

Research article

Internal and External Load Control in Team Sports through a Multivariable Model

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Abstract

Data related to 141 sessions of 10 semi-professional basketball players were analyzed during the competitive period of the 2018-2019 season using a multivariable model to determine possible associations between internal and external load variables and fatigue. Age, height, weight, sessional rate of perceived exertion (sRPE), summated-heart-rate-zones, heart rate variability, total accelerations and decelerations were the covariates, and post-session countermovement jump loss (10% or higher) the response variable. Based on the results observed, a rise in sRPE and accelerations and decelerations could be associated with increased lower-body neuromuscular fatigue. Observing neuromuscular fatigue was 1,008 times higher with each additional sRPE arbitrary unit (AU). Each additional high-intensity effort also increased the probability of significant levels of neuromuscular fatigue by 1,005 times. Fatigue arising from demanding sporting activities is acknowledged as a relevant inciting event leading to injuries. Thus, the methodology used in this study can be used then to monitor neuromuscular fatigue onset, also enhancing proper individual adaptations to training.

Key words: Monitoring, muscle fatigue, countermovement jump, performance, basketball.

Introduction

Basketball is an intermittent sport with short, intense actions typically less than three seconds, with longer periods of moderate activity and recovery (Ben Abdelkrim et al., 2007). Cardiovascular demand is high, highlighting its aerobic nature and anaerobic glycolysis (Delextrat and Cohen, 2008) as the primary energy pathways, with an average maximum heart rate of 89% during competition (Ziv and Lidor, 2009). In this context, knowing the fatigue response to training is essential to maximize the player's adaptation while minimizing the risk of injury and avoiding any overload. Monitoring enables short-term, typically of metabolic origin, and longer-term neuromuscular fatigue to be defined (Wu et al., 2019). Metabolic fatigue is a decreased ability to generate muscle exertion in response to physical exercise that has exceeded the ATP replacement rate. Its effects begin to diminish after five minutes, and it is generally believed to wear off after three hours (Layzer, 1990). Contrarily, neuromuscular fatigue is defined as a prolonged decrease in the muscle's ability to generate force or power output after a period of recovery. Neuromuscular

fatigue can be present for more than 48 hours and can be identified as a complex system with central and peripheral origins (Overton, 2013). This fatigue appears when a player's ability to produce force or power deteriorates (Collins et al., 2018). The use of vertical jump performance as a neuromuscular fatigue monitoring tool is widespread in high-performance sports (Edwards et al., 2018) and, more specifically, the countermovement jump (CMJ) (Komi, 2000). Evaluating CMJ performance has become popular when researching players' recovery processes after regular and congested competition periods. Monitoring this activity/recovery relationship provides an indicator of the session volume and intensity to reduce physical wear in the player and the risk of injury resulting from insufficient neuromuscular control (Spiteri et al., 2013). Methodologically, some articles have used average jump values, although it has been observed that selecting the highest values provides better results (Gorostiaga et al., 2010; Gathercole et al., 2015a; 2015b; Johnston et al., 2016). The CMJ without arm swing seems to be the standard movement when tracking neuromuscular status (Malone et al., 2015). Relationships between longitudinally monitored training load, fatigue variables, and injuries have also been described (Jones et al., 2017), highlighting the assessment of maximum jump height as a variable associated with fatigue in the literature (Claudino et al., 2017).

The possibility of having a scientifically-based fatigue control method to individualize the load prescription, using a variable that expresses deterioration in performance and its relationship with the physiological response could help make decisions in the training process (Jiménez-Reyes et al., 2019). The use of a simple and fatigue-free test, such as the CMJ, enables training sessions to be monitored without the need to measure blood lactate or ammonia concentrations and would be more accurate than recording training times (Gathercole et al., 2015a; Thorpe et al., 2017). Near-perfect relationships were observed between blood lactate and ammonia concentrations and CMJ height loss (Morcillo et al., 2015). This data would enable accurate evaluation of the neuromuscular fatigue induced during a session (Sánchez-Medina and González-Badillo, 2011). An 8-10% loss of jump height corresponds to approximately 8-10 mmol·l⁻¹ and 70-80 μmol·l⁻¹ of lactate and ammonia in the blood, respectively, representing the onset of metabolic instability (Jimenez-

Reyes et al., 2016).

