Development of a Revised Conceptual Framework of Physical Training for Use in Research and Practice

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Title: Development of a revised conceptual framework of physical training for use in research and practice

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Key Points

- The absence of a reference framework presenting hypothesized relations between constructs and measures (e.g., training load), makes the examination of the validity and usefulness of measures of training load process and outcome introduced in the sports science literature confusing and at risk of bias.
- We modified a previous framework by explaining and including four new constructs for the conceptualization of the process and outcomes of physical training: training effects and their possible measures, sport performance outcomes, and individual and contextual factors.
- This proposed conceptual framework may help guide the development, validation, implementation, and interpretation of measures used for athlete monitoring.

Abstract:

A conceptual framework has a central role in the scientific process. Its purpose is to synthesize evidence, assist in understanding phenomena, inform future research and act as a reference operational guide in practical settings. We propose an updated conceptual framework intended to facilitate the validation and interpretation of physical training measures. This revised conceptual framework was constructed through a process of qualitative analysis involving a synthesis of the literature, analysis and integration with existing frameworks (Banister and PerPot models). We identified, expanded and integrated four constructs that are important in the conceptualization of the process and outcomes of physical training. These were: 1) formal introduction of a new measurable component 'training effects', a higher-order construct resulting from the combined effect of four possible responses (acute and chronic, positive and negative); 2) explanation, clarification and examples of training effect measures such as performance, physiological, subjective and other measures (cognitive, biomechanical, etc.); 3) integration of the sport performance outcome continuum (from performance improvements to overtraining); 4) extension and definition of the network of linkages (uni and bidirectional) between individual and contextual factors and other constructs. Additionally, we provided constitutive and operational definitions, and examples of theoretical and practical applications of the framework. These include validation and conceptualization of constructs (e.g. performance readiness), and understanding of higher-order constructs, such as training tolerance, when monitoring training to adapt it to individual responses and effects. This proposed conceptual framework provides an overarching model that may help understand and guide the development, validation, implementation, and interpretation of measures used for athlete monitoring.

Keywords: Training response, contextual factors, performance, subjective measures, acute, chronic, athlete monitoring

1 Background

The goal of any scientific research endeavour, whether quantitative or qualitative, is to postulate theories (or laws) that can explain phenomena and build scientific knowledge. Our progression in science is marked by improvement and refinement in these theories, allowing for more informed logical reasoning. However, lack of conceptualization and articulation of the causal phenomena under investigation may undermine the foundation of solid empirical research. During the last 10 years in sport science, there has been an increased interest in new measures, particularly in subjective measures, with new constructs introduced but never clarified or validated [1]. As such, the usefulness of these measures introduced in the sports science literature is potentially confusing and at risk of bias. Therefore, given that a conceptual framework is the foundation for the validation of measures and their interpretation, we sought to examine and provide an updated conceptual framework for the physical training process for use in research and practice.

2 Aims of the Conceptual Framework

2.1 What is a Conceptual Framework?

A conceptual framework synthesizes evidence, assists in understanding the phenomena under investigation, informs future research and acts as a reference guide in practical settings. In the scientific process, conceptual frameworks allow more precise specification of hypotheses, thus increasing their degree of falsifiability, including when auxiliary or primary hypotheses of the main theory are modified if predictions fail [2, 3]. This prevents ad hoc modifications of the theories, i.e. bias. A conceptual framework may aid in the explanation of particular phenomena providing the background knowledge, based on which the potential causal structure is formally presented as directed acyclic graphs for statistical examination (counterfactual framework) [4, 5]. This also allows the identification of confounders, moderators, mediators, colliders etc. [6, 7]. The second purpose of a conceptual framework is to guide the validation of measurements [8]. Lack of conceptualization and articulation of causal phenomena weakens research in a number of ways including poor methodological arguments, lack of conceptual clarity and undermining of the foundation of solid empirical research [9].

In the context of patient-reported outcome measures, a conceptual framework is a representation of the relationships between the construct to be measured (e.g. using reflective or formative models) [10]. This explanation is consistent with a generic definition, which describes a framework as the structure which the researcher believes to best explain the phenomenon to be studied [11]. It may take the form of a visual representation, arranged in a logical structure, illustrating presumed relationships between key concepts, constructs or variables. The availability of a reference conceptual framework, together with operational definitions of the constructs, is therefore essential for the measurement validation process [12]. This provides a basis for researchers to propose exactly what and why specific variables (objective or subjective) are measured and act as a reference for validation studies. Of particular importance is understanding "why" since a measure can be valid for a specific context and goal but not in another.

