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REVIEW ARTICLE

Periodization: Variation in the Definition and Discrepancies in Study Design

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Abstract

Over the past several decades, periodization has been widely accepted as the gold standard of training theory. Within the literature, there are numerous definitions for periodization, which makes it difficult to study. When examining the proposed definitions and related studies on periodization, problems arise in the following domains: (1) periodization has been proposed to serve as the macro-management of the training process concerning the annual plan, yet research on long-term effects is scarce; (2) periodization and programming are being used interchangeably in research; and (3) training is not periodized alongside other stressors such as sport (i.e., only resistance training is being performed without the inclusion of sport). Overall, the state of the literature suggests that the inability to define periodization makes the statement of its superiority difficult to experimentally test. This paper discusses the proposed definitions of periodization and the study designs which have been employed to examine the concept.

Key Points

Periodization has been proposed to serve as the macro-management of the training process concerning the annual plan, yet research on long-term effects is scarce.

The terms ‘periodization’ and ‘programming’ are being used interchangeably in research leading to confusion over a proper definition.

Training is not periodized alongside other stressors such as sport (i.e., only resistance training is being performed without the inclusion of sport), which may limit the ability to demonstrate the importance of periodization.

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1 Introduction

The theory of training has historically been discussed as a quest for improved physical performance. Particularly, periodization has attracted widespread interest in the exercise and sports science literature. The theory of periodization was published in the Russian monograph by Leonid Matveyev (1964), which summarized information on periodization of training and proposed a general approach to planned training [1]. Since then, this theoretical training concept has spread around the world and later appeared in work by Stone et al. in the United States [2]. Research has been conducted utilizing various periodized models such as reverse linear [3], block [4], and undulating approaches [5]. Although these models differ in structure and supporting rationale, they share a foundation in that they are based on the stress response as outlined by Hans Selye in the general adaptation syndrome (GAS) [6]. According to Selye, if not managed properly, stress will result in a general adaptation syndrome which is typically denoted by tissue degeneration and death. Although there is debate as to whether a general adaptation syndrome can occur following resistance exercise in humans [7–10], sports science developed modern periodization as a means to better manage the stress of exercise and prevent the consequences as noted by Selye (the GAS). Within the sports science literature, the “syndrome” denoted by Selye ended with exhaustion (noted by death of the organism).

This final phase (exhaustion) has been replaced with "overtraining [11]". Thus, periodization attempts to manage the stress of exercise to avoid the consequences associated with overtraining to achieve "peak" performance at a specific time.

Buckner et al. [7, 12] have recently questioned the efficacy of this theoretical framework underlying periodization, and whether periodization is superior to non-periodized resistance training for increasing muscle size and strength. Although this is a debated topic [13], the ability to interpret periodization literature may be hindered by the absence of a universally accepted definition of what periodization actually is. The current works of literature often describe any form of planned training indiscriminately as periodization regardless of the structure [14], making an appropriate definition of periodization difficult to decipher. For example, some definitions of periodization describe the long-term training management of stress [15–17], while other definitions focus more on short-term variations in training variables [18–20]. Furthermore, the scientific strategies employed to examine periodization may not support all definitions proposed in the literature. The purpose of this paper is to review the various definitions of periodization throughout the literature. Furthermore, we will examine the scientific procedures that have been employed to provide evidence for the theory or strategy of periodization.

2 The State of the Definition

There is little agreement on a universally accepted definition of periodization, which may lead to disagreement about what specific components should make up a periodized program or plan. Without reaching an agreement on definition, scientific strategies employed to examine periodization may not be able to appropriately test its efficacy. In other words, do studies measure what they are supposed to measure to examine periodization? To advance the discussion, we created a list of previously used (peer-reviewed articles, textbooks, and expert's opinions) definitions for periodization (Table 1). This examination of the literature is by no means exhaustive. The terms "periodized" and "periodization" were searched on PubMed and Google Scholar. The most cited papers were identified for further examination. In addition, textbooks available to authors were examined for definitions of periodization. From here, references of key papers and textbooks were examined for additional definitions. Due to the extensiveness of this body of literature, it was decided that the search would stop once 80 definitions were acquired. An additional seven definitions were added during the review process. In addition, many papers did not include a general definition of periodization, but provided a definition of a specific model of periodization. Thus, additional 41 definitions are provided in Table 2 which identify a specific periodized model. A similar strategy was used in constructing Fig. 1. 100 periodization interventions were identified to understand the experimental approach employed to examine periodization. When examining the proposed definitions and related studies on periodization, problems arise in the following domains:

- Periodization has been proposed to serve as the macro-management of the training process concerning the annual plan [8, 17, 21], yet research on long-term effects is scarce.
- The terms 'periodization' and 'programming' are being used interchangeably in research leading to confusion over a proper definition.
- Training is not periodized alongside other stressors such as sport (i.e., only resistance training is being performed without the inclusion of sport), which may limit the ability to demonstrate the importance of periodization.

Overall, the state of the literature suggests that the inability to define periodization makes the statement of its superiority difficult to experimentally test. In addition, study designs may align with certain definitions of periodization while failing to address others. The subsequent sections will discuss the proposed definitions of periodization and the scientific strategies which have been employed to examine the concept.

3 Components of Periodization

3.1 Annual Plan

There is a wide array of definitions used to describe the concepts of periodization (Table 1). For example, multiple works of literature have proposed periodization to serve as the macro-management of the training process concerning the annual plan [18, 21–25]. Indeed, it is recommended that coaches begin the planning process by creating a sound annual plan (or larger time-period relevant to the sport of competition) to serve as a road map for the overall training process [17, 21, 25, 26]. The annual plan includes all training, competition, and associated endeavors to project the entire training year, while periodization is used to organize the annual plan into fitness phases and timelines [21–24]. Generally, periodized training can be divided into three stages: the macrocycle (long-length cycle, several months to a year or more), the mesocycle (middle-length cycle, 2–6 weeks), and the microcycle (short-length cycle, several days to 2 weeks) [25]. The structures of the meso- and microcycles are constructed based on the periods included in the macrocycle or annual plan. Thus, periodization divides

Table 1 General definitions of periodization found in the literature

References	Year	Definition
Stone et al. [2]	1981	The basic tenet of periodization is a shift from high volume and low-intensity training during the early season (preparation phase) to an emphasis on high intensity but volume of training (competition phase) during the late season. Technique training also increases during this latter part of the season
Pedemonte [89]	1982	Periodization of training means the scheduled, rational organization of the structure of the entire training process over prolonged periods which acts upon the athletic form in such a manner as to put the athlete in the most suitable condition to obtain his best results during the period of the most important competitions
Willoughby [34]	1993	Strength training that employs the concept of periodization involves the variation in the exercise program. Typically, one periodization cycle, a macrocycle, is performed over the training year, and the macrocycles can be divided into training periods of 2 or 3 months, called mesocycles
Kibler and Chandler [37]	1994	Periodization is a plan for conditioning based on manipulation of the volume (frequency, times, and duration) and intensity of the work an athlete does during various periods of an athletic season
		The goal of periodization is to plan in advance for certain competitions or games, so that peaking of general athletic fitness, sport-specific athletic fitness, and sport-specific skills occurs for these designated competitions or games
Herrick and Stone [41]	1996	Periodization allows for periods of active rest and adaptation of the muscle through variations in intensity, volume, and rest. A program of periodization allows for muscle adaptation according to the principles of the general adaptation syndrome
Fleck and Kraemer [50]	1996	Periodization is a planned, variegated training program where changes are made to ensure long-term fitness gains
		Periodized training, in essence, is nothing more than that—a training plan which changes your workout at regular intervals of time
		Periodization models refer to variations in training that have yielded proven results in increased strength, power, muscle hypertrophy, and athletic performance
Schiotz et al. [51]	1998	Periodization utilizes the theories of general adaptation syndrome, organizing training into cycles of undulating volume and intensity to achieve training objectives, prevent overtraining, and optimize performance
Stone et al. [35]	2000	Periodization may be defined as a logical phasic method of manipulation of training variables to increase the potential for achieving specific performance goals
Brown et al. [19]	2001	A common permutation of periodization is the undulating (nonlinear) model in which training resistance, among other variables, is acutely varied by workout (daily) or by microcycle (weekly)
Freeman [90]	2001	The most effective training plans for today's athletes are very detailed plans that divide the year into phases and microcycles. This method of training is called "periodization"
		Periodization is simply dividing an athlete's training program into a number of periods of time, each with a specific training goal of goals. It is a form of "indexing," developing an objective method of measuring the training load and determining if it meets the athlete's need
Marx et al. [40]	2001	Periodization allows for variation in the training stimulus (i.e., different workouts with different intensities and volumes of exercise) and planned recovery periods to prevent overtraining
Rhea et al. [64]	2002	The concept of periodization can be traced to Selye's general adaptation syndrome, which theorizes that systems will adapt to any changes they might experiences in an attempt to meet the demands of stressors. The goal of a periodized program is to optimize the principle of ''overload'', the process by which the neuromuscular system adapts to unaccustomed loads or stressors
Graham [52]	2002	The cycling of specificity, intensity, and volume of training to achieve peak levels of performance for the most important competitions
Plisk and Stone [15]	2003	Periodization can be defined as planned distribution or variation in training methods and means on a cyclic or periodic basis. The basic goals are to exploit complementary training effects at optimal times, manage fatigue, and prevent stagnation or overtraining. This involves long-term, intermediate-term, and short-term planning. Accordingly, periodized training programs are typically structured into macro-, meso-, and microcycles that progress from extensive to intensive workloads as well as general to specific tasks
Kraemer et al. [53]	2003	The classical model of periodization of resistance training manipulates the intensity and volume of exercise over time with the intent to minimize boredom, prevent overtraining, and reduce injuries

Table 1 (continued)