Therefore, a loss greater than 10% in CMJ could be a valuable and robust indirect measure of the mechanical and metabolic changes induced during a training session and enable decisions to be made about that player (Jiménez-Reyes et al., 2019).

The training load has been described as the variable that, when correctly managed, helps to obtain the desired training response (Impellizzeri et al., 2019; Piedra et al., 2021). Its control aims to optimize this process, facilitating decision-making by coaching staff and reducing injury risk factors (Sánchez Ballesta et al., 2019). Training load encompasses internal load (IL) as well as external load (EL). In indoor sports such as basketball, quantifying the EL implies the collection of variables such as the exposure time (ET), the distance traveled, and accelerometry variables (high-speed running, accelerations (ACC) and decelerations (DEC)) during training or competition (Soligard et al., 2016).

The individualized physiological response of each athlete to this EC is defined as internal load (IL) and is usually expressed in variables such as heart rate (HR), rate of perceived exertion (RPE), lactate, or oxygen consumption (Soligard et al., 2016; Impellizzeri, Marcora and Coutts, 2019). The IQ values can provide information about how the athlete adapts to the training process and how they carry out their recovery processes (Gabbett and Whiteley, 2017). In order to assess the internal load holistically and ecologically, current literature has prolifically studied the use of RPE (Lupo et al., 2017; Conte et al., 2018; Fox et al., 2018; Moreno-Pérez et al., 2019) and the "Sessional rating of perceived exertion" sRPE (Marcelino et al., 2013; Nunes et al., 2014; Vaquera et al., 2018) as indicators of the internal training load in different sports. The sRPE is obtained by multiplying the overall RPE obtained at the end of a training session, using the Borg scale (Borg-CR10) by the total duration (in minutes) of the training session, to provide a training value expressed in arbitrary units (AU) (Foster et al., 2001). The RPE is a fast, economical, and ecological method. It can be instrumental and practical for the coaching staff to supervise and control the internal load to design frequency strategies in basketball (Piedra et al., 2020) and any other sport (Sansone et al., 2018), providing a better understanding of internal load individually in training sessions and competitions (Moreira et al., 2012). This tool can apply regardless of the duration of the session and the sections of the training session (Lupo et al., 2017).

Another IQ parameter used in basketball is the "summated-heart-rate-zones" (SHRZ) (Edwards, 1994; Soligard et al., 2016). This metric is based on the time each player is in HR intensity zones. These are predefined according to five HR zones determined from the maximum heart rate. A multiplier accompanies each HR zone that gives greater weight to higher responses, typical of acyclic sports such as basketball (Scanlan et al., 2014).

Heart rate variability (HRV) is considered an effective tool to monitor adaptation to daily load and training programs (Capdevila et al., 2008; Zamora et al., 2021). From the recording of the electrocardiographic interval between two successive R waves (RR), temporal parameters that define HRV can be obtained: mean of the

RR intervals (RRmean), the standard deviation of the RR intervals (SDNN), mean square root of the RR interval difference (RMSSD), and the difference in the percentage of regular adjacent RR intervals $>50\text{m/s}$ (pNN50) (Moreno Sánchez, Romero and Capdevila Ortís, 2013). These time parameters are associated with a predominance of the parasympathetic system and as a global indicator, among others, of the athlete's psychophysiological fatigue (Schmitt et al., 2015).

In the load control processes, correct handling of the EL becomes very important since it manipulates the variables that affect this type of load, which generates one or another response in the form of internal load in the players (Reina et al., 2017). One of the simplest variables to record, and therefore most used, is the total session time (Svilar et al., 2018a), which can provide quantitative information about the stimulus that players are receiving (Moreira et al., 2012). In competition, recording the exposure time (Caparrós et al., 2018) and knowing the percentage of playing time in relation to the total match time provides information regarding the contribution of each player (Oliveira-Da-Silva et al., 2013). However, the EL registry variables, with the highest presence in the literature, are the number of ACC and DEC (Vazquez-Guerrero et al., 2018), the number of high-intensity ACC ($>2\text{m/s}$), the number of high-intensity DEC ($<-2\text{ m/s}$) (Vazquez-Guerrero et al., 2018), the distance traveled (Caparrós et al., 2018), the number of jumps and changes of direction (Moreira et al., 2012; Nunes et al., 2014; Svilar et al., 2018b).

