



Understanding Player Load: Meanings and Limitations

by

Sarah da Glória Teles Bredt¹, Mauro Heleno Chagas¹, Gustavo Henrique Peixoto¹,
Hans Joachim Menzel¹, André Gustavo Pereira de Andrade¹

We present a critical reflection on the mechanical variable Player Load, which is based on acceleration data and commonly used in sports. Our motivation to write this paper came from the difficulties that we encountered in the calculation and interpretation of Player Load using our own data, since we did not use the Catapult Sports equipment, which is a merchandise of the company that proposed this variable. We reviewed existing literature in order to understand Player Load better; we found many inconsistencies in PL calculation methods and in the meanings attached to it. Accordingly, this paper presents a brief discussion on the meanings that have been assigned to Player Load, its limitations, and the lack of clear and complete information about Player Load calculation methods. Moreover, the use of arbitrary units and different practical meanings in the literature has associated Player Load with many physical quantities, thereby resulting in difficulties in determining what Player Load measures within the context of sports. It seems that Player Load is related to the magnitude of changes in acceleration, but not the magnitude of acceleration itself. Therefore, coaches and sports scientists should take this information into account when they use Player Load to prescribe and monitor external loads. We concluded that a deeper discussion of Player Load as a descriptor of external load is warranted in the sports sciences literature.

Key words: acceleration, external training load, mechanical variables.

Studies on sports training have used inertial sensors to measure the external load, which is the physical demand that is experienced by players during training or competition (Castillo et al., 2017) (e.g., distance covered, mean velocity, and accelerations; Schelling and Torres-Ronda, 2016; Weaving et al., 2017). A commonly used variable to describe the external load is Player Load (PL), which is a term that has been proposed by Catapult Sports, a company that provides sports technology. PL can be calculated based on the acceleration data that are recorded by triaxial accelerometers. To the best of our knowledge, PL was first defined in sports sciences literature as “a modified vector magnitude, expressed as the square root of the sum of the squared rates of change in acceleration between each moment of a training session in each movement axis (x, y, and z)” and it is represented

in arbitrary units (Boyd et al., 2011; Montgomery et al., 2010). The aforementioned definition, which is presented in Montgomery et al.’s (2010) and Boyd et al.’s (2011) works, is accompanied by the following PL equation:

$$PL = \sqrt{\frac{(a_{y1} - a_{y-1})^2 + (a_{x1} - a_{x-1})^2 + (a_{z1} - a_{z-1})^2}{100}}$$

Since the introduction of this equation in the sports sciences literature, PL has been widely used across different sports contexts (McNamara et al., 2015; Schelling and Torres-Ronda, 2016; Wilk et al., 2017; Young et al., 2016). However, some aspects of PL definition and equation do not seem to be clear; moreover, in the recent past, problems related to its physical quantity (i.e., the use of arbitrary units) have also been noticed by other researchers (Staunton et al., 2017).

¹ - Laboratory of Biomechanics - Department of Sports, Universidade Federal de Minas Gerais (Federal University of Minas Gerais), Belo Horizonte, Brazil.

Consequently, we observed possible difficulties in understanding the meanings that are attached to PL as a descriptor of the external load. The following examples, which have been extracted from different journal articles, illustrate the inconsistencies in the meanings that have been assigned to PL:

“Player Load was computed as vector magnitude representing the sum of accelerations recorded in the anterior-posterior, mediolateral and vertical planes of movement” (Castillo et al., 2017).

“Player load is a new indicator of external load obtained by triaxial accelerometry, and to date, only a few studies have used this measure of speed changes and load imposed on the body” (Randers et al., 2014).

“PlayerLoad™ is a modified vector magnitude which aims to encapsulate all velocity, acceleration, change of direction and collision demands experienced by players” (Weaving et al., 2017).

“The straight addition of the instantaneous change of rates of resultant accelerations (also known as jerk) over time represented the acceleration load for a drill or activity” (Schelling and Torres-Ronda, 2016).

Given these varied definitions, it is difficult to delineate what PL actually measures. Catapult Sports proposed that PL is “a modified vector magnitude, expressed as the square root of the sum of the squared instantaneous rate of change in acceleration in each of the three vectors - X, Y and Z axis - and divided by 100” (Boyd et al., 2011). Therefore, from a theoretical perspective, the literal definition of PL is based on the rates of change (derivative) in acceleration, which represent the jerk physical quantity (Δ acceleration/ Δ time) that is expressed in m/s³ units (Nicolella et al., 2018; Schelling and Torres-Ronda, 2016). However, the mathematical definition of PL (i.e., PL equation) does not compute the rates of change in acceleration; instead, it computes only the sum of changes in acceleration ($\Sigma\Delta$ acceleration), which is expressed in m/s² units.