References	Year	Definition
Smith [91]	2003	Periodization is a process of planning that enables the utilization of correct loads and adequate regeneration periods for avoiding excessive fatigue. It is a systematic and methodological planning tool that serves as a directional template for both athlete and coach. The concept is not a rigid one with only one form of approach; rather, it is a framework within and around which a coach and sport science team can formulate a program for a specific situation
		Periodization is the division of a training year into manageable phases with the objective of improving performance for a peak(s) at a predetermined time(s)
Bompa [23]	2004	In sports training, periodization refers to dividing the yearly training plan into smaller and, therefore, easier to manage training phases. Basically, the periodization of an annual plan has three major phases: preparatory or pre-season, competitive or season, and transition or offseason
Gambetta [92]	2004	Periodization is a systematic attempt to gain control of the adaptive response to training in preparation for competition
Plisk [54]	2004	The use of planned unpredictability to manipulate or outmaneuver another player—which in this case is the body's adaptive mechanism
O'Bryant [38] (roundtable)	2004	Defined as a cyclical approach to training where periodic changes in training parameters (volume, intensity, loading, exercise selection, etc.) are planned in order for the athlete to achieve optimal performance at the appropriate time
Plisk [38] (roundtable)	2004	Planned distribution or variation in training means (content) and methods (load) on a cyclic basis. Macro-, meso-, and macrocycles are the long-, intermediate-, and short-term units, respectively, that periodized training programs are structured into
Stone [38] (roundtable)	2004	A logical phasic method of varying training volume, intensity factors, and exercises to optimize training progress. Thus, periodization is a nonlinear method for planning the training process
Kremer [38] (roundtable)	2004	The basis for periodization is the need for program variation and programmed rest to keep the stimulus effective as one works toward his or her genetic predisposition for a given physiological or performance variable
		A concept that can be defined by programmed variation in the training stimuli with the use of planned rest periods to augment recovery and restoration of an athlete's potential
Fleck and Kraemer [18]	2004	Periodization of training refers to planned changes in the acute training program variables of exercise order, exercise choice, number of sets, number of repetitions per set, rest periods between sets and exercise, exercise intensity, and number of training sessions per day in an attempt to bring about continued and optimal fitness gains
Zaryski et al. [27]	2005	Periodization is a training concept in which the year is divided into large, medium, and small training blocks referred to as macro-, meso-, and microcycles
		Periodization provides a framework which allows a coach to formulate a specific program to achieve improvements in physiologic, technical, or psychologic components of performance. When the sequencing of training is correctly applied through a periodized plan, athletes can achieve a high state of competition readiness and during the months of hard training, avoid the overtraining syndrome
		The underlying concept of periodization is that training should progress from general to specific with the intention of peaking at competition time
DeBeliso et al. [42]	2005	Periodization is a training methodology currently used by athletes, fitness enthusiasts, and rehabilitation specialists to optimize strength and power per individual performance goals. Periodization is a planned means of varying the acute program variables (i.e., intensity, repetitions, sets, mode, order, and rest) in a manner that maximizes gains
Zatsiorsky and Kraemer [24]	2006	Periodization refers to a division of the training season, typically 1 year long, into smaller and more manageable intervals (periods of training, mesocycles, and microcycles) with the ultimate goal of reaching the best-performance results during the primary competitions of the season
Buford et al. [20]	2007	Periodization is the planned manipulation of training variables to maximize training adaptations and to prevent the onset of overtraining syndrome
Cissik et al. [93]	2008	With periodization, each individual training cycle is characterized by periodical adjustments in the objectives, tasks, and content with the ultimate objective being to assist the athletes in reaching a peak level of performance for the main competition(s) of the year. Classically in the weight room, this is done through a shift from high volume and low-intensity training during the early season (preparation phase) to an emphasis on high intensity but low volume (competition phase) during the late season
Issurin [94]	2008	In general, periodization theory exploits the periodic changes in all human biological and social activities. The cornerstones of periodization are made up by a hierarchical system of training units that are periodically repeated

Table 1 (continued)

References	Year	Definition
Peterson et al. [95]	2008	In a traditional periodization model, resistance exercise is systematically carried out to enhance fundamental fitness variables through training in a designated succession and during specified mesocycles
Prestes et al. [43]	2009	Periodization involves systematic training variation accomplished by alternating training volume and intensity, with the objective of optimizing performance and recovery
Prestes et al. [3]	2009	The aim of periodization includes maximizing the overload principle and allowing a better relation between stress/recovery
Jiménez [55]	2009	Periodized strength training refers to varying the training program at regular time intervals in an attempt to bring about optimal gains in strength, power, motor performance, and/or muscle hypertrophy
Ratamess et al. [96]	2009	Periodization entails the systematic process of altering one or more program variable(s) over time to allow for the training stimulus to remain challenging and effective
Foschini et al. [44]	2010	It is believed that intensity and volume are the main factors producing the effects of resistance training on the body. These characteristics of resistance training can be varied in a planned way (periodization) to maximize the principle of overload, and thus ensure the correct stress/recovery relationship
Mann et al. [45]	2010	Periodization is a programed manipulation of several key training variables (rest, overall training volume, sets per workout, repetitions per set, intensity of training, and training frequency) throughout a training cycle
Issurin [30]	2010	Traditional periodization described as the purposeful sequencing of different training units (long duration, medium duration, and short-term training cycles and sessions), so that athletes could attain the desired state and planned results
McNamara and Stearne [68]	2010	The classic strength periodization model typically employs the use of macrocycles, mesocycles, and microcycles to organize the training program. Essentially, this type of exercise strategy starts with high volume and low intensity and then progresses to low-volume and high-intensity training
Fleck [46]	2011	Periodization of resistance training refers to planned changes in the acute training program variables of exercise order, exercise choice, number of sets, number of repetitions per set, rest periods between sets and exercises, training intensity, training volume, and number of training sessions per day in an attempt to bring about continued and optimal fitness gains
Apel et al. [5]	2011	Periodization is a training scheme where planned variations in training variables (e.g., number of sets and repetitions, exercise order, load, and rest) are manipulated in a manner that increases the ability of a person to achieve specific performance goals (e.g., strength)
Kell [97]	2011	Periodization is the use of planned variation of both acute and chronic program variables over the course of a training cycle (e.g., macrocycle) with the intent to induce the desired physiological, technical, tactical, and the like adaptations
Turner [98]	2011	Periodization may be defined as a training plan, whereby peak performance is brought about through the potentiation of biomotors and the management of fatigue and accommodation
Kiely [14]	2012	The archetypal periodized model, exemplified by the writings of Matveyev, was typified by a progressive segmented transition from high to low volume, and low-to-high intensity, accompanied by a simultaneous reduction in training variation as competitive peak approached
Hoffman [22]	2012	Periodization is a method for employing sequential or phasic alterations in the workload, training focus, and training tasks contained within the microcycle, mesocycle, and annual training plan. The approach depends on the goals established for the specified training period
Spineti et al. [78]	2013	Periodization of physical training refers to the manipulation of the methodological variables of physical training divided into logical phases and has the aim to perform specific adjustments for physical performance increase and prevention of overtraining
Chandler and Brown [29]	2013	Periodization is defined as the logical and systematic sequencing of multiple training factors in an integrative fashion to optimize specific physiological and performance outcomes at predetermined time points
		A true definition of periodization must take into consideration that training must be sequenced, integrated, and applied in a logical fashion
Naclerio et al. [99]	2013	Periodization has been defined as the methodical planning and structuring of training process that involve a logical and systematic sequencing of multiple training variables (intensity, volume, frequency, recovery period, and exercises) in an integrative fashion aimed to optimize specific performance outcomes at predetermined time points

Table 1 (continued)

References	Year	Definition
DeWeese et al. [100]	2013	The strategic manipulation of an athlete's preparedness through the employment of sequenced training phases defined by cycles and stages of workload. These workloads are varied to facilitate the integration of planned programming tactics that will harmonize the relationship between training-induced fatigue and accommodation. Further, the process of balancing stress stimuli and recovery periods should be based on advanced knowledge regarding the physiological, biochemical, and psychological principles related to human performance. Thus, an individual's response to training can more effectively be measured and be made apparent through the execution of a comprehensive athlete-monitoring program and ongoing scientific study
Bartolomei et al. [4]	2014	Training periodization is a planned distribution of workload to avoid stagnation in performance improvement and to optimize peak performance for the most important competitions of the year
Horschig et al. [101]	2014	Periodization is defined as a systematic planned variation of program variables in a training program. A periodized program optimizes the principles of "specific adaptation to imposed demands" and the "progressive resistance method" to more efficiently promote desired outcomes such as increased strength or muscular hypertrophy through the continual adaptation responses of the neuromuscular system
Ahmadizad et al. [73]	2014	Periodization of training is a systematic manipulation of training variables to optimize training adaptations and performance
Carter et al. [102]	2014	The concepts and philosophies of modern day periodization allow strength coaches to prescribe systematic, progressive, and specific training programs by manipulating exercise programming variables (i.e., intensity, volume, frequency, mode, consistency, variation, etc.) in a scientific and evidence-based format allowing the athletes to obtain the desired training outcomes
Tønnessen et al. [31]	2015	Training periodization has been described as the purposeful sequencing of different training units (long duration, medium duration, and short-term training cycles and sessions), so that athletes can attain the desired state and planned results
		Periodization could rather be defined as the systematic and appropriate organization and dosage of training-load variables (training intensity, duration, frequency, and mode), both in the short and long term, to achieve peak performance at a specific time or at specific junctures in the competitive season
Lorenz and Morrison [47]	2015	Periodization is defined as the planned manipulation of training variables (load, sets, and repetitions) to maximize training adaptations and to prevent the onset of overtraining syndrome
Hartmann et al. [80]	2015	The primary underlying concept of periodization is to transfer a variety of performance variables (strength, speed strength, and strength endurance) to their highest rate of development with the aim of peaking at a precise time and avoiding stagnation, injury, or overtraining
Harries et al. [16]	2015	Periodization is the systematic planning and structuring of training variables (intensity, volume, frequency, and rest) throughout designated training timeframes aimed at maximizing performance gains and minimizing the potential for overtraining or decrements in performance
Ullrich et al. [48]	2015	The concept of periodization refers to manipulation of training variables such as exercise choice, number of sets, number of repetitions per set, training intensities, and volume
Tammam and Hashem [56]	2015	Periodization is a training scheme where planned variations in training variables (e.g., number of sets and repetitions, exercise order, load, and rest) are manipulated in a manner that increases the ability of a person to achieve specific performance goals (e.g., strength)
DeWeese et al. [17]	2015	Periodization is the logical, sequential, phasic method of manipulating training variables to increase the potential for achieving specific performance goals while minimizing the potential for overtraining and injury through the incorporation of planned recovery
Zourdos et al. [74]	2016	Periodization is a systematic approach to optimize an exercise-training program toward peak performance before a planned competition through time-sensitive manipulation of training volume and intensity
Klemp et al. [57]	2016	A periodized training model involves the planned manipulation of training variables (primarily training volume and intensity) in an effort to maximize performance
Hoover et al. [103]	2016	Periodization is characterized by the dividing of the annual training plan into smaller, distinct phases as a means of separating the program into more manageable segments, and represents the most sophisticated method of preparation for competition
Eifler [104]	2016	One primary distinctive characteristic of periodization models in resistance training is the relationship between training intensity (load) and training volume (volume of repetitions). The primary goal of a periodization model in resistance training is to optimize the principle of "overload", the process by which the neuromuscular system adapts to unaccustomed loads or stressors
Conlon et al. [81]	2016	Periodization is a planning process typically applied in sport performance, aiming to achieve peak physical performance at a predetermined time point(s), for example, major competition, while minimizing the risk of overtraining