The purpose of this study is to determine whether a multivariable model can help to control better training loads in a semi-professional men's basketball team, determining associations between IL and EL response variables observed in training situations and the production of more significant local neuromuscular fatigue detected through an objective procedure.

Methods

Subjects

Ten athletes who were members of a semi-professional men's basketball team (EBA League), with a mean age of 26 ± 5 years, a height of 195.8 ± 9.4 cm, and a weight of 91.2 ± 8.7 kg, participated in the study over 15 weeks of the second phase of the competition period (January-April) in the 2018-2019 season. Data were obtained from 141 records of the training sessions. The team participated in three on-court training sessions (technical and tactical drills, small-sided games, 5 vs 5 game-like drills, and simulated competitions), two strength and conditioning sessions, and one game per week. The practices always started at 8:00 p.m. Data collection was gathered daily and jumps tests were carried out every Monday and Wednesday. All research procedures followed the Declaration of Helsinki standards and its subsequent revisions. The data was compiled within the team's daily activity, and the players were informed that they were used for sporting and scientific purposes. Players were assigned an individual identification code to conceal their identity, guaranteeing personal data protection under the EU General Data Protection Regulation (GDPR) (04/14/2016).

Procedures

The data collection process began when the players arrived at the facility, after a standardized team warm-up. All participants underwent a 12-min supervised warm-up procedure including active stretching, running-drills, progressive sprinting and change of direction. The pre-CMJ values (flight time) were collected after this initial physiological activation (Jiménez-Reyes et al., 2019), where they performed three maximum jumps and the best jump record was selected as the initial reference value (Gonzalez-Badillo et al., 2017). During the session, all exertion during training was recorded using the Polar Team Pro software (Boyd et al., 2011) and the training time was controlled (Piedra et al., 2021). HRV variables were also obtained from the session (Zamora et al., 2021). At the end of the session, the CMJ post was carried out, in which the initial process was repeated, selecting the best jump (Claudino et al., 2012). The 10% loss was calculated with the formula: $\text{jump loss (\%)} = 100 * (\text{post-jump} - \text{pre-jump}) / \text{pre-jump}$ (Gonzalez-Badillo et al., 2017). Thirty minutes after the session, the RPE questionnaire was sent to the players with the following question through the messaging application WhatsApp Messenger version 2.19.134 (Facebook Inc, California, USA) (Fox et al., 2020): How much effort was involved in today's training session? 0 implies no effort, and 10 maximum effort, equivalent to not be able to cope with training (Foster, 1998).

The Polar Team Pro technology (Hulka et al., 2013; Sánchez Ballesta et al., 2019; Scanlan et al., 2017; Stojanović et al., 2019) was used to record the internal load (SHRZ), for the heart rate variability variable (RMSSD) and the accelerometry variables (total ACC and DEC). The Chronojump jumping contact platform (Nunes et al., 2014; Vallés-Ortega et al., 2017; Cruz et al., 2018; Moreno-Pérez et al., 2019) was used to perform the jumping tests. This platform has been validated for assessing vertical jumps (De Blas et al., 2012). The RPE questionnaire and the duration annotation were also used in the research (Lupo et al., 2019).

The following variables were analyzed: (a) 10% decrease in the jump after the one before training, using a binary variable (1, a loss greater than 10%; 0, loss lower than 10%), (b) age of the player (years), (c) player's height (m), (d) player's weight (kg), (e) sRPE (AU), (f) SHRZ (AU), (g) RMSSD (ms) and (h) total ACC and DEC of the training (N).

