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External and Internal Loads in Sports Science: Time to Rethink?

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ABSTRACT

The current paper discusses the concepts and definitions of external and internal loads in sports science and the quantification of athletes' performance and psychobiological responses. We provide practical solutions for improving human performance assessment by suggesting related terms and consistent terminology that align with biomechanical standards. This will help to avoid discrepancies in the meaning of terms across various subdisciplines of sport and exercise science and medicine. Where possible, exercise performance should be characterized and quantified according to physical quantities such as time, distance, displacement, speed, velocity, acceleration, force, torque, work, power, and the International System of Units. These quantifications can be performed for exercises, sessions, microcycles, and mesocycles. Standardization of these terms and measurements would enable consistent communication among scientists of all knowledge areas.

Keywords: exercise intensity, exercise volume, rating of perceived exertion.

INTRODUCTION

Many review articles in sports medicine and science have identified misuse of biomechanical terms when quantifying athletes' performance and psychobiological responses to exercise (17, 18, 25, 37, 40-43). Despite these commentaries, the misuse of biomechanical concepts and terminology persists, particularly in failing to distinguish between mass and weight, velocity, and speed, as well as in the improper use of terms such as "work," "power," "workload," and "critical power" (17, 18, 25, 37, 40-43). Additionally, some authors have recognised inaccurate, and inappropriate terms such as "internal load", which have been used to assess the psychobiological responses to exercise (18). These communications emphasise the need for accurate and consistent use of terminology to ensure precise communication and interpretation of research findings in the field.

Among these mechanical misconceptions, training load, is a term/concept used in the sports science literature, that has been challenged regarding its misuse (37) and validity (31). On the other hand, others argue that training load is a multidimensional construct consistent with notions from some fields of epidemiology (20). The term/concept (i.e., training load) accommodates various proxy measures and metrics that can be described as external or internal (19, 24). It has been suggested that external loads can be measured by quantifying speed, accelerations, distance, force, resistance level, and work (22, 24). Otherwise, internal loads can be quantified by measuring psychological (e.g., rating of perceived exertion), and physiological (i.e., heart rate, blood lactate, oxygen consumption) responses to exercise (22, 24). In biomechanics, load is a term that refers to a force. When using the International System of Units (SI), the outcome measure of a force must be reported in the newton (N) (37, 41).

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This article aims to present and discuss the definitions and quantification of external and internal loads in sports science, providing a rationale why, from a biomechanical point of view, they are considered inaccurate and inappropriate terms in the quantification of athletes' performance and the psychobiological responses. Finally, practical recommendations are outlined with the objective of improving human performance assessment by suggesting related terms and terminology that are biomechanically consistent to avoid different meanings of terms in different subdisciplines of sport and exercise science and medicine.

EXTERNAL TRAINING LOAD

In the field of sports science, the term "external load" refers to objective measurements of the work undertaken by athletes during training or competition, independent of their internal workloads (4, 24). Common methods of assessing external load include evaluating power output, speed, acceleration, and employing time-motion analysis using global positioning systems (GPS) and accelerometer-derived parameters (4, 24). These standardized measures provide valuable insights into the physical demands placed on athletes during their training and performance activities.

Even though the term (i.e., external load) has been extensively used in peer-review literature (7, 8, 12, 21, 23, 24), fundamental mechanical inconsistencies in the definition have been previously noted (18, 37). Considering external loads as "objective measures of the work performed…" (4), we propose that there is no external load, but external work. The main mechanical inconsistencies in the definitions/concepts of external loads are due to using incorrect, vague, and colloquial meanings of the terms work and load. We agree that the term "work" should not be solely monopolized by mechanics, as its interpretation and usage can vary depending on the context. However, in the specific context of the exercise description, the general use of the term "work" can be confusing and inappropriate. For instance, when referring to external loads as "objective measures of the work performed", it is important to note that common measures of external load such as power output, speed, acceleration, time-motion analysis, GPS metrics, and accelerometer-derived parameters, except for power, are not considered as measures of work. Therefore, in this case, the use of the term "work" can lead to confusion and is not appropriate. In many articles, it is common to encounter statements like: "The first two workloads were set at 8 and 10 km·h^{-1}" (34). However, it should be noted that km·h^{-1} is a unit of speed. In this instance, the usage of the term work, or workload is incorrect. Instead, the phrase: "The first two speeds were set at 8 and 10 km·h^{-1}" is better suited to avoid the misuse of mechanical terms.