In sports practice, either of these interpretations, mathematical or literal, determines PL using the magnitude of changes in acceleration and not the magnitude of acceleration itself. Changes in acceleration occur especially

during actions that require changes of direction (e.g., jumps and fakes) or during an abrupt initiation or cessation of a movement (e.g., collisions). Thus, higher frequencies of these actions during play increase PL values, which are an important aspect of the PL that describes the external load. Nevertheless, PL is not directly related to the magnitude of acceleration, which limits its potential to prescribe and monitor training loads. For example, two athletes may present different acceleration (e.g., A = 2.0 m/s²; B = 1.0 m/s²) when crossing the field in a fast break during a soccer game; however, if their changes in acceleration are similar (e.g., constant changes of 0.5 m/s²), then their PL will also be similar. Moreover, if these athletes' accelerations result in minimum changes in one direction (e.g., forward-backward), then their PL in this direction will contribute a low percentage to the total PL value, regardless of the magnitude of acceleration in that direction. In addition, PL has been found to correlate moderately ($r = 0.70$) with the total distance covered by players (Casamichana et al., 2013), due to the increased number of foot strikes within larger distances (Davies et al., 2013). This suggests that PL does not reflect the magnitude of acceleration but increases the difficulty in distinguishing between the external load of an athlete who covers a larger distance and that of an athlete who experiences higher intensity actions (e.g., sprints, jumps, collisions). In this regard, variables that encompass the magnitude of acceleration, such as the number of counts or the time spent in different acceleration zones (i.e., for resultant acceleration or acceleration in each axis), may be more informative as well as better at discriminating between athletes who differ in their magnitude of acceleration. If this is the case, then why should we measure the changes in acceleration instead of the magnitude of acceleration?

Another critical aspect of the PL is related to the different PL equations and descriptions that can be found in the literature (Table 1).

For example, Randers et al. (2014) have presented the sigma (Σ), which represents a mathematical sum, outside the square root of the PL equation; however, other descriptions have led to the understanding that the square root must be calculated after computing the sum of all the rates of change in acceleration (Weaving et al., 2017).

Moreover, some studies have also divided PL values by 100 with the objective of downsizing it (Montgomery et al., 2010; Schelling and Torres-Ronda, 2016). When this division is presented within the equation, its position also varies in relation to the square root. Whereas some studies have presented it inside the square root of the equation (Boyd et al., 2011; Casamichana et al., 2013; Wilk et al., 2017), others have presented it outside the square root (Aguiar et al., 2013; Schelling and Torres-Ronda, 2016); interestingly, some studies have simply not mentioned this division (Casamichana et al., 2013; Randers et al., 2014).

To illustrate this problem, we calculated PL based on our understanding of the calculation steps that are involved in the different equations that are presented in Table 1. Acceleration data were collected during a 5-min 3 vs. 3 basketball small-sided game of a randomly selected athlete who carried a 148 Hz triaxial wireless accelerometer (Trigno Wireless EMG System, Delsys Inc.®, Boston, USA) that was attached to an elastic belt. We collected the data in accordance with all the ethical standards of the local ethics committee. As shown in Table 1, we calculated PL from raw acceleration data using MatLab® version 2012b (The MathWorks Inc., Natick, USA). The differences in equations across studies led to different results. Moreover, the different scales that were generated by the different equations could make it difficult to compare the external load of athletes in different contexts (e.g., activity duration or intensity, type of activity, athletes' competitive level). Therefore, these differences could not be distinguished from the differences that were generated by the different calculation methods. For example, the studies of Young et al. (2016) and McLaren et al. (2016) cite the Boyd et al.'s (2011) study, but present very different descriptions of PL calculation (i.e., root mean square of accelerations and root mean square of changes in acceleration) with few details about the calculation steps and movement axes. Therefore, if one decides to use PL to describe the external load, detailed methods that its calculation entails should be provided.