2.2 Why Develop a Conceptual Framework of Physical Training?

In the last decade, there has been an increased interest in subjective measures within sports science, with new constructs (e.g. wellness, wellbeing, performance readiness etc.) introduced but never clarified or conceptualised [1]. Moreover, while the use and development of reference theoretical and conceptual frameworks is common in disciplines such as psychometrics and clinimetrics [12, 13], they are not commonly used when validating measurements used in sport science. Unfortunately, the absence of a reference framework presenting hypothesized relations between these constructs and other measures (e.g. training load), makes the examination of the validity and usefulness of these items introduced in the sport science literature confusing and prone to bias (e.g. post hoc and ad hoc "theories" explaining relations, that are not subsequently tested and that decrease the degree of falsifiability) [14]. For example, some common subjective measures used in research and practice such as "wellness items" have never been validated following appropriate and established methods such as those presented by the COnsensus-based Standards for the selection of health Measurement Instruments (COSMIN) [1]. This may also be due to the fact that available frameworks [15, 16] do not include all components necessary to provide a suitable reference for these kinds of validation studies. For this reason, we examined available frameworks and proposed a conceptual framework that can facilitate the validation of physical training measures. The current conceptual framework refers to physical training, that is the training involving physical activities with the goal of improving sport performance. Physical training encompasses both process and outcomes. Training process is the systematic repetition of physical exercises involving external and internal load [17], and its outcome may include physiological, biochemical, anatomical, and functional changes i.e. training effects and sport performance outcomes [15]. The conceptual framework excludes other kinds of training such as tactical training, watching videos and pure psychological skills training that can improve sport performance but do not require physical exertion.

3 Development Process of the Conceptual Framework

The development of our conceptual framework (Figure 1) was constructed through a process of qualitative analysis. This was an integrative and evolving progression, consisting of a synthesis of the literature and analysis of existing frameworks, coupled with an assimilation of information and concepts from previously developed models and theories. We developed the conceptual framework for the training process using conceptualization, a process in which imprecise constructs and their constituent components are defined in precise terms [18]. The version presented in the current paper is the final result of more than 15 versions and elaborations, that were conceptually tested using a red team approach [19], where the authors challenged conceptually the framework by proposing (worst case) scenarios to test whether it could reasonably fit common measures and training strategies. By conceptualizing and adding other constructs (individual and contextual factors, and training process), we also defined their relationships within the conceptual framework. Below we have documented the main stages in the development process in which we explicitly justify and elucidate decisions about key elements of the conceptual framework.

3.1 The Previous Version of the Physical Training Framework

We decided to re-evaluate and refine a previous physical training framework [15, 16] integrating or modifying, together with the examination of other frameworks or models available in the literature. This original framework was proposed 15 years ago in the context of physiological assessment in soccer, and it was developed to define and conceptualize the essential measurable components of the training process and its outcomes. Being a generic framework for physical training, it has been extended and applied in other sports, and has also been adapted to other fields such as physical activity for health and other contexts such as biomechanics [20, 21]. Briefly, a fundamental notion of this physical training framework was that when delivered appropriately, and according to the training goal and plan, exercise will induce psychophysiological responses leading to adaptations. These responses *during* the exercise are the stimuli initiating the adaptations determining the training outcomes. The training load construct was differentiated into two components, external and internal training load, by redefining and elaborating two terms (external and internal) that were already present, but not operationally conceptualized, in some non-peer-reviewed coaching literature [22] and seminal textbooks on training periodization [23]. In this previous framework, the external training load, and its interaction with various individual and contextual factors, determines the internal training load, which ultimately will produce changes in the training outcome[16].

3.2 Identification of Other Frameworks

A first attempt to systematically search the literature failed because, in sport science, frameworks for physical training are not presented as such and/or they are not clearly indicated in titles and abstracts. We therefore decided to locate suitable frameworks based on the expert knowledge of the authors, scoping searches and publication references. This may have introduced bias, although this is inevitable when developing conceptual frameworks given the qualitative nature of the process. From the examination of the literature (conducted via a literature search and consultation with experts in the field), we identified and selected two other potentially relevant models specifically proposed for the training process: the Banister Impulse-Response (IR) [24, 25] and the Performance Potential Metamodel (PerPot) [26, 27]. The main criterion for selecting reference conceptual frameworks and models was the presence of potentially measurable components and concepts. We ignored further developments or refinements of these two models that did not contain additional concepts or constructs [28, 29]. The model of Banister considered athletic performance to be measurable as the net outcome of two key training responses, also called fitness and fatigue, from the application of a training impulse. The original works by Banister and colleagues [24, 25] applied a systems theory to evaluate the response to physical training using a mathematical function. In this mathematical model, performance is the output, with the athlete regarded as the system, and the training impulse as the input [24, 25]. The functional relationship between the training impulse and the system response is expressed by two differential first order equations attributed to the antagonist effects that were called fitness and fatigue [24, 25]. The PerPot metamodel [26, 27], simulates the interaction between load and performance in adaptive physiological processes in sport, by means of antagonist dynamics (response flow and strain flow). The components of the PerPot [26, 27] have some similar theoretical characteristics to Banister and colleagues, [24, 25] such as the concept of antagonist role of strain and response potential, whilst using a different computational approach. Finally, we also referred to the joint consensus statement of the European College of Sport Science (ECSS) and the American College of Sports Medicine (ACSM) on overtraining [30] because presented the continuum of the training effects on performance and individual/contextual factors on sport performance.