Table 1 (continued)

References	Year	Definition
Bartolomei et al. [77]	2016	Periodization is a systematic planning of training to optimize physiological adaptations and prevent the overtraining syndrome
Loturco and Nakamura [105]	2016	Periodization consists of a 'training cycle' divided into different training phases with distinct physical and physiological objectives to enable the best performance from athletes in a competition (i.e., peak performance)
Haff and Triplett [25]	2016	Periodization is the logical and systematic process of sequencing and integrating training interventions to achieve peak performance at appropriate time points
		Ultimately, periodization is a theoretical and practical construct that allows for the systematic, sequential, and integrative programming of training interventions into mutually dependent periods of time to induce specific physiological adaptations that underpin performance outcomes
Colquhoun et al. [75]	2017	Periodization can be defined as the preplanned, systematic variation in training specificity, intensity, and volume organized in periods or cycles within an overall program
Fairman et al. [106]	2017	The division of an annual training plan into smaller training phases, making it easier to plan, monitor, and adjust a training plan in an effort to optimize key outcomes
		Periodization structures training phases to focus on specific physiological characteristics to develop the highest possible levels of strength, hypertrophy, and endurance, among others
Williams et al. [13]	2017	Periodization is a logical method of organizing training into sequential phases and cyclical time periods to increase the potential for achieving specific performance goals while minimizing the potential for overtraining
		Periodization is considered an integral part of the training process and provides the conceptual framework for designing a training program
Kiely [32]	2017	Many periodization approaches exist, each offering differing rationales and templates for the sub-division of the program into sequential, specifically focused training periods designed to prepare athletes for peak performance during prioritized time frames
Grgic et al. [33]	2017	Periodization enables systematic, sequential, and integrative scheduling and programming of training sessions to maximize specific physiological adaptations underpinning performance outcomes
Pelzer et al. [76]	2017	Periodization of resistance exercise programs refers to systematically manipulating training variables such as volume and load and has regularly been applied in various populations and training periods
Conlon et al. [107]	2017	The process of organizing resistance training variables (load, volume, and frequency) within a training program is typically referred to as periodization, and can be complex in nature, particularly in a high-performance setting where specific training outcomes are warranted at pre-determined timepoints
Housh et al. [58]	2017	Periodization involves systematic changes in the resistance, number of repetitions, and/or number of sets of a resistance training program
Vargas [59]	2017	Periodization is a concept of manipulating training volume and intensity over given periods of time to most efficiently elicit improvements from a training program
Mujika et al. [108]	2018	Periodization should be considered a flexible concept or method, rather than a rigid model, and a systematic attempt to gain control of the adaptive response to training in preparation for competition
		Rather than a rigid concept, periodization could be seen as a framework within and around which a specific program can be formulated for a specific situation. In this respect, the essence of a periodized training program design is to skillfully combine different training methods to yield better results than can be achieved through exclusive or disproportionate use of a single method
Cunanan et al. [8]	2018	Periodization is a term that describes the macromanagement of the training process with respect to time. In other words, time is allocated toward various fitness phases that are strategically aligned in a unilateral fashion toward competition. Conceptually then, periodization is a blueprint that permits the coach to forecast and assign periods of time toward the acquisition and realization of specific fitness characteristics (e.g., endurance, strength endurance, strength, power, and speed)
Boggenpoel et al. [109]	2018	Periodization involves planned training variations relating to the volume, intensity, and frequency of exercises. It also incorporates the principles of training, which are individualization, specificity, progressive overload, and recovery. These principles allow one to objectively assess the individual's capabilities, thereby progressing the exercises in an objective way
Bradbury et al. [49]	2018	Periodization is the process of planning a training program that considers all factors that influence the overall performance of an individual
Suchomel et al. [21]	2018	Periodization is the logical, phasic method of manipulating training variables to increase the potential for achieving specific performance goals. Thus, periodization is the concept used to organize the annual plan into fitness phases and timelines
Afonso et al. [110]	2019	Exercise periodization is defined as the systematic planning of training with the aim of achieving the best performances at specific dates

Table 1 (continued)

References	Year	Definition
Evans [111]	2019	Periodization can be defined as the planned manipulation of training variables to optimize performance at appropriate time points, manage fatigue, and prevent stagnation. These variables (such as volume, intensity, and exercise selection) are varied in a cyclical fashion across training cycles to promote peak fitness levels for targeted competitions
Kenny et al. [79]	2019	Effective training is accomplished by applying the principle of periodization, dividing the entire sport training season into smaller periods of time and training units. Periodization allows for a varied training load over time that enables acute overload and overreaching without overtraining the athlete
Hellard et al. [112]	2019	Periodization is the purposeful sequencing of training units (long-, medium-, and short-term training cycles and sessions) designed to produce cumulated adaptations that peak during major competitions
Myakinchenko et al. [113]	2020	Periodization is the regulation of the content of the training loads (stress on an athlete's organism) and their distribution according to the main training tasks and competition schedule

The table contains 87 general definitions of periodization within the literature. Of these 87 definitions of periodization, 25 represent programming, whereas 62 represent a long-term approach. Some common themes in short-term definition include the manipulation of training variables (i.e., load, volume, frequency, and exercise selections) throughout the training cycle, which has been scrutinized to represent programming as opposed to periodization

the training plan into discrete cycles, phases, or blocks that focus on developing specific physiological adaptations (i.e., muscle hypertrophy, strength, power, speed, aerobic endurance, and others). Over time, the training program will typically progress from general to specific adaptations with the intention of bringing peak performance at competition time [8, 15, 25, 27].

3.2 Phase Potentiation

Another important facet of periodization is the strategic sequencing of physiological adaptations within the annual plan for the possibility of potentiation in subsequent training phases. Cunanan et al. [8] emphasize the efficacy of phase potentiation for long-term programming and the potential adverse effects of improper sequencing. Phase potentiation is the enhancement of subsequent training phases by the delayed (or residual) training effects produced from a previous training phase [21]. For example, prior exposure to strength training that focuses on maximal strength has been claimed to potentiate the gains in the rate of force development during a subsequent training phase that emphasizes power training [28]. Indeed, multiple works of literature and textbooks include phasic or sequential aspects in the definition of periodization [13, 17, 22, 25, 29–35]. For instance, the National Strength and Conditioning Association defines periodization as a: "theoretical and practical construct that allows for the systematic, sequential, and integrative programming of training interventions into mutually dependent periods of time to induce specific physiological adaptations that underpin performance outcomes [25]". Thus, according to many sources, one might define periodization as an organizational approach to training that considers the competing stressors within an athlete's life and creates "periods" of time dedicated to specific outcomes (i.e., strength, hypertrophy, or power). These designated periods are intended to manage the stress associated with exercise, while also creating potentiation in the subsequent training phases.

4 Scarcity of Research on Long-Term Effects

Although many definitions of periodization appear to stress organization of the annual plan and the influence of phase potentiation, experimental studies employed to study the concept of periodization do not seem to match this definition. Of the 100 periodized training studies that examined adaptations to various periodized training programs (i.e., linear periodization, undulating periodization, etc.), 88 followed participants for a 4–18 week time frame (Fig. 1, Table 3). We believe that the duration of these studies is too short to support the efficacy of periodization when the core concepts are modeled around the yearlong plan and phasic adaptations. Although there are some yearlong studies, they have been completed in untrained individuals [36] or published as a case report [31]. This may be problematic as the self-proclaimed goal of periodization is to structure the training process to stimulate specific physiological and performance outcomes at a specific timing (i.e., competition day) for athletes [15, 21, 22, 25, 29, 37, 38]. Therefore, the current works of literature fail to address the long-term effects of phasic structures of macro- and mesocycles, and it is still uncertain whether the effects of periodized training increase, maintain, or diminish over the long-term period of time. This discrepancy may be caused by the presence of varying definitions of what periodization actually is.