Although most of the aforementioned studies have used Catapult equipment and have therefore used its standardized equation to obtain PL values, regardless of their interpretation of the

PL metric, the inconsistent and possibly incautious reporting of the PL equation can lead to its misuse and misinterpretation. This is especially problematic if one calculates PL using equipment that is different from Catapult's (e.g., inertial sensors of distinct brands), as has been the case in some studies (Scanlan et al., 2014; Twist et al., 2017; Young et al., 2016). Consider the example of the coaching staff of a club who use the equation presented by Randers et al. (2014) to calculate the PL of a certain training activity (e.g., 4-min soccer small-sided game). Their results will be very different from those that have been calculated in another club for a similar activity (i.e., the same 4-min small-sided game played by athletes of the same competitive level and age) using a different equation (e.g., equation provided by Aguilar et al., 2013). Therefore, regardless of the equipment used, a thorough description of the methods and equations that have been used in the study is crucial for its reproducibility. In this context, it is important to highlight that many recent studies have neither presented the PL equation nor included any discussion or interpretation about it; instead, they have only cited definitions from previous research reports (Beenham et al., 2017; McNamara et al., 2015; Twist et al., 2017; Zurutuza et al., 2017). As suggested by other authors (Nicoletta et al., 2018; Schelling and Torres-Ronda, 2016), we understand that PL is the summation of all the rates of change in acceleration (or the sum of jerks) of athletes during a training activity. Therefore, future studies that investigate this metric should report it as so (jerk), along with the equation and an appropriate measurement unit (m/s³). Furthermore, it is also important to reflect why should we use jerk-based variables to describe the external load instead of variables that are related to other physical quantities (e.g., time spent at different acceleration zones, the distance covered at high speeds).

Given the aforementioned issues and the lack of clarity in existing literature, it seems that PL entails a few limitations in describing the external load. The use of variables that are based on the changes of acceleration rather than the magnitude of acceleration must be supported in future studies. In addition, PL equations that have been used in past studies lack standardization; this may have led to difficulties in understanding

the PL metric and adversely affected its reproducibility. A better explanation and deeper understanding of PL, as a descriptor of the

external load, appears to be crucial for training load prescription and monitoring.

Table 1
Player Load descriptions and equations used in different studies and their respective values for a 5-min basketball small-sided game.

Reference	Description of PL calculation	Equation	Player Load
Boyd et al. (2011)	It is expressed as the square root of the sum of the squared instantaneous rate of change in acceleration in each of the three vectors (X, Y and Z axis) and divided by 100 (p. 313).	$PL = \sqrt{\frac{(a_{y1}-a_{y-1})^2 + (a_{x1}-a_{x-1})^2 + (a_{z1}-a_{z-1})^2}{100}}$	10.76
Aguiar et al. (2013) ¹	Body Load is expressed, as the square root of the sum of the squared instantaneous rate of change in acceleration in each of the three vectors (x, y, and z) and divided by 100 (p. 1289).	$PL = \sqrt{\frac{(a_{y1}-a_{y-1})^2 + (a_{x1}-a_{x-1})^2 + (a_{z1}-a_{z-1})^2}{100}}$	1.07
asamichana et al. (2013)	No description of PL calculation.	$PL = \sqrt{(a_{y1} - a_{y-1})^2 + (a_{x1} - a_{x-1})^2 + (a_{z1} - a_{z-1})^2}$	107.62
Randers et al. (2014)	Accumulated player load is an estimate of physical demand combining the instantaneous rate of change in acceleration in three planes, forward/backward X, side/side Y, and up/down Z (p. 132).	$PL = \sum_{t=0}^{t=n} \sqrt{(X_{t=n} - X_{t=n-1})^2 + (Y_{t=n} - Y_{t=n-1})^2 + (Z_{t=n} - Z_{t=n-1})^2}$	10681.84

¹ Although the study conducted by Aguiar et al. (2013) used the same equation and description of PL and cited the study conducted by Boyd et al. (2011) on Catapult PL, they refer to it as "Body Load".

Funding

This work was supported by the Pró-Reitoria de Pesquisa da Universidade Federal de Minas Gerais (PRPq-UFMG), Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brasil (CAPES), finance code 001, Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), and Fundação de Amparo à Pesquisa do Estado de Minas Gerais (FAPEMIG).

Acknowledgements

We thank to professor Amanda Silvatti from the Federal University of Viçosa (Viçosa, MG, Brazil) for equipment support, to Minas Tênis Clube for participating in data collection, and to Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brasil (CAPES), finance code 001, Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), and Fundação de Amparo à Pesquisa do Estado de Minas Gerais (FAPEMIG) for financial support.