3.3 Integration with Other Frameworks

While these two models [24-27] included, albeit with different names, a negative and positive component, the theoretical framework of physical training by Impellizzeri and colleagues [15, 16] did not include these two elements. Therefore, we initially attempted to combine the two components (fitness and fatigue) of the IR-Banister model into a new framework. However, there was a conceptual problem related to the definitions, or lack thereof, for the terms ‘fitness’ and ‘fatigue’. Originally, these two terms were arbitrarily used to define two mathematical components reflecting the positive and negative training responses. They were computationally and not conceptually defined since they just represented an assigned name for two “model components of performance ability” and not two theoretical constructs. However, the interpretation of these two terms may result in confusing overlapping with the more generic definitions reported in the literature, making it challenging to achieve a clear understanding of these constructs for conceptualizing into a general framework. For example, the ACSM defines fitness as “a set of attributes that people have or achieve that relates to the ability to perform physical activity” [31]. Fitness has been also operationalized as ‘‘[a set of] measurable health and skill-related attributes’’ that include cardio-respiratory fitness, muscular strength and endurance, body composition, flexibility, balance, agility, reaction time and power [32]. These definitions refer, however, to a set of attributes which are outcome measures (output) and do not reflect the fitness component of the IR Banister model (input). Similarly, this problem also relates to the many definitions of fatigue [33-35], none reflecting the second input variable of the Banister model and even the strain of the PerPot. Indeed, fatigue is a complex construct that can be interpreted in terms of an acute reduction in muscle force/power, higher perception of effort, task failure, a mood dimension or as a symptom of disease depending on the context [36, 37]. Whilst some kinds of fatigue can be considered negative effects of training, the term fatigue cannot be used as a synonym of negative effects because fatigue is not the only negative effect of training. For example, training can induce muscle damage and delayed-onset muscle soreness (DOMS) [38] and other negative alterations in mood such as an increase in depression [37]. Therefore, whilst we considered it worth adding these two competing components, we decided not to use the terms fitness and fatigue due to the above issues. We then replaced “fitness” and “fatigue” in Banister’s model, with positive and negative training effects. This was still consistent with the original meaning of these two components that were defined as positive or negative based on their direct effects on performance [24, 39]. Additionally, it was also compatible with the PerPot model where Perl described the antagonist dynamics as: "*the same load input has two contradictory effects, namely the performance increasing response flow* [our positive training effects] *and the performance decreasing strain flow* [our negative training effects]" [27]. However, we did not want to use the term strain and response, as in the PerPot model, since these terms are loaded and may create confusion in the physical training context. We also specify that the PerPot model can be applied to various "performances" and not necessarily competitive performance. In the PerPot model, performance is a generic term that can include biological and physiological outcomes (e.g., hemoglobin and heart rate) [26, 27, 40].

In a further evolution of our conceptual framework, we expanded the training effect construct with the additional acute and chronic dimensions. Below, each section of the conceptual framework is described in further detail. Finally, we integrated the ECSS/ACSM [30] overtraining framework to define the possible sport performance outcomes resulting from the balance between positive and negative training effects.

3.4 New and Expanded Constructs

Above we identified the lack of the two positive and negative training effects in the previous framework [15, 16]. We therefore adapted the previous framework to overcome this limitation and to integrate, elaborate and clarify constructs and concepts of existing frameworks. Specifically, we identified and conceptualized four constructs that could be integrated or extended. An iterative process was utilized to determine the final version of the conceptual framework.

The first construct we expand and integrate is the *training effect*, which in the previous framework [15, 16] was mixed with the generic notions of 'adaptations' and of training outcome. However, it did not constitute a formal and defined (measurable) construct of the framework. We acknowledge that the lack of the training effect construct may have contributed to confusion, where measures of effects occurring *after* the training session have been misinterpreted as measures of internal training load [41], which is by definition the psychobiological response *during* the exercise(s) constituting the training session [16].

The second aspect we more formally clarified is training effect *measures*. The training effect can be assessed in several ways, including using proxy measures when the training effect of interest cannot be directly quantified. This is an important clarification since the validation process may also refer to proxy measures, e.g. whether measures are adequate reflections of the construct of interest.

The third construct we further articulate is sport performance outcomes. The previous frameworks of Impellizzeri et al. [15] and Impellizzeri et al. [16] used the term 'training outcomes' which does not properly differentiate between the chronic training effect and sport performance outcomes. In the current conceptual framework, these two constructs are differentiated and sport performance outcomes further elaborated by including the potential range, i.e. from improvement to overtraining.

The fourth construct we expand on is individual and contextual factors (e.g. training status, health, nutrition and environmental factors). In the previous frameworks, [15, 16] contextual factors were only mentioned as aspects influencing internal load and thereby training outcomes. Here, we clarify that modifiable and non-modifiable individual/contextual factors have a more widely integrated relationship with all components of our conceptual framework, including bidirectionality with training effects. These four areas are further discussed in the next section.

4 Conceptual Framework

This conceptual framework for physical training is intended to illustrate the relationship between stimulus, training effects and their measures and sport performance. Similar to the previous versions, we wanted to develop a parsimonious conceptual framework presenting the essential measurable components such that it may be elaborated and expanded for specific applications and needs. The internal and external training load constructs have been presented in earlier sections and in previous publications [15, 16] and although essential parts of the current conceptual framework, will not be further discussed here. For the measurement of external and internal load we direct readers to the following reference [42]. Similarly, in a previous publication we have described the process leading to the training prescription [16] consisting in defining the training strategy (plan) considered optimal or acceptable to improve the determinants of the performance of interest. This phase has been condensed in the training prescription box included in the new conceptual framework visually depicted in Figure 1. In Table 1, we have provided the labels used to distinguish each construct or concept and we have explained their meaning by providing the constitutive definitions. For the main constructs we also presented operational definitions and examples of measures, elaborated from a previous version [43]. Operational definitions were presented in generic terms because not possible to specify the variety of all possible measures that can be used to quantify the constructs and their components. For this reason, researchers should provide their reference operational definitions in relation to the conceptualization of the construct. In the following sections we provide details of the additional or modified constructs: training effects, sport performance outcomes, and individual/contextual factors.

