyses lack information about the effective relationship between training variables and the training load applied in Rugby athletes (Colby et al., 2014). Thus, it can be seen that there is not yet a robust scientific literature that relates to and studies the variability of stimuli and physical and physiological adaptations in Rugby athletes (Duthie, Pyne, & Hooper, 2003; Weaving et al., 2014).

Future studies should detail, in a more concrete way, the acute adaptations in Rugby athletes as a result of certain different training loads and different contexts, as well as to understand patterns of player load for different levels of Rugby competition as a minimum performance and its evolution within the different competitive phases and throughout the training periods and the elite/senior period (Scantlebury, Till, Sawczuk, Weakley, & Jones, 2018). It is also important to try to relate the player load *to* other variables, such as collisions, injuries or injury risk reduction, and to create guidelines for these relationships in order to help standardise and monitor training load application strategies for Rugby athletes (Caparrós et al., 2016; Gómez-Carmona, Bastida-Castillo, González-Custodio, Olcina, & Pino-Ortega, 2020). Coaches, players, and analysts may be able to properly select variables that may better quantify the training load in rugby players. Based on this information, it will be possible for practitioners to measure and control, especially intensity and volume.

CONCLUSION

Following the results presented in the studies compiled in this review, there seems to be a strong correlation between the subjective RPE and the prescription and definition of the training load applied in Rugby athletes. The RPE reflects the variable most applied and analysed throughout all the studies. Several articles reflect that there is a strong relationship between *training load* and each athlete's inter-individual capacity and tolerability to load (*player* load).

REFERENCES

Abt, G., & Lovell, R. (2009). The Use of Individualized Speed and Intensity Thresholds for Determining the Distance Run at High-Intensity in Professional Soccer. *Journal of Sports Sciences*, *27*(9), 893-898. https://doi.org/10.1080/02640410902998239

Akubat, I., Barrett, S., & Abt, G. (2014). Integrating the Internal and External Training Loads in Soccer. *International Journal of Sports Physiology and Performance*, *9*(3), 457-462. https://doi.org/10.1123/ijspp.2012-0347

Akubat, I., Patel, E., Barrett, S., & Abt, G. (2012). Methods of Monitoring the Training and Match Load and Their Relationship to Changes in Fitness in Professional Youth Soccer Players. *Journal of Sports Sciences*, *30*(14), 1473-1480. https://doi.org/10.1080/02640414.2012.712711

Ardern, C. L., Büttner, F., Andrade, R., Weir, A., Ashe, M. C., Holden, S., Impellizzeri, F. M., Delahunt, E., Dijkstra, H. P., Mathieson, S., Rathleff, M. S., Reurink, G., Sherrington, C., Stamatakis, E., Vicenzino, B., Whittaker, J. L., Wright, A. A., Clarke, M., Moher, D., Page, M. J., Khan, K. M., & Winters, M. (2022). Implementing the 27 PRISMA 2020 Statement Items for Systematic Reviews in the Sport and Exercise Medicine, Musculoskeletal Rehabilitation and Sports Science Fields: The PERSiST (Implementing Prisma in Exercise, Rehabilitation, Sport Medicine and SporTs Science) Guidance. *British Journal of Sports Medicine*, *56*(4), 175-195. https://doi.org/10.1136/bjsports-2021-103987

Aughey, R. J. (2011). Applications of GPS Technologies to Field Sports. *International Journal of Sports Physiology and Performance*, *6*(3), 295-310. https://doi.org/10.1123/ijspp.6.3.295

Bourdon, P. C., Cardinale, M., Murray, A., Gastin, P., Kellmann, M., Varley, M. C., Gabbett, T. J., Coutts, A. J., Burgess, D. J., Gregson, W., & Cable, N. T. (2017). Monitoring Athlete Training Loads: Consensus Statement. *International Journal of Sports Physiology and Performance*, 12(Suppl. 2), S2161-S2170. https://doi.org/10.1123/IJSPP.2017-0208