The misuse of these terms (i.e., work and load) in sport and exercise science has been previously addressed (37, 41). In biomechanics, load is a term that refers to a force and work is done when a force moves an object through a displacement in the direction of the force. Work is a scalar quantity representing energy transfer from one object to another. For a constant net force, the work done equals the force component in the direction of the displacement multiplied by the magnitude of the displacement (see Equation 1).

$$W = \overrightarrow{F_x}\Delta x = \overrightarrow{F_x}\,|\Delta x| cos\theta$$

Equation 1.

Where $\overrightarrow{F_x}$ is the magnitude of the constant force, Δx is the change in displacement (x) provided by applying the force, and θ is the angle between the directions of the force and displacement vectors.

Although, in most sports activities, force is not constant, and therefore, work is calculated as the integral of force over the distance through which it has acted (see Equation 2).

$$W = \int_{x_1}^{x_2} \overrightarrow{F_x}\, dx$$

Equation 2.

The SI-derived unit of work is the joule (J), which equals the product of a newton and a meter (N·m). Additionally, work has no relationship with time so seem that force can be applied to an object, but if there is no displacement of the object, there is no work. Studies that present an athletes' physical work in units other than joules are incorrect (37) and, when described for dynamic activities, there is a differentiation between the work done to move the limbs and that required to move the whole body or an external object (43). Additional mechanical inconsistency on the definition of external training load, includes using the term workload (17). Previous commentaries have already highlighted that this term is nonsensical and should not be used to describe exercise performance (17, 41). When

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using the term workload, can refer to (a) the load or force applied, reported in newtons (N), or (b) the amount of work performed, reported in joules (J) (17). Therefore, authors should specify the intended meaning and report the appropriate outcome measure accordingly.

In addition to a proper use of load and work, during team sports, the parameters provided by global navigation satellite systems (GNSS) and accelerometer/gyroscope devices (4) may provide measurements of basic components of player position (6, 14). Displacement (x), velocity ($\vec{v}$) and distance travelled, can be calculated from this data. Displacement (x) is a vector quantity that refers to both the change in the position (Δx) and the direction of the net motion from the initial position to the final position. Displacement is represented graphically as the integral of velocity over time (see Equation 3). The distance travelled is a scalar quantity calculated as the length from the initial to the final position.

$$\Delta x = \lim_{\Delta_t \to 0} \sum_i \vec{v}_{ix}\, \Delta t_t = \int_{t_1}^{t_2} \vec{v}_x\, dt$$

Equation 3.

Velocity and acceleration ($\vec{a}$) represent the first and second derivative of the displacement to time, respectively. Similarly, the change in velocity is represented graphically as the area under the acceleration versus time curve. Thus, acceleration is defined as a first-order derivative of the velocity-time curve (see Equations 4 and 5).

$$\vec{v_x}(t) = \lim_{\Delta_t \to 0} \frac{\Delta_x}{\Delta_t} = \frac{dx}{dt}$$

Equation 4.

$$\vec{a} = \lim_{\Delta_t \to 0} \frac{\Delta v}{\Delta t} = \frac{dv}{dt}$$

Equation 5.

Although often considered as synonyms, velocity and speed are different concepts. The speed of an object is expressed as the magnitude of the change in position per unit of time. Speed is a scalar quantity because it does not reveal in what directions the object moves. On the other hand, velocity is a vector quantity and describes an object's displacement per unit of time and in what direction the object is moving (e.g., 5 m·s^{-1} east.). Therefore, many sports science studies have made the error of reporting velocity without direction (42, 43). Nevertheless, the mean or peak speed of motion is the most relevant performance variable, not velocity.