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4.1 Training Effects

The main new construct added to this conceptual framework is “training effect”, which is the combination of four possible effects denoted by four quadrants (Figure 1). These four quadrants represent the possible acute/chronic and positive/negative effects that can influence sport performance and interact with each other, i.e. all combinations. We decided to conceptualize acute and chronic training effects according to two related criteria: the amount of training required to induce a measurable effect and the time needed to return to baseline once training is stopped. Acute and chronic are common terms used in several fields (medicine, psychology, physiology, etc.) to define effects or conditions in relation to duration; in some areas such as medicine they may also indicate intensity but not in the current context. Clearly, it is not possible to dichotomise the temporal criteria since they should be seen as a continuum, where acute or chronic can just be described as conditions, effects, symptoms, responses occurring (and/or disappearing) after a short or extended period of time. From an operational and practical point of view, it may be reasonable to use the duration of a microcycle as generic reference, and hence training effects that occur after a single training session or few training sessions (e.g., up to one week of training which is the typical microcyle duration) may be classified as acute, whilst training effects occurring after longer periods of training requiring more microcycles can be classified as chronic (cumulative effects over weeks, months, years). A similar time frame may be used with regards to return to baseline: training effects requiring a short period to disappear may be classified as acute, whilst those lasting longer as chronic. This is consistent with some standard testing operating procedures in both research and practice, that also fits the current framework and proposed classification. Indeed, it is common to test athletes after a period of recovery such as few days of reduced training load or at the end of a recovery microcyle, typically one week [44]. This is important in order to limit the negative effects, such as acute fatigue, induced by the preceding training. Accordingly, testing for examining efficacy of training should try to isolate and measure the chronic effects by reducing the negative acute effects. However, for some training strategies, you may need more weeks (e.g. up to three or four) to show benefit such as after intense plyometric training [45] and heavy sled sprinting [46] . Therefore, it is important to highlight the difficulty of suggesting clear benchmarks when defining acute and chronic effects based on specific time frames. Consequently, understanding whether an effect (positive or negative) is acute or chronic is a qualitative approach, informed by the literature and experience, and context dependent. Acute and chronic should be seen more as a continuum than a strict dichotomy.

The training effect can be both positive or negative and, as indicated by the conceptual framework, can occur concurrently. In other words, a positive effect (increased muscle protein synthesis after resistance training) [47] may be accompanied by a negative effect (neuromuscular fatigue) [48]. With the terms positive and negative, we indicate an acute or chronic effect that directly improves (positive) or directly impairs (negative) the sport performance outcome. This definition is consistent with the original Banister (and PerPot) model, where effects referred directly to performance [24-27]. More specifically, however, our use of the terms negative and positive qualifies the direct effects but does not necessarily imply that their indirect effects are also positive or negative. For example, glycogen depletion has a *direct* negative effect on endurance performance [49]. However, training in a glycogen depleted state can enhance activation of key cell signaling kinase transcription factors and transcriptional co-activators, resulting in a coordinated up-regulation of nuclear and mitochondrial genomes [50, 51] (*indirect* positive effect).

Therefore, whilst the *direct* effect of glycogen depletion is negative, its *indirect* effect by enhancing mitochondrial biogenesis can have a positive effect on endurance performance [50, 51].

As mentioned previously, we have introduced acute and negative training effects to conceptually integrate the two competing components from previous models (fatigue and fitness in the IR Banister model and strain and response flow in the PerPot model) [24-27]. However, a fundamental difference with these models is that while we integrated the concepts of two competing effects, we did not identify these effects with the input measures as in their models, where inputs are measures of external training load. Indeed, while we provided a conceptual framework, the aforementioned models aimed to predict performance outcomes using computational methods. Nevertheless, the current conceptual framework is coherent with these two models since they tried to predict performance outcomes by using external training load measures as proxies (surrogates) to quantify the negative and positive effects, with the balance between these two competing effects determining the performance. The use of these proxy measures is conceptually supported by the causal relation between *training* effects and *training* load. The two models differed in the way the negative and positive effects were computationally determined, but they both fit into the current conceptual framework, supporting the plausibility of our proposal.

4.1.1 Measures of training effects

The components included in the training framework are constructs for which, commonly, there are no gold standards, but there are various measures, including surrogate (proxy) measures reflecting the construct. New candidate measures can be proposed but they necessitate proper validation before implementing in practice and research, and the current framework provides the conceptual model to develop testable hypotheses to support their validity. Here we present and discuss some examples of training effect measures that we have classified, for simplicity, in four main categories as presented in Figure 1: 1) performance measures, 2) physiological measures; 3) subjective measures, 4) other measures (cognitive, biomechanical, etc.).