Table 2 Definitions of specific models of periodization

References	Year	Definition
Baker et al. [114]	1994	The linear periodized method is characterized by a large initial training volume at a moderate intensity (5X10 RM), with progressive increases in intensity and sharp decrease in volume while working toward a peaking of intensity (3 × 1–3 RM) over typical 10- to 12-week training cycle
Rhea et al. [64]	2002	The classic form of linear periodization divides a typical strength-training program into different periods or cycles: macrocycles (9–12 months), mesocycles (3–4 months), and microcycles (1–4 weeks), gradually increasing the training intensity while decreasing the training volume within and between cycles
		A less used form of periodization called undulating periodization is characterized by more frequent alterations in the intensity and volume. Rather than making changes over a period of months, the undulating model makes these same changes on a weekly or even daily basis
DeBeliso et al. [42]	2005	Linear periodization is characterized by a progression over time (i.e., weeks and months) that increases intensity as volume decreases
		Nonlinear (undulating) periodization varies intensity and volume within 7–10-day training cycles
Buford et al. [20]	2007	Linear periodization is based on changing exercise volume and intensity across several mesocycles
		Undulating periodization is based on the idea that volume and intensity are altered more frequently (daily, weekly, or biweekly) to give the neuromuscular system more frequent periods of recovery
Issurin [94]	2008	General idea of block periodization suggests the use and sequencing of specialized mesocycle blocks, where highly concentrated training workloads are focused on a minimal number of motor and technical abilities. Unlike traditional periodization, which usually tries to develop many abilities simultaneously, the block concept suggests consecutive training stimulation of carefully selected fitness components. The rational sequencing of specialized mesocycle-blocks presupposes the exploitation and superimposition of residual training effects, an idea that has recently been conceptualized and studied
Peterson et al. [95]	2008	Undulating periodization includes diverse training stimuli to induce multidimensional fitness parameters concurrently. It is characterized by frequent ‘‘nonlinear’’ fluctuations in prescription variables that may elicit a specific array of physiological fitness components
Prestes et al. [43]	2009	The classical method of linear periodization divides typical strength training into different periods or cycles: macrocycles (9–12 months), mesocycles (3–4 months), and microcycles (1–4 weeks), increasing intensity gradually while training volume is reduced between and within these cycles as training progresses
		Another form of periodization used is undulating or nonlinear which is characterized by more frequent alterations in intensity and volume
Prestes et al. [3]	2009	Classical linear periodization divides a strength training program into different periods or cycles: macrocycles (9– 12 months), mesocycles (3–4 months), and microcycles (1– 4 weeks), gradually increasing the training intensity while decreasing the training volume within and between cycles
		Reverse linear periodization follows the modification in intensity and volume, but in a reverse order as compared with linear periodization, increasing volume, and reducing intensity
		Daily undulating periodization consists of increasing and decreasing intensity and volume, with the alterations occurring within the same week; that is, the variation of training components is more frequent and lasts for shorter periods
Kok et al. [63]	2009	Linear periodization is characterized by training that starts with high-volume and low-intensity exercises, with volume reduced and intensity increased as the athlete/trainee works toward a peak, typically over a 10- to 12-week cycle
		Undulating periodization is characterized by a type of periodization in which training volume and intensity undulate on a daily or weekly basis
Hoffman et al. [115]	2009	The steplike alteration of training intensity increases and volume decreases is commonly referred to as the traditional model of periodization. It is also referred to as linear periodization, in which each phase of the training program emphasizes a specific training goal (i.e., hypertrophy, strength, or power)
		Alterations in daily program emphasis would provide the ability for athletes to train for both at the same time. This periodized training model is often referred to as nonlinear or an undulating training model
Monteiro et al. [67]	2009	In a linear periodization, training loads progress from high volume and low intensity, to low volume and high intensity, over the course of several weeks
		In a nonlinear periodization, high-volume and low-intensity sessions are alternated with low-volume and high-intensity sessions within a training week

Table 2 (continued)

References	Year	Definition
Ratamess et al. [96]	2009	The classic (linear) model of periodization is characterized by high initial training volume and low intensity, and as training progresses, volume decreases and intensity gradually increases
		Reverse periodization is the inverse of the classical model in which intensity is initially at its highest and volume at its lowest. Subsequently, over an extended time, intensity decreases, and volume increases with each phase
		The undulating (nonlinear) model of periodization enables variation in intensity and volume within a cycle by rotating different protocols to train various components of neuromuscular performance (e.g., strength, power, and local muscular endurance)
Mann et al. [45]	2010	Classic linear periodization is a breakdown of macrocycles, mesocycles, and microcycles, in which intensity gradually increases and volume gradually decreases within and between cycles
McNamara and Stearne [68]	2010	In an undulating periodization model, more rapid fluctuations occur, and an athlete may train hypertrophy, strength, and power in the same week
		In flexible nonlinear periodization, the athlete's physiological or mental readiness to exercise is determined immediately before the workout
Miranda et al. [69]	2011	Linear periodized training focuses on training volume and intensity variations gradually throughout the year, dividing training into specific mesocycles of 3–4 months. In this model, the first mesocycle involves a higher training volume, and throughout the training period, intensity is increased, while volume decreases every 1–4 weeks
		Daily undulating periodization depicts large changes in volume and intensity with each workout. The volume and intensity variation in shorter periods are aimed to maintain high-performance levels during longer training periods, whereas linear periodization is designed for a peak performance at a planned time
Fleck [46]	2011	Long-term programs of classic, linear, or traditional strength/power periodization programs begin with high volume-low high intensity training and progress toward low volume high-intensity training
		In nonlinear periodization, training intensity and volume are changed much more frequently. In this type of periodization, training zones are changed in successive training sessions, i.e. a different number of repetitions per set are performed from training session to training session
Reiman and Lorenz [116]	2011	Linear periodization is characterized by high initial training volume and low intensity. As training progresses, volume decreases and intensity gradually increases based on changing exercise volume and load across several predictable mesocycles
		Non-linear periodization is based on the concept that volume and load are altered more frequently (daily, weekly, and biweekly) to allow the neuromuscular system more frequent periods of recovery
		Reverse periodization is the inverse of the linear model in which intensity is initially at its highest and volume at its lowest
Apel et al. [5]	2011	Traditional periodization (also known as linear periodization) is divided into three cycles. Generally, within each cycle, there is a large initial training volume at a moderate intensity progressing to an increase in intensity and a decrease in volume
		Undulating periodization relies more on irregular manipulation of volume and intensity across the training cycle. This type of training has short periods of high-volume training alternated with short periods of high-intensity training, all potentially within 1 week
Kell [97]	2011	Traditional periodization is characterized by a step-loading pattern, gradually increasing volume and intensity
Simão et al. [70]	2012	In linear periodization models, initial training volume is high and intensity is low, and as training progresses through specific mesocycles, training volume decreases, whereas training intensity increases
		Nonlinear periodization involves a dramatic variation of training volume and intensity in shorter periods of time, occurring frequently from one training session to the next
De Lima et al. [71]	2012	Linear periodization increases intensity gradually, while training volume is reduced as training progresses, whereas undulating periodization is characterized by more frequent alterations in intensity and volume

Table 2 (continued)

References	Year	Definition
Bakken [72]	2013	The traditional periodization training model is based on the simultaneous development of many physiological components or target abilities. In the preparation period, high-performance athletes have a mixed training program for simultaneously developing general aerobic and anaerobic ability, muscle strength, endurance strength, basic technique- and muscle coordination, etc.
		Block periodization uses specialized mesocycle blocks, which focus on developing a few selected abilities over a short timeframe. The general idea is implementing specialized training blocks (mesocycle-blocks). These blocks contain highly concentrated training workloads directed to a small number of targeted abilities, enabling a larger training stimulus
Moraes et al. [117]	2013	Daily nonlinear periodization, during which training zones (i.e., 4–6, 8–10, and 12–15 repetitions per set) are changed on a training session by training session basis
Bartolomei et al. [4]	2014	Block periodization is based on the original idea of workload distribution that provides a concentrated training stimulus focused on a specific aspect of performance. It is first characterized by an accumulation mesocycle that demands a high volume of work performed at relative low intensity followed by transformation and realization blocks. The block model of periodization is made up of several mesocycles, each with a unique training goal. The progression of training blocks is performed in a logical order, which prepares the athletes for the next training block
Souza et al. [118]	2014	In traditional periodization, the training load progresses from high-volume low-intensity to low-volume high-intensity loads over time
		The undulating periodization alternates between high-volume low-intensity training sessions and low-volume high-intensity sessions within a training week
Smith et al. [119]	2014	Linear periodization is the increase of intensity and decrease of volume over time to achieve peak performance at the end of the training period
		Nonlinear periodization is the continuous variation of increased or decreased intensity and volume throughout a training period (whether it be day by day or week by week)
Horschig et al. [101]	2014	Classical linear periodization emphasizes a breakdown of the training program into time periods or training cycles of macrocycles (9–12 months), mesocycles (3–4 months), and microcycles (1–4 weeks) with ever fluctuating changes in volume and intensity
		Non-linear periodization includes undulating models, in which programming variables such as volume and intensity are changed more frequently such as on a daily or weekly basis
Ahmadizad et al. [73]	2014	Classical linear periodization training is characterized by high initial training volume and low intensity, and as training progresses, volume decreases and intensity gradually increases
		In a daily undulating periodization protocol, the intensity and volume of exercise are different among the sessions performed in a week
Hartmann et al. [80]	2015	Dividing training objectives into consecutive phases to gain morphological adaptations (hypertrophy phase) and neural adaptations (strength and power phases) is called strength–power periodization or block periodization
		Another popular periodization model is based on an undulating load dynamic in which hypertrophy and strength–power phases are alternated every week (weekly undulating periodization) or 2 weeks (undulating periodization). Daily undulating periodization, also called non-linear periodization, is characterized by daily alterations in volume, intensity, and exercise choice or type
Harries et al. [16]	2015	Linear periodization has been described as involving the breakdown of the training year into weekly (microcycle), monthly (block or mesocycle), and multi-monthly (cycle or macrocycle) periods. A key characteristic of linear periodization is an initial high volume and low intensity of training with gradual increases in intensity and decreases in volume within and across training periods
		Undulating periodization is commonly identified as daily undulating periodization or weekly undulating periodization depending on whether volume and intensity of resistance training are manipulated on a daily or weekly basis. Undulating periodization has been described as more frequent, daily, weekly, or biweekly variation of intensity and volume, and generally uses repetition maximum zones to prescribe exercise intensity
Inoue et al. [120]	2015	Linear periodization is a classical form of periodization that divides a typical strength training program into different cycles gradually, increasing the training intensity while decreasing training volume, within and between cycles
		In daily undulating periodization, the intensity and volume are modified daily
Klemp et al. [57]	2016	The linear periodization model modifies training variables every mesocycle (i.e., every 3–6 weeks), whereas a nonlinear periodization program can alter variables daily or weekly
Bartolomei et al. [77]	2016	Weekly undulating periodization is characterized by variations of training contents within each mesocycle and a wave-like distribution of training stimuli