Statistical analysis

A central tendency analysis was performed, and later an inferential analysis using a step-by-step binary logistic regression (Peña et al., 2013) with a loss greater than 10% (neuromuscular fatigue) as the dependent variable (Jiménez-Reyes et al., 2019). Previously, a multicollinearity diagnosis was carried out to find intercorrelations between predictive variables. Once the data included in the model had been reconsidered, avoiding highly intercorrelated variables, different variables were analyzed using a logistic regression technique. To assess the "goodness of fit," the Nagelkerke R² and Mc Fadden R² tests were carried out. Logistic regressions enable models to be tested to predict the results of a binary dependent variable based on

one or more predictor variables using the following formula, where p is probability and is a mathematical constant equal to approximately 2.71828:

$$p = e^z / (1 + e^z) \text{ or } p = 1 / (1 + e^{-z})$$

Z is the linear combination of:

$$Z = B_0 + B_1X_1 + B_2X_2 + \dots + B_pX_p$$

where B is the coefficient estimated by the model and X is the independent variable. The significance level for the variables in the equation was established as $p \leq 0.05$. After the analysis, the statistically significant variables were included in the final logistic regression model. All statistical analyses were performed with the statistical software package JASP for Windows (Version 0.11.1, University of Amsterdam, The Netherlands, 2020).

Results

The mean duration of the workouts was 67.80 ± 10.90 minutes, and the mean RPE of the sessions was 6.90 ± 1.74 . The mean values of sRPE were 472.99 ± 157.15 AU, the mean values of SHRZ were 164.81 ± 65.19 AU, and of RMSSD, 109.51 ± 75.50 ms. An average of 1093.30 ± 253.21 ACC and DEC of any intensity was performed per training session, representing 16.31 ACC and DEC per minute.

The values obtained for the Nagelkerke R-squared test were 0.417 and 0.460 for the Mc Fadden R-squared test. The area under the ROC curve (AUC) presented a value of 0.946, and the precision was located at a value of 1.00, with only four cases mispredicted by the model. Five percent of the cases analyzed showed 10% or higher jump-loss and were coded as "1" in the database.

All records (141) were included in the analysis, with 0 cases excluded. The variables (b) player's age, (c) player's height, (d) player's weight, (f) SHRZ, (g) RMSSD were considered non-significant and were excluded from the final model. Probability ratios indicated that the probability of observing neuromuscular fatigue in the study was 1,008 times greater with each additional arbitrary unit (AU) in the sRPE, and the total number of ACC and DEC increased by 1,005 times the probability of observing higher levels of neuromuscular fatigue with each additional exertion executed by the athletes. Therefore, these two variables (sRPE, ACC and DEC) were included in the model.

The 95% confidence intervals for the probability ratios were adjusted for the variables sRPE and total accelerations and decelerations, indicating that the probability ratios of generating neuromuscular fatigue are correct (Table 1).

With the data described above, the logistic regression could estimate the probability (from 0 to 1) of increasing neuromuscular fatigue in the semi-professional men's basketball team during the 2018-2019 season using the constants and coefficients of the model with the following calculations:

$$Z = \text{CONSTANT} + 0.008 (\text{sRPE}) + 0.004 (\text{total accelerations and decelerations})$$

For example, a player with a sRPE of 1200 AU and a total of 1800 ACC and DEC will have a Z value of 3.579:

$$Z = -13.221 + 0.008(1200) + 0.004(1800) = 3.579$$

The probability that a player will experience neuromuscular fatigue with this Z-value would be 0.9728544085:

$$p = 1 / (1 + e^{-Z})$$

$$e^{-Z} = e^{-3.579} = 0.0279035879$$

$$p = 1 / (1 + 0.0279035879) = 0.9728544085$$

Table 1. Model coefficients for post-session countermovement jump 10% loss (PLOSS 10%), including sRPE and total accelerations and decelerations as covariates.

Parameter	Estimate	Standard Error	Odds Ratio	z	Wald Test			95% Confidence interval (odds ratio scale)	
					Wald Statistic	df	p	Lower bound	Upper bound
(Intercept)	-13.221	3.801	1.811e-6	-3.478	12.098	1	< .001	0.000	0.003
sRPE	0.008	0.004	1.008	1.998	3.993	1	0.046	1.000	1.016
ACC+DEC	0.004	0.002	1.005	1.847	3.412	1	0.065	1.000	1.009

PLOSS 10% level '1' coded as class 1.