4.1.1.1 Performance Measures

Performance measures are measures of performance during a task that is either related to competitive performance or that is thought to measure a specific fitness component (e.g., strength). An example of such measures commonly used in sport is the countermovement jump (CMJ) test. As many other measures of training effects, the CMJ test can be used in two ways. Firstly, to quantify neuromuscular fatigue [52, 53] as an acute negative effect of training. In this case, the CMJ test can be performed after the training session (or the day after) and a reduction compared to the values in rested conditions is a measure of neuromuscular fatigue [54, 55]. The second use of the CMJ test is to measure the chronic effect of training on lower body power (proxy measure) or jumping performance. For this purpose, conditions need to be standardized to limit as much as possible the influence of acute training effects and contextual/individual factors. For example, by reducing the training load and allowing recovery from neuromuscular fatigue and by controlling time of testing and sleep, nutrition, motivation before and/or during test [56]. Standardization has the dual roles of increasing reliability [10] and providing a measure reflective of a chronic training effect [44]. Other examples of performance measures that are used to assess acute and/or chronic training effects are agility tests, sprints and multistage fitness tests [57-60].

4.1.1.2 Physiological Measures

There are various physiological measures that may be suitable for monitoring acute or chronic training effects. The better validated and most widely adopted are the physiological measures used to assess the positive chronic training effects of endurance training. These measures include maximal oxygen consumption, running economy and lactate threshold [61-63]. Although critical power or critical velocity are often considered measures of a physiological construct [61], we have arbitrary classified these as performance measures as they are based on performance during time to exhaustion tests or time trials.

Another variable often monitored in athletes is creatine kinase (CK) because the elevated CK levels that may occur after eccentric and/or unaccustomed exercise are used as a proxy measure for muscle damage which is an acute negative training effect [64-66]. Another example of physiological measures is the assessment of central and peripheral fatigue using electrical or magnetic stimulation. However, contrary to the CMJ test mentioned earlier, these tests are less frequently utilized in practical settings due to the expertise required and need for specialized equipment [67, 68].

A physiological measure that can be used to measure both acute or chronic training effects is heart rate variability (HRV). Indeed, HRV can indicate acute post-exercise perturbation and recovery of the cardiac autonomic system (acute training effect). Additionally, HRV can signify chronic adaptations to training by means of vagally mediated indices (chronic training effect) [69, 70].

4.1.1.3 Subjective Measures

Subjective measures are now commonly used for monitoring the training process. However, whilst the use of subjective measures is considered sound [71], this area is characterized by the widespread use in sport research and practice of improperly validated instruments [1]. Among the most utilized in research and practice (also implemented in athlete management systems and commercial software), are the so-called “wellness” items [1]. However, it is difficult to understand why the term “wellness” is used, given the lack of clarity surrounding this construct, and why it would be relevant in the training process. For example, is it intended to measure training effects (acute or chronic) or individual/contextual factors? The wellness items, depending on the versions, are supposed to measure fatigue, sleep quality, stress, muscle soreness, enjoyment of training, irritability, health causes of stress and unhappiness [72, 73]. Even ignoring that these items have not been properly validated, it is not clear whether these items are supposed to measure acute effects, chronic or individual and contextual factors; that can be influenced by the acute training effects. Nevertheless, among the items, fatigue and muscle soreness are good candidates as measures of acute training effects. Constructs such as stress, irritability and unhappiness appear more as individual/contextual factors or chronic effects. However, this is speculative as no framework has been previously provided or used as reference. Therefore, we are using a “reverse engineering” approach, starting with the measures used and going back to understand what components of the training process they are supposed to measure. As such, it is difficult to suggest practical subjective measures of acute training effects other than muscle pain, which is a validated measure, and fatigue for which single and multiple item instruments exist but they should be validated in the athletic populations [74-76]. This highlights that a reference conceptual framework for validating these measures is needed.

4.1.1.4 Other Measures

There are other potential measures that can be used to assess acute or chronic training effects. These include biomechanical (e.g. force-velocity profile, acceleration load) [77] or other more area specific measures such as cognitive tests [78, 79]. For instance, assessment of acute training effects has been examined using cognitive function tests, such as the Stroop and response time tests, in elite cyclists and ultramarathon runners [78, 79]. We have provided examples of measures that can be relatively easily implemented in practice (e.g. jump tests, CK, HRV). However, there are other measures that theoretically can be used but because of their complexity are relegated to the research area such as measures of mitochondrial biogenesis, muscle protein synthesis and markers of various signal transduction pathways [80]. Whilst these cannot be measured in a practical manner (e.g. in a field setting), it does not mean they should be disregarded, as they play an integral role within the physical training process. Frameworks can be used to organize and contextualize fundamental science when thinking about training and its possible effects.

4.2 Sport Performance Outcomes

Sport performance outcomes are the result of the balance between positive and negative training effects, again consistent with the IR-Banister and PerPot models [24-27]. We provide a possible range of sport performance outcomes according to the ECSS/ACSM consensus on overtraining [30]. These include improvement, no change, and then a progression from functional to non-functional overreaching and finally over training [30]. Functional overreaching is used to improve performance and often applied during normal training cycles. It involves intensified training, which generally results in reduced performance, however after adequate rest an athlete’s performance will improve relative to baseline levels. Conversely, if intensified training continues, without adequate rest, this may result in non-functional overreaching causing decrease in performance or stagnation potentially lasting for several weeks or more [30]. Despite this, with appropriate rest an athlete should fully recover. Towards the end of the continuum is overtraining in which performance decrement may last for months.