Table 2 (continued)

References	Year	Definition
Colquhoun et al. [75]	2017	A linear periodization model involves the progressive shift from high volume, low intensity in the early stages, to low volume, high intensity in the later portion of the training period
		An undulating periodization model generally varies the volume and intensity throughout a given period, such as a week or month
Williams et al. [13]	2017	Block periodization is based on the concept of concentrating training loads into ''blocks'' to develop specific physiological systems and motor abilities. In block periodization, each training block emphasizes the development of a specific training goal, and when properly sequenced, these concentrated loads produce fitness after-effects that may enhance future training through phase potentiation
		The daily variations at the microcycle level are characteristic of daily undulating periodization, which alters training phases (i.e., endurance, strength, power) or repetition patterns within the week
Grgic et al. [33]	2017	Linear periodization gradually increases training intensity and decreases volume, with these changes being made approximately every 4 weeks
		A nonlinear form of periodization is characterized by more frequent alterations in intensity and volume. Daily fluctuations in intensity and load are often referred to as ''the daily undulating periodization,'' while the periodization with weekly fluctuations is termed ''the weekly undulating periodization''
Conlon et al. [107]	2017	Block periodization classically uses a 4-week block of highly concentrated training targeting specific training outcomes, e.g., muscular hypertrophy or maximal strength
		Daily undulating periodization varies training volume and intensity on a daily basis; hence, there is a more frequent manipulation of the training stimulus
Androulakis-Korakakis et al. [121]	2018	A common approach to powerlifting competition preparation is the use of the traditional model of periodization where the athlete begins with a preparatory period consisting of high-volume training with loads ranging from 70 to 85% 1RM. This is then followed by a gradual reduction in training volume and a gradual increase in training load, moving from the range of 70–85% 1RM to a heavier 80–97.5% 1RM as the competition approaches
Issurin [122]	2019	Unlike the traditional model that proposes concurrent development of many athletic abilities, block periodization presupposes sequencing of specialized block mesocycles directed at developing a minimal number of compatible targeted abilities
Pinto et al. [36]	2019	The classical periodization approach consists of a linear progression, typically moving from general training (high volume/low intensity) toward specific training (low volume/high intensity)
Evans [111]	2019	Linear periodization initiates with high training volumes and low intensities and gradually progresses toward low training volumes and high intensities over the course of several months
		Reverse linear periodization initiates with low training volumes and high intensities and gradually progresses toward high training volumes and low intensities
		Undulating periodization entails more frequent variations in loading that may vary on a daily, weekly, or bi-weekly basis

The majority of these specific models of "periodization" merely represent the components of programming, making it difficult to distinguish between periodization and programming

RM repetition maximum

5 Periodization or Programming?

It has been discussed within the literature that "periodization" and "programming" are separate entities [8, 21, 26, 39]. In short, periodization is a global process that manages the training with respect to time, whereas programming involves the micromanagement of different phases of training by modifying the number of sets, repetitions, exercise selections, volume, load, frequency of training, and rest periods, amongst others [8, 21, 26]. Interestingly, the inconsistency of definitions used in the periodization literature (Table 1), as well as the scientific strategies that have been employed to examine periodization (Fig. 1, Table 3), make it challenging to distinguish between periodization and programming. Many definitions of periodization focus more on short-term variations in training variables [5, 18–20, 38, 40–59]. For example, Fleck and Kraemer (2004) define periodization as the following: "Periodization of training refers to planned changes in the acute training program variables of exercise order, exercise choice, number of sets, number of repetitions per set, rest periods between sets and exercise, exercise intensity, and number of training sessions per day in an attempt to bring about continued and optimal fitness gains [18]". Here, the definition focuses on the acute changes in training variables rather than a global process within the long-term timeframe. This inconsistency is not limited to a

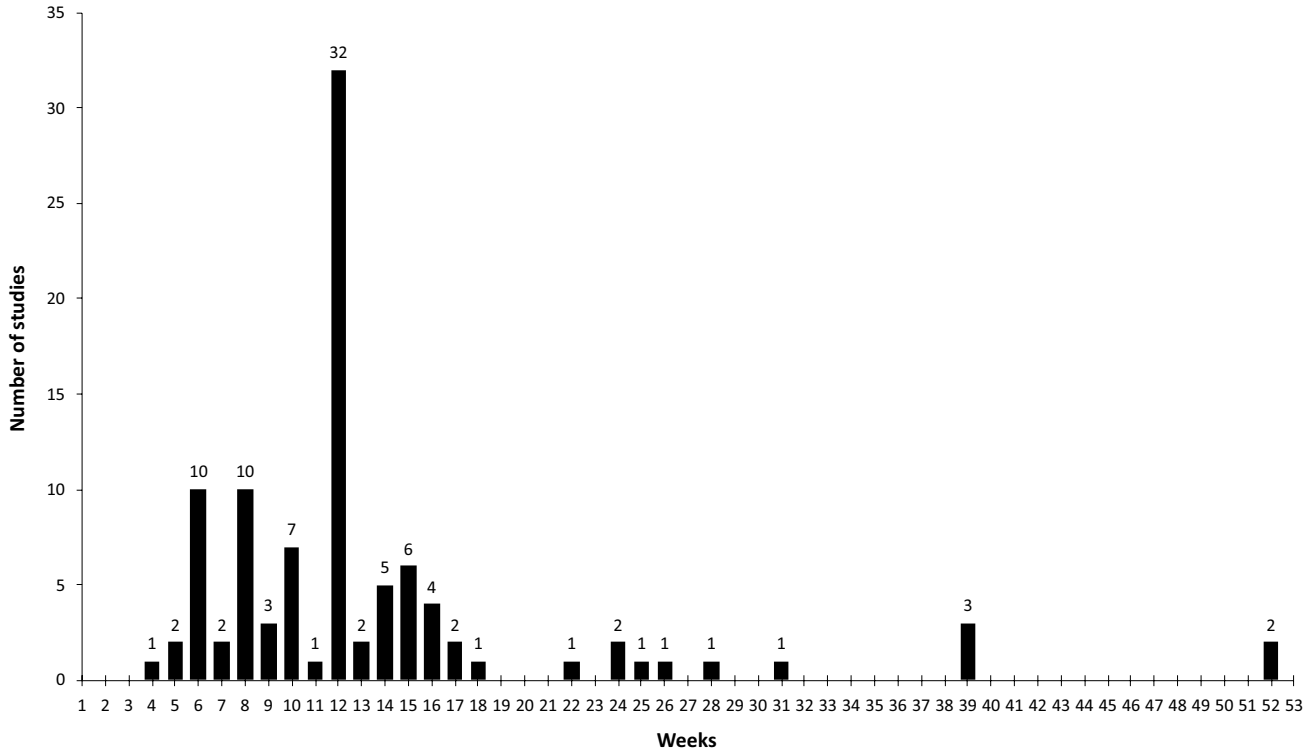

Fig. 1 Numbers of periodized training studies for a given duration. Of 100 periodized training studies reviewed, 88 were examined within a 4–18 week time period. The authors of this review believe that the duration of these studies is too short to support the efficacy of periodization when the core concepts are centered around the year-long plan and phasic adaptations. The details of each study (author, year, subject, design, and duration) are listed in Table 3

few instances in the literature. Table 1 contains 87 general definitions of periodization. Of these 87 definitions of periodization, 25 represent programming [5, 18–20, 38, 40–59], whereas 62 represent a long-term approach. Some common themes in short-term definitions include the manipulation of training variables (i.e., load, volume, frequency, and exercise selections) throughout the training cycle. Such definitions stray away from what many may consider to be the core components of periodization [8, 26], which include the organization of the training plan into different phases and timelines and the management of stress to avoid overtraining. It is unclear which definition(s) of periodization is/are most appropriate; however, it seems that short-term studies have been accepted as the evidence for periodization. Overwhelmingly, the scientific approach to examine the efficacy of periodization [35, 60–65] can only be used as evidence for short term or "programming" definitions of periodization.

The confusion regarding the definition of periodization is further increased by the scientific strategies employed to study the concept. The majority of studies cited as evidence that a periodized resistance training program is superior to a non-periodized resistance training program have utilized study designs that align only with the definition of programming [34, 35, 60, 66]. This is evident in Fig. 1 and Table 3, which illustrate that periodization is being studied using mostly 8–12 week long studies. Many of these interventions focused on the manipulation of resistance training variables to maximize adaptations of muscle size and strength, failing to examine phase potentiation or the long-term projection of performance outcomes. Similarly, modern studies focus more on which model of periodization is superior to others over a relatively short time period [3–5, 20, 43, 48, 49, 56, 57, 63, 64, 67–78]. Table 3 demonstrates that 73 out of 100 periodized training studies utilize the intervention design that compares one periodization model versus different periodized model(s). For example, Rhea et al. (2002) compared the strength gains between daily undulating periodization and a linear periodization program over 12 weeks, and reported that a daily undulating periodized program elicited a greater percentage increase in strength compared to a linear periodized program [64]. Such studies may give some short-term insight, but ultimately they compare different programming strategies against one another and are inconsistent with longer term definitions of periodization.