Branquinho, L., Ferraz, R., Teixeira, J., Neiva, H., Sortwell, A., Forte, P., Marinho, D., & Marques, M. (2022). Effects of a Plyometric Training Program in Sub-Elite Futsal Players During Pre-Season Period. *International Journal of Kinesiology and Sports Science*, *10*(2), 42-50. https://doi.org/10.7575/aiac.ijkss.v.10n.2p.42

Campos-Vazquez, M. A., Mendez-Villanueva, A., Gonzalez-Jurado, J. A., León-Prados, J. A., Santalla, A., & Suarez-Arrones, L. (2015). Relationships between Rating-of-Perceived-Exertion- and Heart-Rate-Derived Internal Training Load in Professional Soccer Players: A Comparison of on-Field Integrated Training Sessions. *International Journal of Sports Physiology and Performance*, *10*(5), 587-592. https://doi.org/10.1123/ijspp.2014-0294

Campos-Vazquez, M. A., Toscano-Bendala, F. J., Mora-Ferrera, J. C., & Suarez-Arrones, L. J. (2017). Relationship Between Internal Load Indicators and Changes on Intermittent Performance After the Preseason in Professional Soccer Players. *Journal of Strength and Conditioning Research*, *31*(6), 1477-1485. https://doi.org/10.1519/JSC.0000000000001613

Caparrós, T., Alentorn-Geli, E., Myer, G. D., Capdevila, L., Samuelsson, K., Hamilton, B., & Rodas, G. (2016). The Relationship of Practice Exposure and Injury Rate on Game Performance and Season Success in Professional Male Basketball. *Journal of Sports Science & Medicine*, *15*(3), 397-402.

Chavarro-Nieto, C., Beaven, M., Gill, N., & Hébert-Losier, K. (2023). Hamstrings Injury Incidence, Risk Factors, and Prevention in Rugby Union Players: A Systematic Review. *The Physician and Sportsmedicine*, *51*(1), 1-19. https://doi.org/10.1080/00913847.2021.1992601

Colby, M. J., Dawson, B., Heasman, J., Rogalski, B., & Gabbett, T. J. (2014). Accelerometer and GPS-Derived Running Loads and Injury Risk in Elite Australian Footballers. *Journal of Strength & Conditioning Research*, *28*(8), 2244-2252. https://doi.org/10.1519/JSC.0000000000000362

Colquhoun, D. (2014). An Investigation of the False Discovery Rate and the Misinterpretation of P-Values. *Royal Society Open Science*, *1*(3), 140216. https://doi.org/10.1098/rsos.140216

Cormier, P., Freitas, T. T., & Seaman, K. (2021). A Systematic Review of Resistance Training Methodologies for the Development of Lower Body Concentric Mean Power, Peak Power, and Mean Propulsive Power in Team-Sport Athletes. *Sports Biomechanics*, 1-34. https://doi.org/10.1080/14763141.2021.1948601

Cunniffe, B., Proctor, W., Baker, J. S., & Davies, B. (2009). An Evaluation of the Physiological Demands of Elite Rugby Union Using Global Positioning System Tracking Software. *Journal of Strength & Conditioning Research*, *23*(4), 1195-1203. https://doi.org/10.1519/JSC.0b013e3181a3928b

Cunningham, D. J., Shearer, D. A., Carter, N., Drawer, S., Pollard, B., Bennett, M., Eager, R., Cook, C. J., Farrell, J., Russell, M., & Kilduff, L. P. (2018). Assessing Worst Case Scenarios in Movement Demands Derived from Global Positioning Systems during International Rugby Union Matches: Rolling Averages versus Fixed Length Epochs. *PLOS One*, *13*(4), e0195197. https://doi.org/10.1371/journal.pone.0195197

Coutts, A. J., Reaburn, P., Piva, T. J., & Rowsell, G. J. (2007). Monitoring for overreaching in rugby league players. *European Journal of Applied Physiology*, *99*(3), 313-324. https://doi.org/10.1007/s00421-006-0345-z