Discussion

The present study highlights that some physiological markers are related to the onset of local neuromuscular fatigue in male basketball settings. Our results reflect that each sRPE arbitrary unit (AU) increases the chances of observing neuromuscular fatigue by 1,008 times. And sRPE values from 700 to 1000 AU reduced jumping capacity to a greater extent (Figure 1). Thus, it is expected that designing practices similar to real competitions, and therefore, with 5 vs. 5 and game-like drills, may generate higher load values (Vazquez-Guerrero et al., 2018). In basketball, training demands usually exceed those of competition (Fox, Stanton and Scanlan, 2018). RPE should be recorded then independently of other perceptions related to the same exercise, and therefore special attention should be paid when collecting this data (Pageaux, 2016). Subjective training load measures may reflect mental load, which appears to be a significant moderator of the relationship of training load with performance and injury (Coyne et al., 2018). If RPE is adequately contextualized, it could provide highly relevant individualized information (Piedra et al., 2020).

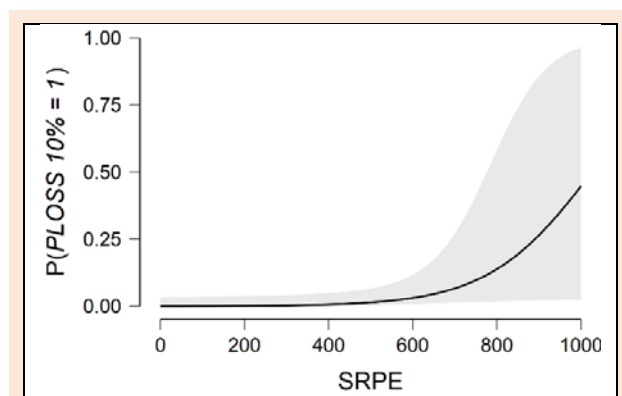


Figure 1. Association between 10% decrease in CMJ and sRPE.

In this study, it has also been observed that if the total number of ACC and DEC increases, Players generate an additional exertion that increases the probability of observing neuromuscular fatigue by 1,005 times. When more than 1000 ACC and DEC were performed per session (Figure 2), each volume increase generated less final jump production and, therefore, more local fatigue. This association can be used to propose individualized training loads, recovery protocols and to tailor better practices. The use of a

multivariable model to identify the appropriate response variables can be helpful to sports scientists and practitioners to control training loads adequately. These statistical models are well-documented and have been used previously in sports. Detecting parameters showing association with a higher level of local neuromuscular fatigue can also help to identify drills with different adaptive responses at an individual and group level.

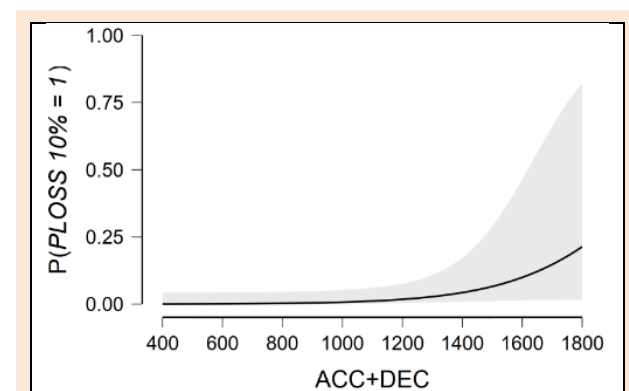


Figure 2. Association between 10% decrease in CMJ and total accelerations and decelerations.