INTERNAL TRAINING LOAD

In sports science, internal (training) load typically refers to and incorporates all the psychophysiological responses experienced by an athlete during the exercise and can be quantified by measuring psychological (e.g., rating of perceived exertion [RPE]), and physiological (i.e., heart rate, blood lactate, or oxygen consumption) responses to exercise (4, 24). The RPE scales and the so-called training impulse metric (TRIMP) are the most common methods proposed for quantifying internal training loads. TRIMP is typically calculated as the product of training duration and average heart rate (HR) (multiplied by a weighting factor that reflects the exponential rise of blood lactate during incremental exercise) during the exercise session (13).

Due to the similarities with the psychophysiological stress (18, 24) concept, internal load is a highly confusing topic created in sports science literature. Contradictory definitions and statements are found (24) when authors first define mechanical load as, "the forces experienced by specific tissues or biological structures and can be externally or internally sourced" (see Table 1 article (24)). However, in the same Table it is also stated that "internal load does not describe the forces or internal stresses and strains experienced by specific biological tissues" (24). Additional inconsistencies were highlighted in a commentary (18) that identified that the concepts of internal training load and psychophysiological stress are basically the same.

In biomechanics, external and internal loads are considered as forces acting externally and internally, inducing stress and strain in the biological tissues (30). The internal forces generated by the neuromuscular system and other tissues hold any material together under externally applied forces (30). Muscles, their constituent cells, and their molecular filament mesh structure are mechanosensitive to the changes in the magnitude of the forces and stresses that arise during the actions (16). When a body subjected to external load is sectioned, the distribution of force acting over the sectioned area holds each body segment in equilibrium (15). The intensity of this internal force at a point in the body is called stress (15), a force that tends to stretch, shear, or compress the body, changing its shape (39) – see Equation 6.

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$$Stress = \frac{F}{A}$$

Equation 6.

Where 'F' is force and 'A' is the area of the body.

After removing the forces, if the body returns to its original shape, it is composed of elastic materials (39). The fractional change in the length of the body is called strain (39) – see Equation 7.

$$Strain = \frac{\Delta L}{L}$$

Equation 7.

Where 'L' length of the body.

Regarding internal training loads quantification methods (i.e., RPE and TRIMP), specifically TRIMP, connoted as training impulse (i.e., the product of training duration and average HR multiplied by a weighting factor which reflects the exponential rise of blood lactate during incremental exercise) (13), is a mechanically inconsistent and inappropriate term to be used as a metric associated with RPE and HR (37). Impulse is a vector quantity that can be determined by integrating force concerning time (see Equation 8) and is also equivalent to the area under the force-time curve (29).

$$\vec{I} = \int_{t_1}^{t_2} \vec{F}_x \, dt$$

Equation 8.

Where, $\vec{I}$ is the impulse, $\vec{F_x}$ is the magnitude of the force, and 't' is time.

Further increasing the mechanical confusion around internal training loads, some papers use the term strain as the product of training load and monotony (9, 10). Otherwise, as stated above, in biomechanics, strain is a term that refers to the deformation of a body (39). Therefore, like impulse, strain has been proposed to be considered a different concept than the one proposed in mechanics. We recommend that terms defined in classical mechanics and the SI should not be used in other ways.

In summary, the analysis of markers used to quantify the psychobiological responses to exercise (e.g., RPE, HR, and blood lactate) may represent specific cardiovascular, neuromuscular, and metabolic internal responses to exercise, but not internal loads.

RECOMMENDATIONS FOR THE CORRECT ASSESSMENT AND QUANTIFICATION OF ATHLETES' PERFORMANCE

The following sub-topics are intended to offer practical recommendations to address the misuse of the term "external training load" in assessing and quantifying athletes' performance across team sports, endurance training, and strength training. These recommendations aim to improve the accuracy and effectiveness of performance evaluation in these domains.