Delaney, J. A., Duthie, G. M., Thornton, H. R., & Pyne, D. B. (2018). Quantifying the Relationship between Internal and External Work in Team Sports: Development of a Novel Training Efficiency Index. *Science and Medicine in Football*, *2*(2), 149-156. https://doi.org/10.1080/24733938.2018.1432885

Dubois, R., Paillard, T., Lyons, M., McGrath, D., Maurelli, O., & Prioux, J. (2017). Running and Metabolic Demands of Elite Rugby Union Assessed Using Traditional, Metabolic Power, and Heart Rate Monitoring Methods. *Journal of Sports Science & Medicine*, *16*(1), 84-92.

Duthie, G., Pyne, D., & Hooper, S. (2003). Applied Physiology and Game Analysis of Rugby Union. *Sports Medicine*, *33*(13), 973-991. https://doi.org/10.2165/00007256-200333130-00003

Fox, J. L., Stanton, R., Sargent, C., Wintour, S.-A., & Scanlan, A. T. (2018). The Association between Training Load and Performance in Team Sports: A Systematic Review. *Sports Medicine*, *48*(12), 2743-2774. https://doi.org/10.1007/s40279-018-0982-5

Gabbett, T. J. (2016). The Training—Injury Prevention Paradox: Should Athletes Be Training Smarter and Harder? *British Journal of Sports Medicine*, *50*(5), 273-280. https://doi.org/10.1136/bjsports-2015-095788

Gabbett, T. J., Whyte, D. G., Hartwig, T. M., Wescombe, H., & Naughton, G. A. (2014). The Relationship between Workloads, Physical Performance, Injury and Illness in Adolescent Male Football Players. *Sports Medicine*, *44*(7), 989-1003. https://doi.org/10.1007/s40279-014-0179-5

Garnica-Caparrós, M., & Memmert, D. (2021). Understanding Gender Differences in Professional European Football through Machine Learning Interpretability and Match Actions Data. *Scientific Reports*, *11*(1), 10805. https://doi.org/10.1038/s41598-021-90264-w

Gómez-Carmona, C. D., Bastida-Castillo, A., González-Custodio, A., Olcina, G., & Pino-Ortega, J. (2020). Using an Inertial Device (WIMU PRO) to Quantify Neuromuscular Load in Running: Reliability, Convergent Validity, and Influence of Type of Surface and Device Location. *Journal of Strength & Conditioning Research*, *34*(2), 365-373. https://doi.org/10.1519/JSC.0000000000003106

Gómez-Carmona, C. D., Pino-Ortega, J., Sánchez-Ureña, B., Ibáñez, S. J, & Rojas-Valverde, D. (2019). Accelerometry-Based External Load Indicators in Sport: Too Many Options, Same Practical Outcome? *International Journal of Environmental Research and Public Health*, *16*(24), 5101. https://doi.org/10.3390/ijerph16245101

Graham, S. R., & Greenham, G. (2018). Physiological Basis for Training and Monitoring the Training Response. In K. Norton & R. Eston (Eds.). *Kinanthropometry and Exercise Physiology*. Routledge.

Grainger, A., Neville, R., Ditroilo, M., & Comfort, P. (2020). Changes in performance markers and wellbeing in elite senior professional rugby union players during a pre-season period: Analysis of the differences across training phases. *Journal of Science and Medicine in Sport*, *23*(1), 20-26. https://doi.org/10.1016/j.jsams.2019.08.012

Haddad, M., Stylianides, G., Djaoui, L., Dellal, A., & Chamari, K. (2017). Session-RPE Method for Training Load Monitoring: Validity, Ecological Usefulness, and Influencing Factors. *Frontiers in Neuroscience*, *11*, 612. https://doi.org/10.3389/fnins.2017.00612