Table 3 Periodized training studies

References	Year	Subject	Design	Duration
Ronnestad et al. [123]	2014	19 trained male cyclists	Block periodization vs. traditional periodization	4 weeks
Bakken [72]	2013	19 trained cross-country skiers and biathletes	Block periodization vs. traditional periodization	5 weeks
Ronnestad et al. [124]	2016	19 elite cross-country skiers and biathletes	Block periodization vs. traditional periodization	5 weeks
Caldwell [125]	2004	19 males or females ages 18–55 years	Linear periodization vs. daily undulating periodization	6 weeks
Eifler [104]	2016	200 healthy mature subjects with at least 12 months experience in resistance training	Non-periodization vs. linear periodization vs. reverse linear periodization vs. daily undulating periodization	6 weeks
Loturco et al. [126]	2016	23 professional soccer players	Traditional periodization vs. optimum power load	6 weeks
Mann et al. [45]	2010	23 Division I collegiate football players	Linear periodization vs. autoregulatory progressive resistance exercise	6 weeks
Pelzer et al. [76]	2017	19 female university students that had experience with total body resistance exercises of 27.9 ± 4.4 months	Traditional periodization vs. daily undulating periodization	6 weeks
Souza et al. [118]	2014	31 recreationally active male engaged in sports such as soccer, volleyball, and basketball, but not undergoing regular strength training for at least 6 months prior to the experimental period	Non-periodization vs. traditional periodization vs. undulating periodization vs. control	6 weeks
Zourdos et al. [74]	2016	18 male, college-aged powerlifters	Traditional daily undulating periodization (a weekly training order: hypertrophy-specific, strength-specific, and power-specific training) vs. modified daily undulating periodization (a weekly training order: hypertrophy-specific, strength-specific, and power-specific training)	6 weeks
Ronnestad et al. [127]	2019	16 well-trained ice hockey players competing at the highest national level in Norway in their age-group	Block periodization vs. traditional periodization	6 weeks
Ullrich et al. [128]	2018	22 athletes from different team sports such as soccer, handball, basketball, tennis, and field hockey	Traditional periodization vs. daily undulating periodization	6 weeks
Gonelli et al. [129]	2018	20 young male elite Brazilian soccer players	Linear periodization vs. daily undulating periodization	6 weeks
McGee et al. [130]	1992	27 young male (17–26 years) involved in college weight training classes	Group 1: 1×8–12 vs. group 2: 3×10 vs. group 3 linear periodization	7 weeks
Stowers et al. [60]	1983	84 untrained college-age males	Group 1: 1 set to exhaustion vs. group 2: 3 sets to exhaustion vs. group 3 linear periodization	7 weeks
Sabido et al. [131]	2018	15 young male handball players from two different Spanish clubs and without previous experience in strength training	Block periodization vs. daily undulating periodization	8 weeks
Ahmadizad et al. [73]	2014	32 sedentary overweight men	Linear periodization vs. non-periodization vs. daily undulating periodization vs. control	8 weeks

Table 3 (continued)

References	Year	Subject	Design	Duration
Fink et al. [132]	2016	21 young male gymnastics athletes unaccustomed to resistance training volunteered to participate in this study	High load vs. low load vs. undulating periodization	8 weeks
Franchini et al. [133]	2015	13 Male judo athletes experienced with weight training (i.e., more than 6 months)	Linear periodization vs. daily undulating periodization	8 weeks
Klemp et al. [57]	2016	16 college-aged, resistance-trained males	Daily undulating periodization (high rep) vs. daily undulating periodization (low rep)	8 weeks
Marques et al. [134]	2011	12 young volleyball players	Linear periodization vs. non-linear periodization	8 weeks
Schoenfeld et al. [135]	2016	19 trained, male volunteers with a minimum of 1 year of resistance training experience training at least 3 days-per-week and an average experience of 4.7 ± 3.2 years	Constant-rep resistance training vs. daily undulating periodization	8 weeks
Pliauga et al. [136]	2018	10 collegiate basketball players	Block periodization vs. traditional periodization	8 weeks
Vargas [59]	2017	27 resistance trained males (18–45 years), healthy, resistance trained males	Daily undulating periodization vs. Tiered daily undulating periodization	8 weeks
Javaloyes et al. [137]	2019	15 well-trained cyclists (ranging from 18 to 46 years old) with at least a 2-year personalized training history	Heart rate variability vs. block periodization	8 weeks
Buford et al. [20]	2007	28 recreationally trained college men and women	Linear periodization vs. daily undulating periodization vs. weekly undulating periodization	9 weeks
Colquhoun et al. [75]	2017	25 resistance trained men with a minimum of 6 months of experience	Daily undulating periodization vs. flexible daily undulating periodization	9 weeks
Harris et al. [138]	2000	42 previously trained men who had at least 1 year of supervised strength training experience	High force group vs. high power vs. combination group (daily undulating periodization model)	9 weeks
Painter et al. [88]	2018	19 male collegiate level track athletes between 18 and 22 years of age	Block periodization vs. daily undulating periodization	10 weeks
Androulakis-Korakakis et al. [121]	2018	10 competitive powerlifters with at least 1 year of experience and at least 2 years of resistance training experience	Daily max training vs. traditional periodized powerlifting training	10 weeks
Bartolomei et al. [65]	2015	17 recreationally resistance trained women who had participated regularly in resistance training (minimum 1 time a week during the last 2 years) and completed at least 1 bout of squat each week in the last year	Block periodization vs. weekly undulating periodization	10 weeks
Painter et al. [28]	2012	31 division I track and field athletes	Block periodization vs. daily undulating periodization	10 weeks
Schiotz et al. [51]	1998	14 trained college men	Periodized training vs. non-periodized training	10 weeks
Smith et al. [119]	2014	60 experienced resistance-trained American football players on an NCAA Division I football team	Non-linear periodization (hypertrophy-based) vs. non-linear periodization (strength-based) vs. non-linear periodization (power-based)	10 weeks

Table 3 (continued)

References	Year	Subject	Design	Duration
Clemente-Suarez and Ramos-Campo [139]	2019	32 amateur physical active triathletes	Traditional periodization vs. reverse periodization vs. control	10 weeks
O'Bryant et al. [66]	1988	90 healthy college males	Linear periodization vs. non-periodization	11 weeks
Medeiros et al. [140]	2020	58 women aged 50–75 years, who had performed regular physical activity (strength and aerobic training) for at least 6 months for a minimum of 150 min per week	Non-periodization vs. daily non-linear periodization vs. flexible daily non-linear periodization	12 weeks
Apel et al. [5]	2011	42 healthy recreationally active men	Traditional periodization vs. weekly undulating periodization vs. control	12 weeks
Baker et al. [114]	1994	22 males, weight trained at least past 6 months	Linear periodization vs. undulating periodization vs. non-periodization	12 weeks
De Lima et al. [71]	2012	28 sedentary women aged 20–35 years	Linear periodization vs. daily undulating periodization vs. control	12 weeks
Harries et al. [61]	2016	26 sub-elite adolescent rugby union players	Linear periodization vs. daily undulating periodization vs. control	12 weeks
Hoffman et al. [62]	2003	28 freshman football players of an NCAA Division III football team were examined during the course of two separate seasons	Linear periodization vs. non-linear periodization	12 weeks
Kell [97]	2011	60 healthy men ($n=30$) and women ($n=30$)	Traditional periodization (men) vs. traditional periodization (women) vs. control (men/women)	12 weeks
Kok et al. [63]	2009	20 female students who were recreationally involved in social- and amateur-level sports (basketball, soccer, netball, and hockey)	Linear periodization vs. undulating periodization	12 weeks
McNamara and Stearne [68]	2010	16 beginner weight training students between the ages of 18 and 23 years	Flexible non-linear periodization vs. non-linear periodization	12 weeks
Miranda et al. [69]	2011	20 recreationally trained men	Linear periodization vs. daily undulating periodization	12 weeks
Monteiro et al. [67]	2009	27 healthy trained men	Non-periodization vs. linear periodization vs. non-linear periodization	12 weeks
Moraes et al. [117]	2013	38 untrained male adolescents	Non-periodization vs. daily non-linear periodization vs. control	12 weeks
Pacobahyba et al. [141]	2012	24 soccer players in pre-competitive period	Non-linear periodization vs non-periodization	12 weeks
Peterson et al. [95]	2008	14 well-trained firefighter academy attendees	Undulating periodization vs. control	12 weeks
Prestes et al. [43]	2009	40 men ranging from 18 to 25 years of age with a minimum 1-year strength raining experience	Linear periodization vs. daily undulating periodization	12 weeks
Prestes et al. [3]	2009	20 women ranging from 20 to 35 years of age with minimum of 6 months of experience in strength training	Linear periodization vs. reverse linear periodization	12 weeks

Table 3 (continued)