4.3 Individual and Contextual Factors

Contextual factors can be defined as all the factors not part of the main process (training) such as environmental, social and cultural factors [81]. Individual factors are characteristics of the individual athlete such as genetics, psychological traits and states, training background, etc. These factors interact, influence, alter, facilitate or constrain all the components of the training process [81]. In the conceptual framework, paths are depicted graphically by uni or bidirectional arrows. We conceptualized arrows as representing lines or directions of influence (potential causality). The bidirectional arrow represents a reciprocal nature of interactions between variables. We have included a bidirectional arrow between individual and contextual factors and the training effects constructs. For example, a negative training effect (e.g. increased fatigue) can act as an individual factor subsequently influencing the internal training load in the following training session (indicated by the unidirectional arrow). On the other hand, other individual or contextual factors may also influence the training response (e.g. causing higher or lower negative effects) [82]. The unidirectional arrows indicate that the internal training load resulting from a specific external load will vary based on individual or contextual factors. For example, individual or contextual factors can moderate the effect of residual fatigue on the internal training load elicited by the planned external load. Similarly, modifications of individual and contextual factors can influence sport performance outcomes. For example, psychological status, nutrition (interventions or cultural aspects) or recovery strategies may impact sport performance outcomes, in either a negative or positive way [83-86]. Hypoxia induced by altitude training is an example of a contextual factor that can influence all the training process components, and that can be influenced by other contextual factors and interventions [87, 88]. Clearly, some individual and contextual factors are modifiable (health, nutritional status, environmental conditions, etc.) and others non modifiable (e.g. genetics, training history, etc.). We clarify that forms of training other than physical may be classified as contextual factors, that is strategies altering individual factors that can influence performance (e.g. mental or cognitive training) [89, 90].

5 Examples of Practical and Theoretical Applications of the Conceptual Framework

5.1 Training Monitoring

One practical utility of this conceptual framework is its application to training monitoring, that is the identification of the measurable components and their role within the training process. The conceptual framework together with the operational definitions allows us to understand what components to measure and why, thus also facilitating the interpretation of the measures. As another practical example of application, it can be used to adjust and adapt the training process and periodization plans. Typically, periodization for athletic preparation focuses on the exercise component, by developing a program using external load, eventually estimating the induced internal training load using background knowledge and available evidence. In parallel, the planned external training load can be adjusted based on athlete responses and feedback [91]. This is an approach that may also require coaches to use heuristic methods [92]. Our conceptual framework does not present any innovative strategy in this regard [93], however it may assist in accommodating training based on individual responses by taking advantage of the measures that are nowadays possible to collect. We provide a model according to which the measures (type and timing) are selected based on what construct we want to quantify and for what reason (to measure an acute or chronic effect, an individual factor, etc.).

Overall, the measures of the component of the training process can assist in identifying and developing measures useful for informing decisions, controlling training load and determining if responses are progressing as intended, and/or the program needs to be modified. For example, a negative effect that is planned is not necessarily a problem. However, when a negative but unplanned effect occurs, this may be a signal of something amiss or something is changing (e.g., in contextual and individual factors). Therefore, modulation of external training load using feedback from the training effects, which are influenced by individual and contextual factors (bidirectional), may provide a supplementary "optimization" of the training process. With the term "optimization" we mean a training process which is flexible enough to be modified based on individual training responses and effects.

Differentiation between acute and chronic effects is also possible. The monitoring of acute training effects over time (time series) allows for the evaluation of trends to see if an acute effect is becoming chronic (e.g. fatigue). By adding a short recovery period (e.g., a few days, one week) this may help identify if this trend indicates a chronic condition or whether this is just an acute and transient training effect (i.e., according to one of the criteria we proposed for the differentiation between acute and chronic). Other strategies to assess acute and not chronic negative effects can be to measure fatigue before and after training, with the difference used as acute fatigue induced by the training. The measure before training can be seen as an integration of an acute-chronic effect with individual and contextual factors. For example, fatigue due to recent and accumulated negative effects (chronic) combined with other factors such as nutrition and psychologically stressful situations outside of training. The difference between pre- and post-training measures of fatigue is the acute training effect.

5.2 Training Tolerance

It is common to refer in the training context to the ability of an athlete to cope with the demands of the training load. For example, to understand whether or how to adjust the training program, i.e. proceeding as planned or needing modification. The “ability to cope” may be defined as training tolerance, which is a “field” term commonly used and can be interpreted as a higher order construct, difficult to directly quantify. The proposed conceptual framework provides the opportunity and method to better define and assess training tolerance. For example, higher-than-normal fatigue (quantified using subjective or performance-based measures) caused by a typical internal training load may indicate lowering in training tolerance. Also, for consideration is the external training load, where for example, high levels of muscle soreness are to be expected when training includes eccentric exercise or in unaccustomed athletes [64, 94]. However, if high levels of muscle soreness are reported after training, including primarily concentric exercise in accustomed athletes, this acute negative training effect may be indicative of poor training tolerance.