References

- Aguiar M, Botelho G, Gonçalves B, Sampaio J. Physiological responses and activity profiles of football small-sided games. *J Strength Cond Res*, 2013; 27: 1287–1294
- Beenham M, Barron DJ, Fry J, Hurst HH, Figueirido A, Atkins S. A Comparison of GPS Workload Demands in Match Play and Small-Sided Games by the Positional Role in Youth Soccer. *J Hum Kinet*, 2017; 57: 129–137
- Boyd LJ, Ball K, Aughey RJ. The Reliability of MinimaxX Accelerometers for Measuring Physical Activity in Australian Football. *Int J Sports Physiol Perform*, 2011; 6: 311–321
- Casamichana D, Castellano J, Calleja-Gonzalez J, San Román, J Castagna C. Relationship between indicators of training load in soccer players. *J Strength Cond Res*, 2013; 27: 369–374
- Casamichana D, Castellano J, Dellal A. Influence of different training regimes on physical and physiological demands during small-sided soccer games: continuous vs. intermittent format. *J Strength Cond Res*, 2013; 27: 690–697
- Castillo D, Weston M, McLaren SJ, Cámara J, Yanci J. Relationships Between Internal and External Match-Load Indicators in Soccer Match Officials. *Intl J Sports Physiol Perform*, 2017; 12: 922–927
- Davies MJ, Young W, Farrow D, Bahnert A. Comparison of Small-sided Games on Agility Demands in Elite Australian Football. *Int J Sports Physiol Perform*, 2013; 8: 139–147
- McLaren SJ, Weston M, Smith A, Cramb R, Portas MD. Variability of physical performance and player match loads in professional rugby union. *J Sci Med Sport*, 2016; 19: 493–497
- McNamara DJ, Gabbett TJ, Chapman P, Naughton G, Farhart P. Variability of PlayerLoad, bowling velocity, and performance execution in fast bowlers across repeated bowling spells. *Int J Sports Physiol Perform*, 2015; 10: 1009–1014
- Montgomery PG, Pyne DB, Minahan CL. The physical and physiological demands of basketball training and competition. *Int J Sports Physiol Perform*, 2010; 5: 75–86
- Nicolella DP, Torres-Ronda L, Saylor KJ, Schelling X. Validity and reliability of an accelerometer-based player tracking device. *PLoS ONE*, 2018; 13: 1–13
- Randers MB, Nielsen JJ, Bangsbo J, Krstrup P. Physiological response and activity profile in recreational small-sided football: No effect of the number of players. *Scand J Med Sci Sports*, 2014; 24(suppl 1): 130–137
- Scanlan AT, Wen N, Tucker PS, Dalbo VJ. The relationship between internal and external training load models during basketball training. *J Strength Cond Res*, 2014; 28: 2397–2405
- Schelling X, Torres-Ronda L. Accelerometer Load Profiles for Basketball-Specific Drills in Elite Players. *J Sports Sci Med*, 2016; 15: 585–591
- Staunton C, Wundersitz D, Gordon B, Kingsley M. Construct Validity of Accelerometry-Derived Force to Quantify Basketball Movement Patterns. *Int J Sports Med*, 2017; 38: 1090–1096
- Twist C, Highton J, Daniels M, Mill N, Close G. Player responses to match and training demands during an intensified fixture schedule in professional rugby league: a case study. *Int J Sports Physiol Perform*, 2017; 12: 1093–1099
- Weaving D, Whitehead S, Till K, Jones B. The validity of real-time data generated by a wearable microtechnology device. *J Strength Cond Res*, 2017; 31: 2876–2879
- Wilk EH, Luteberget LS, Spencer M. Activity profiles in international female team handball using PlayerLoad TM. *Int J Sports Physiol Perform*, 2017; 12: 934–942
- Young CM, Gustin PB, Sanders N, Mackey L, Dwyer DB. Player load in elite netball: Match, training, and positional comparisons. *Int J Sports Physiol Perform*, 2016; 11: 1074–1079
- Zurutuza U, Castellano J, Echeazarra I, Casamichana D. Absolute and Relative Training Load and Its Relation to Fatigue in Football. *Front Psychol*, 2017; 8: 878

Corresponding author: André Gustavo Pereira Andrade,

Laboratory of Biomechanics – Physical Education, Physiotherapy, and Occupational Therapy School, Federal University of Minas Gerais. Address: Avenida Antônio Carlos, 6627 – Pampulha, Belo Horizonte, MG - Brasil. Zip code: 31 270 901. ; Phone: +55 (31) 3409 2329. ; E-mail: andreguto@yahoo.com.br