References	Year	Subject	Design	Duration
Rhea et al. [64]	2002	20 men, all subjects reported participating in a strength-training program (at least 2 days per week) for a minimum of 2 years before beginning the study	Linear periodization vs. daily undulating periodization	12 weeks
Simão et al. [70]	2012	30 untrained men from the Brazilian Navy	Non-linear periodization vs. linear periodization vs. control	12 weeks
Spineti et al. [78]	2013	32 men, students from the Brazilian Marine corps sergeant's course	Ondulatory periodization vs. linear periodization vs. control	12 weeks
Stone et al. [35]	2000	21 college-age men meeting following criteria: initial 1RM squat > 110 kg and > 1.3 × 3 body mass and the ability to complete at least 80% of the programmed repetitions	Non-periodization vs. stepwise periodization vs. overreach periodization	12 weeks
Storer et al. [142]	2014	34 healthy men, 30–44 years of age, with a history of exercising 5–7 days per month at the club over the previous 3 months	Non-linear periodization (regimen by individually assigned trainer) vs. self-directed training	12 weeks
Garcia-Pallares et al. [143]	2009	11 male world-class, flat-water kayak paddlers (all of whom were finalists at the World Championships, including two Olympic gold-medalists)	All subjects followed the same strength and endurance program with special emphasis on prioritizing the sequential development of specific physical fitness components in each training phase	12 weeks
Ronnestad et al. [144]	2014	15 male competitive cyclists	Block periodization vs. traditional periodization	12 weeks
Sylta et al. [145]	2016	63 male trained cyclists	Three different HIT models periodized in a specific mesocycle order or in a mixed distribution: the increasing HIT group vs. the decreasing HIT group vs. the mixed HIT group	12 weeks
De Souza et al. [146]	2018	33 recreationally active male college students engaged in sports such as soccer, volleyball, and basketball, but not undergoing regular strength and endurance training for at least 6 months prior to experimental period	Non-periodization vs. traditional periodization vs. undulating periodization vs. control	12 weeks
Gavanda et al. [147]	2019	47 male adolescent volunteers recruited from a German first Division American football team	Block periodization vs. daily undulating periodization	12 weeks
Harries et al. [148]	2018	26 adolescent males (aged 15–18 years) recruited from a rugby union talent development squad	Linear periodization vs. daily undulating periodization vs. control	12 weeks
Rodrigues et al. [149]	2019	54 physically active, postmenopausal women (range age of 50–75 years) who had been engaged in regular multicomponent exercise training	Flexible non-linear periodization vs. non-linear periodization vs. non-periodization	12 weeks
Boidin et al. [150]	2019	39 coronary heart disease patients	Linear periodization vs. non-linear periodization	12 weeks
Tjønna et al. [151]	2019	25 healthy, trained/well-trained cyclists competing for a minimum of 2 years	Traditional periodization vs. block periodization	12 weeks

Table 3 (continued)

References	Year	Subject	Design	Duration
Buskard et al. [152]	2018	36 older adults, 58–80 years of age, lived independently in the community and were college-educated professionals who were either retired or currently actively employed	Linear periodization vs. daily undulating periodization	12 weeks
Barjaste and Mirzaei [153]	2018	18 amateur soccer players with very little experience in resistance training	Linear periodization vs. control	12 weeks
Tammam and Hashem [56]	2015	11 volleyball players of total 16 from Tanta club with minimum 1-year experience of strength training	Daily undulating periodization vs. weekly undulating periodization	13 weeks
Bessa et al. [154]	2018	23 males who compete as world-class wrestlers (24.5 + 3.9 years old)	Matveev periodization model vs. Verkhoshansky periodization model	13 weeks
Bradbury et al. [49]	2018	30 recreational runners, male and female, age range 19–45 with no less than 2-year running experience and a 5000-m personal best less than 25 min	Linear periodization vs. reverse linear periodization vs. control	14 weeks
Foschini et al. [44]	2010	32 post-puberty obese adolescents (BMI > 95th percentile of the CDC reference growth charts), aged 16.50 ± 1.74 years, including 15 boys and 17 girls	Linear periodization vs. daily undulating periodization	14 weeks
Hartmann et al. [155]	2009	40 male sport students recruited from the Institute of Sport Sciences, Goethe University	Strength-power periodization vs. daily undulating periodization vs. control	14 weeks
Kramer et al. [156]	1997	43 male college students recreational weight trainer	Group 1: 1 set to failure vs. group 2: multiple sets of 10 reps group 3: multiple sets with variations, sets and reps (classic periodization)	14 weeks
Ullrich et al. [48]	2015	10 female university students who were recreationally involved in social physical activities (basketball, hockey, tennis, running, dancing), but who had no experience in systematic strength training	Traditional periodization vs. daily undulating periodization	14 weeks
Bartolomei et al. [4]	2014	24 experienced strength trained men who were strength trained at least three times per week for more than 3 years	Block periodization vs. traditional periodization	15 weeks
Bartolomei et al. [77]	2016	18 competitive strength and power athletes competing in wrestling, rugby or throwing events of track and field	Block periodization vs. weekly undulating periodization	15 weeks
Herrick and Stone [41]	1996	20 untrained college women	Classic periodization vs. progressive resistance exercise	15 weeks
Hoffman et al. [115]	2009	51 experienced resistance trained American football players of an NCAA Division III football team	Non-periodization vs. linear periodization vs. planned non-linear periodization	15 weeks
Rhea et al. [157]	2003	60 subjects (men and women) were recruited from college weight-training courses	Linear periodization vs. daily undulating periodization vs. reverse linear periodization	15 weeks

Table 3 (continued)

References	Year	Subject	Design	Duration
Bezerra et al. [158]	2018	30 healthy untrained aging adults	Mixed session periodization vs. traditional periodization vs. control	15 weeks
Willoughby [34]	1993	92 previously weight-trained males	Group 1: 5 × 10 RM vs. group 2: 6 × 8 RM vs. group 3: classic periodization vs. group 4: control	16 weeks
De Freitas et al. [159]	2019	20 older adults with the diagnosis of sarcopenia	Linear periodization vs. non-periodization	16 weeks
Jaimes et al. [160]	2019	29 girls, training experience in skating = 1.5 ± 0.2 years, from the infant category in speed skating of the Speed Cats team of the city of Villavicencio	Linear periodization vs. undulating periodization	16 weeks
De Assis Lauria et al. [161]	2019	16 male non-smokers, non-medicated individuals aged 15.5 (± 1.5) years, all athletes from the basketball team of the Military College of Juiz de Fora	Athletes underwent a 4-month training period, with training frequency of 2 weekly sessions. Training macrocycle with wave periodization, structured in 2 periods, basic and specific, was elaborated	16 weeks
Ullrich et al. [162]	2016	11 adolescent judokas, aged from 14 to 16 years, from regional to elite levels	Athletes performed two 4-week strength training mesocycles with either traditional periodization or daily undulating periodization	17 weeks
Manchado et al. [163]	2018	11 female team handball players who played over 2 consecutive seasons for a Spanish first league team	Traditional periodization vs. block periodization	17 weeks (a cross-over design over two consecutive seasons from August to the end of November)
DeBeliso et al. [42]	2005	Subjects ($n = 60$) included both males ($n = 27$) and females ($n = 33$) in either their 7th, 8th, or 9th decade of life, mean age 71.6 ± 5.3 years (age range = 63–83 years)	Fixed repetition vs. periodized training vs. control	18 weeks
Conlon et al. [107]	2017	41 healthy older adults (female = 21, male = 20; 70.9 ± 5.1 years; 65–81)	Non-periodization vs. block periodization vs. daily undulating periodization	22 weeks
Kraemer et al. [164]	2004	85 untrained but physically active college aged women	Intensity loading ranges were varied over the training program in a following periodized format: Group 1: Upper body (3–8 RM) Group 2: Upper body (8–12 RM) Group 3: Total body (3–8 RM) Group 4: Total body (8–12 RM) Group 5: Control	24 weeks
Marx et al. [40]	2001	34 healthy and active, but untrained women	Low-volume, single set circuit vs. periodized high-volume multiple sets vs. non-exercising control	24 weeks
Hunter et al. [165]	2001	36 old adults aged between 61 and 77 years	High-resistance training vs. variable resistance training (daily undulating periodization model) vs. control	25 weeks

Table 3 (continued)

References	Year	Subject	Design	Duration
Inoue et al. [120]	2015	45 post-puberty obese adolescents	Aerobic training vs. aerobic plus strength training with linear periodization vs. aerobic plus strength training with daily undulating periodization	26 weeks (post-measurement was done after a year, but the duration of training intervention was 26 weeks)
Vanni et al. [166]	2010	27 premenopausal women	Linear periodization vs. undulating periodization	28 weeks
Conlon et al. [81]	2016	41 apparently healthy untrained older adults (women = 21, men = 20)	Non-periodization vs. block periodization vs. daily undulating periodization	31 weeks
Horschig et al. [101]	2014	The patient was an active 17-year-old male American high school football player with a history of anterior cruciate ligament reconstruction of his dominant right lower extremity	The autoregulatory progressive resistance exercise method of periodization was used during the rehabilitation	39 weeks
Kraemer et al. [87]	2000	24 collegiate women tennis players	Single-set training vs. periodized training vs. control	39 weeks
Kraemer et al. [53]	2003	27 collegiate women tennis players	Periodized training vs. non-periodized training vs. control	39 weeks
Pinto et al. [36]	2019	50 patients with coronary artery disease	Linear periodization vs. non-periodization	52 weeks
Tønnessen et al. [31]	2015	8 (males = 6, and female = 2) former and current Norwegian elite orienteers	Athletes included in the investigation recorded their day-to-day training in training diaries designed by the Norwegian Orienteering Association. In these diaries, athletes recorded time spent on different forms of training for each training session, along with the intensity of all aerobic endurance training. In addition, athletes described the session structure in a comments box. For example, interval length, number of repetitions, recoveries, heart rate, and subjective feelings of exertion were recorded, as well as other comments related to the quality of the session	52 weeks

Of 100 periodized training studies reviewed, 73 utilize the intervention design that compares one periodization model versus different periodized model(s). Such definitions stray away from the core components of periodization which appear to be the organization of the training plan into different phases and timelines

RM repetition maximum, *BMI* body mass index, *CDC* Centers for Disease Control and Prevention, *NCAA* National Collegiate Athletic Association, *HIT* High-intensity training

6 Periodization Without Competing Stressors

One of the core concepts included in the definition of periodization is the stress/fatigue management to minimize the risk of overtraining [13, 15–17, 20, 40, 47, 51, 53, 77–81]. Overtraining has been defined as the accumulation of training stress resulting in long-term decrements in performance with or without associated physiological and psychological signs and symptoms of maladaptation [25, 82]. Indeed, some of the symptoms associated with overtraining (i.e., frequent injuries, sleep issues, and burnout) have been reported among various types of sports [83, 84]. In the context of periodization, overtraining occurs when there is an imbalance between the recovery and the summation of all stress related to training and sports events (i.e., sport-specific practices and competitions). Considering that the periodization of training was established to manage stress in conjunction with the sport [85], the management of overall stress plays a role to maximize performance outcomes.