Endurance training

When prescribing an endurance training program for cyclic modalities (e.g., running, cycling, and swimming), relative or absolute speed and power output, exercise duration, distance travelled, and rest intervals (when interval training is prescribed) are considered in the training progression. Furthermore, when a maximal oxygen consumption test is performed, it allows for determining the ventilatory threshold (VT) and respiratory compensation threshold (RCT) velocities and/or power outputs. Such metrics will enable the categorization of training stimulus into relative zones of intensity: zone 1 (low intensity, lower than the VT); zone 2 (moderate intensity, between VT and RCT); and zone 3 (high intensity, above the RCT). Different types of endurance exercise (e.g., running, swimming, cycling) may be prescribed using the manipulation of the above variables to differentiate the adaptations (11).

Relationships between the manipulation of endurance training variables and performance during competitions has been reported in the studies that analyze the training intensity distribution of the athletes. Readers are directed to the following review articles for further information that is beyond the scope of this article (26, 38). Endurance performance may be manipulated via speed or power output, and time spent in each training zone. On the other hand, confusion when adopting the term training load to connote these variables is present in the taper of athletes (3). Aimed at optimizing performance, a taper is defined as 'a reduction in the training load' of athletes in the final days before an important competition (3). According to the literature, this reduction can be achieved by manipulating training duration, intensity, and frequency, as well as the pattern of the taper and its duration (3). Bosquet et

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al. (3) reported that the optimal strategy is a tapering intervention of 2-week duration, where the training duration is exponentially decreased by 41–60%, without any modification of either training intensity, or frequency. Because training intensity and frequency are training variables that are not recommended to be reduced, defining tapering as a reduction in the training load remains somewhat unclear an open to interpretation. A more acute definition of tapering would include 'manipulation of training variables (i.e., training duration, intensity, and frequency) in the final days before the critical competition' via an exponential decrease in training duration, without modification of either training intensity, or frequency, which has been reported as an optimal strategy for optimizing performance (3).

In summary, the prescription and monitoring of endurance training can be effectively carried out by evaluating a comprehensive set of exercise training variables, such as intensity, duration, frequency, and rest intervals. It is important to specify these physical quantities accurately while avoiding the misuse of the term "training load". This approach can help alleviate confusion and contribute to advancements in endurance training research and practice.

Strength training

When prescribing a strength training program, the variables that can be manipulated are the exercise choice (mode), load, number of repetitions per set, rest period length, and exercise order (36). In this case, load is not a general term but the specific mechanical load (i.e., amount of weight carried or external resistance) during resistance training. The relative load lifted (e.g., % of one-repetition maximum [1RM]) can also be referred to as the training or exercise intensity (35), and the literature emphasizes that the manipulation of these variables may induce specific neuromuscular responses, contributing to the increases in muscle size and function (36). Therefore, proper quantification and monitoring of these variables is required.

In this context, reporting the total external mechanical work completed during resistance exercises would be one of the most appropriate procedures to quantify the programs. Unfortunately, the calculation of mechanical work during strength training requires the measurement of the object's displacement; data that is not easily available in daily practice. Nowadays, the use of high-speed video capture, linear position/velocity transducer, inertial measurement unit, or laser optic technologies during strength training sessions (28), allows the assessment of object's vertical displacements. However, these devices are relatively expensive and time demanding, challenging the monitoring of large groups of individuals (28).

The consensus statement of monitoring athlete training load (4) recommends that strength training programs should be typically quantified by reporting the metric volume load (number of repetitions × external load). The maximum dynamic strength volume load metric has also been proposed (27), which accounts for body or shank mass when performing the exercise. According to studies, the volume load performed during resistance exercises seems to play a significant role in determining muscle size increases in both males and females (32). Interestingly, regardless of the specific training system employed (e.g., crescent pyramid and drop-set), equalizing the volume load among resistance training programs appears to lead to similar muscular adaptations (1). Hence, it becomes crucial to properly monitor this metric. However, a limitation of using volume load arises when exercises are performed without external load, such as bodyweight exercises, as it restricts the quantification to the number of repetitions performed alone. Despite this limitation, volume load still offers a convenient and straightforward approach for quantifying resistance exercises without the need for additional equipment.