Hulin, B. T., Gabbett, T. J., Johnston, R. D., & Jenkins, D. G. (2018). PlayerLoad Variables: Sensitive to Changes in Direction and Not Related to Collision Workloads in Rugby League Match Play. *International Journal of Sports Physiology and Performance*, *13*(9), 1136-1142. https://doi.org/10.1123/ijspp.2017-0557

Impellizzeri, F. M., Jeffries, A. C., Weisman, A., Coutts, A. J., McCall, A., McLaren, S. J., & Kalkhoven, J. (2022). The "Training Load" Construct: Why It Is Appropriate and Scientific. *Journal of Science and Medicine in Sport*, *25*(5), 445-448. https://doi.org/10.1016/j.jsams.2021.10.013

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

Kelly, D. M., Strudwick, A. J., Atkinson, G., Drust, B., & Gregson, W. (2016). The Within-Participant Correlation between Perception of Effort and Heart Rate-Based Estimations of Training Load in Elite Soccer Players. *Journal of Sports Sciences*, *34*(14), 1328-1332. https://doi.org/10.1080/02640414.2016.1142669

Killen, N. M., Gabbett, T. J., & Jenkins, D. G. (2010). Training Loads and Incidence of Injury During the Preseason in Professional Rugby League Players. *Journal of Strength & Conditioning Research*, *24*(8), 2079-2084. https://doi.org/10.1519/JSC.0b013e3181ddafff

Lovell, T. W. J., Sirotic, A. C., Impellizzeri, F. M., & Coutts, A. J. (2013). Factors Affecting Perception of Effort (Session Rating of Perceived

Exertion) during Rugby League Training. *International Journal of Sports Physiology and Performance*, *8*(1), 62-69. https://doi.org/10.1123/ijspp.8.1.62

McLaren, S. J., Macpherson, T. W., Coutts, A. J., Hurst, C., Spears, I. R., & Weston, M. (2018). The Relationships Between Internal and External Measures of Training Load and Intensity in Team Sports: A Meta-Analysis. *Sports Medicine*, *48*(3), 641-658. https://doi.org/10.1007/s40279-017-0830-z

McLaren, S. J., Smith, A., Spears, I. R., & Weston, M. (2017). A detailed quantification of differential ratings of perceived exertion during team-sport training. *Journal of Science and Medicine in Sport*, *20*(3), 290-295. https://doi.org/10.1016/j.jsams.2016.06.011

Memmert, D. (2021). *Match Analysis: How to Use Data in Professional Sport*. Routledge.

Parmley, J., Jones, B., Sawczuk, T., & Weaving, D. (2022). A four-season study quantifying the weekly external training loads during different between match microcycle lengths in professional rugby league. *PLoS One*, *17*(1), e0263093. https://doi.org/10.1371/journal.pone.0263093

Ramirez-Campillo, R., Thapa, R. K., Afonso, J., Perez-Castilla, A., Bishop, C., Byrne, P. J., & Granacher, U. (2023). Effects of Plyometric Jump Training on the Reactive Strength Index in Healthy Individuals Across the Lifespan: A Systematic Review with Meta-Analysis. *Sports Medicine*, *53*(5), 1029-1053. https://doi.org/10.1007/s40279-023-01825-0

Reilly, T., & Gilbourne, D. (2003). Science and Football: A Review of Applied Research in the Football Codes. *Journal of Sports Sciences*, *21*(9), 693-705. https://doi.org/10.1080/0264041031000102105

Scanlan, A. T., Fox, J. L., Borges, N. R., Dascombe, B. J., & Dalbo, V. J. (2017). Cumulative Training Dose's Effects on Interrelationships Between Common Training-Load Models During Basketball Activity. *International Journal of Sports Physiology and Performance*, *12*(2), 168-174. https://doi.org/10.1123/ijspp.2015-0708