5.3 Performance Readiness

As mentioned in previous sections, subjective instruments may be used to assess training effects. Unfortunately, commonly used subjective measures have not been properly validated and as a consequence it is unclear whether they are actually measuring what they are supposed to measure, and what their role is within the training process. However, using a reference framework assists in understanding how, why and what constructs we wish to measure to support and understand the training process. Not without reason, the COSMIN guidelines require a reference framework for evaluating the validity of an instrument.

Understanding of the necessity and application of frameworks in the validation process is a conceptual matter grounded in research methodology. To explain how a framework can be used in the validation process, we provide an example of performance readiness, a construct widely used in sport settings, although never properly or clearly conceptualized [56]. The lack of conceptualization is evident from the measures used to assess this construct, and variations of the descriptors (e.g. player readiness, readiness to train). Furthermore, the same items for measuring wellness are also used for assessing performance readiness [95, 96]. It is questionable how it is possible that the same items can measure two constructs. In an effort to provide an explanation, we speculate they implicitly represent two different but related constructs. Differentiating between these would require separate constitutive and operational definitions, from concept elicitation studies. Unfortunately, no such information or research exists. For exemplificative purposes, we refer to "wellness" to identify items commonly used in the sport science literature under this name [1]. The link between the two constructs can be hypothesized using the conceptual framework. Wellness items may reflect training effects, with performance readiness as a higher order construct influenced by or "incorporating" these subjective training effects. In one of the few attempts to provide an operational definition, Ryan and colleagues [97] proposed that optimal player readiness is a condition where an athlete has no impairment of physical performance, no mental fatigue or excessive psychological distress, and which represents "the athlete's capacity to complete training activities and perform during competition". This is consistent with the use of this construct in the literature that refers to subsequent performance or physical training [98, 99]. Using this definition (others may be possible), physical performance seems to be the criterion for validation. Therefore, the lack of association between candidate training response effects, assumed to be related to performance readiness and hence subsequent training or competition physical performance, would not support the validity of these items as measures of performance readiness [98]. However, they still may be valid measures of training effects. For example, fatigue perception can be a valid measure of acute training effects, although may not be related to subsequent physical performance (e.g. high fatigue corresponding to lower external load) and therefore cannot be used for assessing performance readiness, or readiness to train.

To further illustrate, we provided hypothetical examples for items assumed to measure a subjective training effect that may be related to performance readiness. In figure 2A and 2A, we presented two reference models and various testable hypotheses that may be derived. Depending on the hypothesized relations, the presence or lack of associations provide or do not provide evidence for validity of these items as measures of performance readiness. In example 2A, we hypothesized there is no interest in the correlations between physical performance and the single items assumed to measure a training effect but in the association with a summary score (assuming the summary score has been validated). In example 2B, our interest is specifically the single items of which some are *not* expected to be correlated with performance readiness. In that case, even if the items combined measure a specific training effect construct, our focus is on single items as we are interested in their isolated association to another construct, which is performance readiness. Simply calculating all possible correlations would not be useful without a reference framework, and associations would not be interpretable. Exploratory correlational studies are clearly possible, but at least two issues should be considered. First, the finding can only be used to generate hypotheses that need to be subsequently tested and are not findings that can suggest how or whether to implement these items in the monitoring process. Second, the multiple associations increase the risk of alpha inflation, and this should be considered when interpreting the results and/or building hypotheses based on the findings.

These are hypothetical examples and although based on background knowledge and theories, different kinds of relations and/or causal structures can be hypothesized and tested. However, in validation studies these predictions should be explicitly declared and the conceptual framework (or theory) supporting these hypotheses should be presented. Similarly, the nature and real goal of the study should be explicitly reported (e.g. confirmatory, exploratory), thus limiting the risk of p-hacking and HARKing (hypothesized after results are known). Again, we underline it is important to differentiate whether a measure is an attempt to quantify an effect, an individual or contextual, or an effect influencing individual or contextual factors. It is also important to understand how single items, or composite scores, are supposed to influence the associated constructs. This can have a profound effect on the validation process and interpretation of the results. Validating measures is theoretically complex and for this reason necessitates a reference conceptual framework.

>>>>>> **INSERT FIGURE TWO ABOUT HERE**<<<<<<

6 Limitations

Given the qualitative approach of this study, researcher bias is a potential limitation that should be acknowledged. We have assumed, as generally accepted, that optimizing training using measures of the constructs of the training process is superior in terms of sport performance outcomes. However, this assumption is based on existing training theory, experience and inductive reasoning, but not experimental studies. Furthermore, we have purposely revised our previous framework and not created a new one. Finally, our conceptual framework provides a *tentative* theory of the phenomena under investigation (physical training), and may need refinement, verification or further explanation.

7 Summary and Conclusion

A conceptual framework synthesizes evidence by conceptualizing a phenomenon. Furthermore, it allows for a rigorous, valid and reliable research process, and may serve as a practical tool for interpretation of measures collected in training monitoring. In the development of our conceptual framework, we have built on existing frameworks and models to better explain the training process and its outcomes. In this paper, we have described the conceptual framework development process and presented constitutive and operational definitions. We introduced and expanded on four constructs: training effects and its possible measures, sport performance outcomes, and individual and contextual factors. Additionally, we explained the relevance and interconnections of these constructs within the training process. The resulting conceptual framework is coherent and fits conceptually available models such as IR-Banister and PerPot. Finally, we presented examples of theoretical (role in the validation process) and practical applications (monitoring, training tolerance, periodization) based on the current conceptual framework. These examples were clearly hypothetical to practically demonstrate how the use of a framework may clarify and explicitly present precise and theoretically grounded testable hypotheses. This is an attempt to provide a useful overarching framework for understanding the scientific literature regarding training and additionally guides the development, implementation, and evaluation of a more comprehensive and transparent approach to athlete monitoring and validation of measures.