In addition to the confusion surrounding tapering highlighted in the endurance training topic, the term "deload" is commonly used in strength training literature by athletes and coaches (2). Deloading refers to a purposeful reduction in training demand with the aim of improving preparedness for subsequent training cycles (2). However, the training demand is often reported and quantified in terms of exercise load and volume, which includes training frequency and the number of repetitions per exercise (2). Nonetheless, it is important to note that the term "load" specifically refers to the mechanical load imposed on the body, and therefore, a true deload cannot occur without a decrease in the amount of weight lifted or external resistance. To enhance clarity, it would be more appropriate for studies to avoid using the term "deload" and instead describe a 'regenerative period' that is characterized by a deliberate manipulation of strength training variables. This would provide a more precise understanding of the intended training approach and its impact on the athlete's performance and recovery.

In summary, the prescription and monitoring of

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strength training can be effectively carried out by evaluating the load of the exercises, the number of repetitions per set, and calculating the volume load. It is crucial to specify these variables and metrics accurately while avoiding the misuse of terms like "training load" and "deload". This approach can help mitigate confusion and contribute to advancements in strength training research and practice.

Team sports

During games and training sessions, such as small-sided games, the assessment and quantification of athletes' performance can be enhanced with the use of GNSS and accelerometer/gyroscope devices (4). The GNSS technology allows for the tracking of two-dimensional player coordinates (x, y position) from wearable devices synchronized with overhead satellites. By utilizing this technology, valuable information such as athletes' displacement, velocity, distance travelled, and acceleration can be obtained. Equations 3, 4, and 5, as presented in the external training load topic, provide the means to calculate and analyze these parameters.

In summary, like endurance and strength training, the analysis of resultant athletes' performance in team sports can be effectively conducted by assessing physical quantities such as displacement, speed, and acceleration. This approach allows for a more accurate evaluation of athletes' performance without relying on the misuse of terms or concepts such as external training load and workload. By utilizing appropriate measurements and terminology, researchers and practitioners can gain valuable insights into athletes' performance and make informed decisions in training and performance optimization.

FINAL CONSIDERATIONS AND FUTURE RECOMMENDATIONS

We are conscious that, in sports science, load is a generic term that is qualified by the term training in a fashion similar to other areas of research that have adopted the term within a variety of contexts (e.g., allostatic load, cognitive load, and teaching load) (24). Although, during specific training prescriptions (i.e., strength training), load is not a generic term but refers to the specific mechanical load and the magnitude of the forces and stresses that arise during muscle actions (16).

Regarding the confusion, we propose the following:

1. Avoid using the term external load when assessing exercise time, distance, displacement, speed, velocity, acceleration, torque, work, power, and impulse.
2. Avoid using the term internal load when referring to the assessment of psychobiological stress markers (i.e., session RPE, HR, blood lactate, or oxygen consumption).
3. Avoid using the term impulse when expressing other calculus than integrating force concerning time, and strain, when expressing other phenomena than the body deformation.

Throughout the history of sports science there have been major reconsiderations of physiological concepts/paradigms. For example, it was once considered that lactate was responsible for inducing delayed onset muscle soreness (5) or that insufficient O_2 was the primary basis for lactataemia (e.g., lactate threshold concept) (33). However, as science develops in response to phenomena that emerge the understanding of these concepts has adapted. We propose that it is time to rethink the training load paradigms. The present article extends previous research by highlighting mechanical misconceptions when adopting external and internal load in quantifying athletes' performance and psychobiological responses and provides recommendations from a constructive point of view.

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no conflicts of interest relevant to the content of this article.

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