Scantlebury, S., Till, K., Beggs, C., Dalton-Barron, N., Weaving, D., Sawczuk, T., & Jones, B. (2020). Achieving a desired training intensity through the prescription of external training load variables in youth sport: More pieces to the puzzle required. *Journal of Sports Sciences*, *38*(10), 1124-1131. https://doi.org/10.1080/02640414.2020.1743047

Scantlebury, S., Till, K., Sawczuk, T., Weakley, J., & Jones, B. (2018). Understanding the Relationship Between Coach and Athlete Perceptions of Training Intensity in Youth Sport. *Journal of Strength and Conditioning Research*, *32*(11), 3239-3245. https://doi.org/10.1519/JSC.0000000000002204

Scott, B. R., Lockie, R. G., Knight, T. J., Clark, A. C., & Janse de Jonge, X. A. K. (2013). A Comparison of Methods to Quantify the In-Season Training Load of Professional Soccer Players. *International Journal of Sports Physiology and Performance*, *8*(2), 195-202. https://doi.org/10.1123/ijspp.8.2.195

Scott, D., & Lovell, R. (2018). Individualisation of Speed Thresholds Does Not Enhance the Dose-Response Determination in Football Training. *Journal of Sports Sciences*, *36*(13), 1523-1532. https://doi.org/10.1080/02640414.2017.1398894

Stagno, K. M., Thatcher, R., & van Someren, K. A. (2007). A Modified TRIMP to Quantify the In-Season Training Load of Team Sport Players. *Journal of Sports Sciences*, *25*(6), 629-634. https://doi.org/10.1080/02640410600811817

Staunton, C. A., Abt, G., Weaving, D., & Wundersitz, D. W. T. (2021). Misuse of the Term "Load" in Sport and Exercise Science. *Journal of Science and Medicine in Sport*, *25*(5), 439-444. https://doi.org/10.1016/j.jsams.2021.08.013

Suarez-Arrones, L., Núñez, J., Villareal, E. S. de, Gálvez, J., Suarez-Sanchez, G., & Munguía-Izquierdo, D. (2016). Repeated-High-Intensity-Running Activity and Internal Training Load of Elite Rugby Sevens Players During International Matches: A Comparison Between Halves. *International Journal of Sports Physiology and Performance*, *11*(4), 495-499. https://doi.org/10.1123/ijspp.2014-0523

Teixeira, J. E., Alves, A. R., Ferraz, R., Forte, P., Leal, M., Ribeiro, J., Silva, A. J., Barbosa, T. M., & Monteiro, A. M. (2022a). Effects of Chronological Age, Relative Age, and Maturation Status on Accumulated Training Load and Perceived Exertion in Young Sub-Elite Football Players. *Frontiers in Physiology*, 13, 832202.

Teixeira, J. E., Forte, P., Ferraz, R., Branquinho, L., Silva, A. J., Monteiro, A. M., & Barbosa, T. M. (2022b). Integrating Physical and Tactical Factors in Football Using Positional Data: A Systematic Review. *Peer Journal*, *10*, e14381. https://doi.org/10.7717/peerj.14381

Teixeira, J. E., Forte, P., Ferraz, R., Leal, M., Ribeiro, J., Silva, A. J., Barbosa, T. M., & Monteiro, A. M. (2021a). Monitoring Accumulated Training and Match Load in Football: A Systematic Review. *International Journal of Environmental Research and Public Health*, *18*(8), 3906. https://doi.org/10.3390/ijerph18083906

Teixeira, J. E., Forte, P., Ferraz, R., Leal, M., Ribeiro, J., Silva, A. J., Barbosa, T. M., & Monteiro, A. M. (2021b). Quantifying Sub-Elite Youth Football Weekly Training Load and Recovery Variation. *Applied Sciences*, *11*(11), 4871. https://doi.org/10.3390/app11114871

Teixeira, J. E., Forte, P., Ferraz, R., Leal, M., Ribeiro, J., Silva, A., Barbosa, T., & Monteiro, A. (2022c). The Association between External Training Load, Perceived Exertion and Total Quality Recovery in Sub-Elite Youth Football. *The Open Sports Sciences Journal*, *15*. https://doi.org/10.2174/1875399X-v15-e2207220