To elicit desired training adaptations while managing fatigue and optimizing performance in line with the seasonal demand of sport, it is recommended to have an annual schedule that includes a preparatory, competitive, and transition phase [25, 29, 38]. Within this structure, the preparatory phase begins with higher volume/lower load training with an emphasis on developing a general physical base (i.e., muscle hypertrophy, strength endurance, and basic strength) to increase an athlete's ability to tolerate more intense training [25]. A competitive phase is used to prepare an athlete for the competitive season by increasing strength and power via increasing training load while decreasing volume [29]. In addition, more emphasis is placed on sport-specific skills and tactics during this phase. The transition phase, often termed active rest, provides lower workloads to recuperate before preparation for the next competitive cycle [38]. Over the course of the year, the manipulation of training volume and load occurs with the intention of peaking performance at competition time. Thus, the concept of periodization would exist when the alteration of those training variables (i.e., load, volume, and frequency) is based around the competition demand in sport.

When coaches prescribe the resistance training program alongside sports practice, the level of the complexity to manage stress is greater compared to performing resistance training alone [39]. Numerous sports require an athlete to improve various types of physiological characteristics (i.e., anaerobic and aerobic capacity). As such, periodized training attempts to manage the total physical demand of an athlete's time spent in sport with that spent on strength and conditioning. Indeed, other stressors should also be considered. For example, Stults-Kolehmainen et al. [86] demonstrated the capacity for psychological factors to influence recovery following strenuous resistance exercise. However, it may be assumed the sport and strength and conditioning provide the two primary physical stressors. Kraemer et al. (2003) investigated whether a nonlinear periodized resistance training program would result in superior training adaptations compared to a non-periodized program in competitive female tennis players [53]. Over the 9 months, the periodized training group rotated the loading schemes; 4–6 RM, 8–10 RM, and 12–15 RM over workouts on Monday, Wednesday, and Friday, respectively. The non-periodized group performed a traditional moderate loading scheme (8–10 RM) in which the relative intensity of load remained constant throughout the intervention. The volume was equated between the groups. Although the authors concluded that periodization of resistance training produced a greater magnitude of improvement in strength and sport-specific skill (the percent increases in the ball velocities for serve, forehand stroke, and backhand stroke) compared to the non-periodized training program, the majority of the strength gains in 1RM bench press were observed during the first 4 months only in the periodized training group. Similarly, the gain in 1RM shoulder press plateaued after 6 months only in the periodized training group. On the other hand, the non-periodized group continued to experience improvements in 1RM of both bench press and shoulder press. By the end of 9 months, 1RM of bench press performance increased by 23% and 17% in the periodized and non-periodized training groups, respectively. In terms of the gains in shoulder press 1RM strength, the periodized and non-periodized groups increased by 24% and 23% after the 9 months of training, respectively. The authors attributed the inability to continually improve over the entire periodized training program to the potential upper limits of physiological adaptation, as the last 3.5 months of training were performed in conjunction with the competitive season [53]. Indeed, the goal of periodization is to balance the stress of lifting weights with the stress of sport and other life stressors. However, the results of Kraemer et al. [53] might suggest that periodization failed to result in continued gains throughout the competitive season. Furthermore, Kraemer et al. [53] did not vary the volume between the periodized and non-periodized groups (athletes performed the same routine the entire study). Thus, any differences between groups would be a result of one condition's habitual programming versus the other group's habitual programming. It seems reasonable to suggest that this study does not study periodization defined by a long-term training plan, but instead studies a version of periodization that is defined as programming. One group had

one program strategy for 9 months and the other group had a different programming strategy for 9 months. The only aspect that may suggest components of longer term definitions of periodization is the mention that the number of resistance training sessions would decrease from three sessions per week to two sessions per week if there was an increase in the number of tennis matches (consideration of competing stressors). However, the change in number of sessions to account for the stress of tennis was the same between periodized and non-periodized groups.

Since periodization attempts to manage the overall stress to avoid the consequences associated with overtraining while increasing performance [8], studies examining periodization would better test the theory when training is periodized against the sport. However, the scientific discussion of periodization seems to occur (often times) without considering the competition demand of sport (i.e., in-season stress), with some exceptions [53, 87]. Procedures employed to examine periodization are rarely conducted with competitive athletes in the yearlong season, and the majority of studies only include the stress of lifting weights (i.e., resistance training program) without adding the stress from sport. Admittedly, this is a difficult concept to study considering coaches and athletes would be reluctant to surrender their strength and conditioning practices for the advancement of scientific knowledge. As a result, there are large gaps between the theoretical concepts of periodization and empirical evidence to support the usefulness of periodization in the context of the sport.

7 Suggestions for Future Research

An examination of the scientific literature studying periodization will quickly lead to the conclusion that periodization has been studied primarily in using short-term study designs (what most would consider the duration of a single or possibly two mesocycles). Within a period of 8–12 weeks, it is unlikely that an individual is at risk of overtraining and would require manipulations in training volume or intensity of load. Using Stone et al. [2] as an example:

> Stone et al. compared a periodized program to a non-periodized program in a group of college aged males enrolled in a weight training class. Both groups trained three times per week. However, the non-periodized group performed 3 sets of a 6 repetition maximum (RM) on all exercises for the entire 6-weeks; whereas, the periodized group performed 5 sets of a 10RM for the first three weeks, followed by 5 sets of a 5RM for week 4, 3 sets of a 3RM for week 5 and 3 sets of a 2RM for week 6. According to the present literature review, the purpose of periodization is to avoid overtraining and potentially peak performance at a specific time. The first part of this definition is not addressed by this study design. There is little to no risk of overtraining from performing 3 sets of a 6RM for 6 weeks. Thus, the purpose of changing volume in this study was not to avoid overtraining. If there is no risk of overtraining, then programming can simply be designed with the intention of maximizing the strength or performance variables that are of interest (1RM squat and vertical jump in the case of Stone et al.).

Although studies like Stone et al. [2] are often accepted as evidence for (or against) periodization, the concept would be better studied in a sport context where there are competing stressors and an opportunity to employ strategic techniques aimed at managing recovery. Painter et al. conducted two studies [28, 88] comparing different periodized programming models in track and field athletes; however, their studies were limited to 10 weeks. Thus, we would suggest study designs like that employed by Kraemer et al. who examined whether a nonlinear periodized resistance training program would result in superior training adaptations compared to a non-periodized program in competitive female tennis players on a 9-month time period [53]. The authors conducted a study where one group performed a different repetition scheme throughout each week (4–6 RM, 8–10 RM, and 12–15 RM on Monday, Wednesday, and Friday, respectively), and the non-periodized group performed a moderate loading scheme (8–10 RM) which remained constant throughout the intervention. This study is set up nicely to compare a periodized program versus a non-periodized program. However, volume was equated between the groups. This is problematic as a periodized program would decrease volume during the sport season to account for sport. Thus, we would suggest that both of these programs actually employed periodization (they both reduced the number of resistance training sessions during the season). Future studies might use a similar study design as Kraemer et al. However, the periodized group should employ specific periods of time dedicated to different attributes believed important for the sport (i.e., hypertrophy, strength, speed/power, and others). At the same time, periodization should consider the total stress of the strength and conditioning program and decreasing training volume when sport demand increases. This can be compared to a group that does a similar rep scheme indefinitely (while still employing progressive overload). The non-periodized group might also continue their normal training throughout the sports season. This study design would reflect the majority of definitions of periodization provided in the literature. Such study designs are undoubtedly difficult, and might be best examined in recreational sport or amateur sport looking to incorporate resistance exercise.

8 Conclusion

Over the past several decades, periodization has been accepted as the gold standard of training theory, yet there is a wide variety of definitions used to describe the concepts of periodization, making an appropriate definition of periodization difficult to decipher. Among others, periodization has been proposed to serve as the macro-management of the training process within the annual plan. However, long-term studies with competitive athletes are scarce. If periodization serves as the macro-management of the training within the annual timeline, any claims made regarding the benefits of periodization should be based on the studies that have a similar timeframe. Nevertheless, the evidence used to support the efficacy of periodization is centered around short-term studies that do not capture the overall picture of the annual process and performance outcomes. Hence, the scientific procedures employed to examine periodization do not seem to line up with the proposed definitions. As such, it is still uncertain whether the effects of periodized training increase, maintain, or diminish over the long-term period of time. Instead, current works of literature focus more on the comparison between different models of periodization over a relatively short time-period. To bridge the gap between the theory and practice of periodization, future research could conduct experiments with competitive and recreational athletes in the context of the yearlong season to advance further discussion. This will include the examination of the effects of each phasic structure associated with macro- and mesocycles, and the long-term projection of performance outcomes. Finally, a universal definition of periodization should be established. Based on a review of the literature, we would suggest the following definition:

> Periodization is an organizational approach to training that considers the competing stressors within an athlete's life and creates "periods" of time dedicated to specific outcomes (i.e., strength, hypertrophy or power). These designated periods are intended to manage the stress associated with exercise, while also creating potentiation in the subsequent training phases. Through proper stress management and program design this approach may also attempt to peak various performance measures at a specific time relevant to competition.

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