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Table 1. Definitions of the constructs and concepts included in the framework

Label of the constructs or concept	**Definitions**
Training prescription	*Constitutive definition:* Short (single training session) to long (multiannual periodization) plans defining the nature and organization of the exercises/training sessions supposed to target factors causally (directly or indirectly) related to sport performance. The training prescription is influenced and adapted based on performance models, contextual and individual factors, training effects, previous training load experienced by the athletes, and coach experience. *Operational definitions:* parameters describing and quantifying the training prescription.
Training load	*Constitutive definition:* Training load can be described as a higher-order construct reflecting the amount of physical training that is actually done and experienced by the athletes and not what was planned, which is training prescription. Within this context, *load* is a generic term which is qualified by the term *training* in a fashion similar to other areas of research that have adopted the term *load* within a variety of contexts (i.e., allostatic load, cognitive load, musculoskeletal load, etc.). Accordingly, *training load* does not specifically define physical quantities like in mechanics given the use of *load*, but it just represents the label assigned to a construct, as aforementioned defined. *Operational definitions:* Training load, as a generic construct, accommodates a variety of measures of various nature and it can be quantified using indicators of external and/or internal training load (see below) such as spatio-temporal, mechanical, psychological and physiological measures reflecting what the athletes do or experience. Training load can also be quantified aggregating and combining measures representing lower-level dimensions such as intensity and volume.
External training load	*Constitutive definition:* External (training) load can be simply defined as 'what the athlete does' and can be observed, i.e. the physical work actually performed by the athlete during the training. Notably, this does not refer to *work* in the physics sense but more so in a generic manner ("to do something that involves physical [or mental] effort", online Oxford dictionary), and the term *physical* (like in physical training) differentiates it from other kinds of purely mental works, such as psychological skill training. *Operational definitions:* the term e*xternal load* accommodates quantification in a variety of manners, enabling the use of a diverse range of measures and metrics. External training load can be measured by quantifying what the athlete does for example using GPS derived units (e.g. speed, accelerations, distance), force, level of resistance, work, etc. It is in the context of the construct quantification that *work* is operationally defined in its physics and not in the generic sense used in the constitutive definition.
Internal training load	*Constitutive definition:* internal (training) load typically refers to the internal (to the body) responses experienced by an athlete *during* the exercise or the training session. Despite internal loads typically being measured using psychological and physiological measures (essentially due to relative ease of application and quantification), the stress and strain experienced by specific tissues in response to an applied force can be also internal and may therefore also fall within this category. *Operational definitions:* internal load can be quantified by using valid measures of the internal responses to the external load. The internal responses can be measured using psychological (e.g. rating of perceived exertion), physiological (e.g. heart rate and EMG) or other kinds of measures representing internal responses during exercise.
Training effects	*Constitutive definition:* effects caused and occurring *after* a single or series of training session. These effects occur at different levels (physiological, psychological, biomechanical, etc.). Components of this construct includes acute and chronic, positive and negative effects (described below). *Operational definitions*: effects can be quantified using (validated) functional, physiological, subjective, biomechanical and other measures of the systems supposed to be influenced by the stimulus provided by the exercise(s) included in the training session.
Acute effects	Effects induced by one or few training sessions (e.g., up to one week of training which is the typical micro-cyle duration) that requires only a relatively brief time to occur and to return to baseline once training has stopped or decreased.
Chronic effects	Effects induced by more micro-cycles of training (cumulative effects over weeks, months, years), that requires a longer time to occur and to return to baseline once training is stopped or decreased.
Positive effects	Acute or chronic response that *directly* improves the sport performance outcome.
Negative effects	Acute or chronic response that *directly* impairs the sport performance outcome.
Sport performance outcomes	*Constitutive definition:* the sport-specific performance outcome as a result of the balance between the positive and negative training effects, and influenced by contextual and individual factors such as genetics, environment, psychological states, level of the opponent(s), etc. More details can be found in the Joint consensus statement of the European College of Sport Science (ECSS) and the American College of Sports Medicine (ACSM) [30]. *Operational definition*: the sport-specific outcome can be measured in various ways using both absolute (time, load lifted, distance, height, etc.) or relative and aggregate measures (such as final ranking, winning/loosing, competitive level, etc.). Lower-level (causal) dimensions or proxies can be used (e.g. measures of tactical behaviour).
Contextual factors	All the factors not part of the main process (physical training) such as environmental, social, cultural factors, etc that can influence the training process or the training outcome (training effect and sport performance).

	These factors have an integrated relationship with all components of the conceptual framework, including bidirectionality with training effects.
Individual factors	Characteristics of the individual athlete such as genetics, psychological traits and states, training background, etc. that can influence the training process or the training outcome. These factors have an integrated relationship with all components of the conceptual framework, including bidirectionality with training effects.