Tricco, A. C., Lillie, E., Zarin, W., O'Brien, K. K., Colquhoun, H., Levac, D., Moher, D., Peters, M. D. J., Horsley, T., Weeks, L., Hempel, S., Akl, E. A., Chang, C., McGowan, J., Stewart, L., Hartling, L., Aldcroft, A., Wilson, M. G., Garritty, C., Lewin, S., Godfrey, C. M., Macdonald, M. T., Langlois, E. V., Soares-Weiser, K., Moriarty, J., Clifford, T., Tunçalp, Ö., & Straus, S. E. (2018). PRISMA Extension for Scoping Reviews (PRISMA-ScR): Checklist and Explanation. *Annals of Internal Medicine*, *169*(7), 467-473. https://doi.org/10.7326/M18-0850

Weaving, D., Dalton-Barron, N., Hickmans, J. A., Beggs, C., Jones, B., & Scott, T. J. (2021). Latent variable dose–response modelling of external training load measures and musculoskeletal responses in elite rugby league players. *Journal of Sports Sciences*, *39*(21), 2418-2426. https://doi.org/10.1080/02640414.2021.1936406

Weaving, D., Dalton-Barron, N., McLaren, S., Scantlebury, S., Cummins, C., Roe, G., Jones, B., Beggs, C., & Abt, G. (2020). The relative contribution of training intensity and duration to daily measures of training load in professional rugby league and union. *Journal of Sports Sciences*, *38*(14), 1674-1681. https://doi.org/10.1080/02640414.2020.1754725

Weaving, D., Dalton, N. E., Black, C., Darrall-Jones, J., Phibbs, P. J., Gray, M., Jones, B., & Roe, G. A. B. (2018). The Same Story or a Unique Novel? Within- Participant Principal-Component Analysis of Measures of Training Load in Professional Rugby Union Skills Training. *International Journal of Sports Physiology and Performance*, *13*(9), 1175-1181. https://doi.org/10.1123/ijspp.2017-0565

Weaving, D., Jones, B., Marshall, P., Till, K., & Abt, G. (2017). Multiple Measures Are Needed to Quantify Training Loads in Professional Rugby League. *International Journal of Sports Medicine*, *38*(10), 735-740. https://doi.org/10.1055/s-0043-114007

Weaving, D., Marshall, P., Earle, K., Nevill, A., & Abt, G. (2014). Combining Internal- and External-Training-Load Measures in Professional Rugby League. *International Journal of Sports Physiology and Performance*, *9*(6), 905-912. https://doi.org/10.1123/ijspp.2013-0444

Weaving, D., Sawczuk, T., Williams, S., Scott, T., Till, K., Beggs, C., Johnston, R. D., & Jones, B. (2019). The peak duration-specific locomotor demands and concurrent collision frequencies of European Super League rugby. *Journal of Sports Sciences*, *37*(3), 322-330.

Williams, S., Trewartha, G., Kemp, S. P. T., Brooks, J. H. M., Fuller, C. W., Taylor, A. E., Cross, M. J., Shaddick, G., & Stokes, K. A. (2017). How Much Rugby Is Too Much? A Seven-Season Prospective Cohort Study of Match Exposure and Injury Risk in Professional Rugby Union Players. *Sports Medicine*, 47(11), 2395-2402. https://doi.org/10.1007/s40279-017-0721-3

Yeomans, C., Comyns, T. M., Cahalan, R., Warrington, G. D., Harrison, A. J., Hayes, K., Lyons, M., Campbell, M. J., & Kenny, I. C. (2018). Current Injury Monitoring and Player Education Practices in Irish Amateur Rugby Union. *Physical Therapy in Sport: Official Journal of the Association of Chartered Physiotherapists in Sports Medicine*, *33*, 27-32. https://doi.org/10.1016/j.ptsp.2018.06.008