The methodology proposed in this research can be used to control fatigue in an ecological and non-invasive manner in team sports, given that several IL and EL variables show associations with an increase in local neuromuscular fatigue detected through the CMJ test. Determining values that reveal the individual physiological state is essential when monitoring players' performances and fatigue (Atkinson and Nevill, 1998; Weir, 2005). As stated in previous research, the CMJ is a promising test that can optimally provide information in training situations due to its ease of use and replicability (Claudino et al., 2012). In the present study, and differently from some other pieces of research, we recorded the best jump in every set since it indicated the best performance that the player could generate at that time. This value seems to be related not only to the ability to jump vertically, but to change of direction and specific basketball performance (Claudino et al., 2012; Edwards et al., 2018). CMJ-loss can inform staff members, providing an efficient, non-invasive, non-time-consuming, and low-cost metric correlated with objective physiological fatigue. Objective fatigue monitoring can be combined with other ways of attempting to quantify fatigue, such as heart rate or RPE measurements (Arcos et al., 2015).

Measurements based on jumps during training could approximate a more precise adjustment and prescription of training loads (Gabbett and Domrow, 2007; Jiménez-Reyes et al., 2019). In the present study, our methodological proposal was tested in a semi-professional basketball environment. Adequate management of the training load is a relevant element in any phase of the season (Drew and Finch, 2016), and monitoring how this imposed load affects the players could help decision-making within the process (Piedra et al., 2021). The use of specific basketball actions, adapted in intensity and volume to actual demands, should be the primary training content since it guarantees the specificity of the stimulus (Oliveira-Da-Silva et al., 2013).

To the date, and to our knowledge, this is the first study that has sought the association between RPE values and neuromuscular fatigue in semi-professional basketball players. This research is a preliminary study whose methodology could be applied to competitive environments, taking the validity of the results obtained into account. The possibility of detecting fatigue through the CMJ shows promising results, although it should be verified with more events registered, with longitudinal monitoring, and it should be tested in other competitive contexts (i.e., elite, female athletes). In conclusion, in this specific context, the increase in sRPE and a higher number of ACC and DEC could be associated with increased local neuromuscular fatigue detected through the CMJ test, using flight times, in semi-professional men's basketball.

Practical application

Detecting the values of local neuromuscular fatigue by performing the CMJ test on the players would enable the design and application of individualized recovery strategies to optimize their performance. The management of the training load with variables such as ACC and DEC of the exercises and the sRPE is a tool that would make it possible to propose optimal load values and modulate the players' neuromuscular fatigue during training. The use of large data aggregates makes it possible to generate multivariate models in which, through one or several response variables, it is possible to diagnose ecologically significant local muscle fatigue states. Using this methodology, we can understand better what practices and contents generate higher levels of fatigue, how players adapt to the proposed loads, and hypothetically, prevent injuries by controlling this factor more adequately.

Study limitations

The present study was carried out in a specific competition context, so the interpretation of the results should be limited to this specific group of players, bearing in mind that the analysis carried out is group analysis. However, the methodology can also be used to study individual responses. The study was carried out with a small sample, a limited period and with fatigue expressed as 10% jump loss occurring in a low percentage of cases. However, considering the ecology of the obtained data and the high applicability of the model, that can be easily used in professional and amateur sports, the results enable new research lines to be opened. In future pieces of research, the use of mixed

models can be employed, as they present interesting advantages when considering inter-individual differences over time and variability among players. Jump height or flight time may also be misinterpreted in calculations, and other variables, such as force or power may be more informative about neuromuscular function. To obtain these other metrics, technology, such as force platforms, that is more expensive, heavy, and needs proper calibration. This aspect should be considered when using it in applied settings.

Future scientific works can confirm the results presented here, broaden the knowledge about which internal and external load variables can be associated with a higher level of neuromuscular fatigue in each period and context to optimize the periodization of training and recovery processes.

Conclusion

It is possible to monitor loads effectively and ecologically in team sports. However, it is necessary to consider different internal and external load variables and using advanced statistical models to observe complex realities. A multivariable model seems to be a reliable, sensitive, and promising tool to monitor loads in semi-professional basketball settings.

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Key points

- Several internal and external load variables show associations with an increase in local neuromuscular fatigue detected through the countermovement jump test.
- Our main findings show promising results detecting the lower-body neuromuscular fatigue originated by specific training through an ecological, practical, and low time-consuming methodology. The proposed method can outline the players' physiological state and inform decisions regarding the application of different training loads within a complex setting and multi-factorial process.

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