The General Adaptation Syndrome: A Foundation For The Concept Of Periodization

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The General Adaptation Syndrome: A Foundation for the Concept of Periodization

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Abstract Recent reviews have attempted to refute the efficacy of applying Selye's general adaptation syndrome (GAS) as a conceptual framework for the training process. Furthermore, the criticisms involved are regularly used as the basis for arguments against the periodization of training. However, these perspectives fail to consider the entirety of Selye's work, the evolution of his model, and the broad applications he proposed. While it is reasonable to critically evaluate any paradigm, critics of the GAS have yet to dismantle the link between stress and adaptation. Disturbance to the state of an organism is the driving force for biological adaptation, which is the central thesis of the GAS model and the primary basis for its application to the athlete's training process. Despite its imprecisions, the GAS has proven to be an instructive framework for understanding the mechanistic process of providing a training stimulus to induce specific adaptations that result in functional enhancements. Pioneers of modern periodization have used the GAS as a framework for the management of stress and fatigue to direct adaptation during sports training. Updates to the periodization concept have retained its founding constructs while explicitly calling for scientifically based, evidence-driven practice suited to the individual. Thus, the purpose of this review is to provide greater clarity on how the GAS serves as an appropriate mechanistic model to conceptualize the periodization of training.

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Key Points

- The general adaptation syndrome (GAS) provides a mechanistic model to understand the relationship between stress, adaptation, and fatigue.
- Coaches and practitioners can use the GAS as a conceptual framework for the periodization of training to direct adaptation in accordance with the competitive schedule.
- The integration of ongoing monitoring reaffirms the foundation of periodization on the GAS to model individual responses to training, thereby enabling coaches to validate and optimize the training process.

1 Introduction

The concept of periodization has received substantial attention in recent years, with much of this focus centering on presenting periodization as being irrelevant to the modern athlete [1–3]. However, the term 'periodization' is not owned by sport and instead lies within the greater realm of scholarly activity as a term used to describe specific periods of time, such as in the arts, history, and architecture [4]. Similarly, within competitive sport planning, periodization conceptually allows coaches to fragment a continuum of time into definable and manageable components for enhanced organization and pattern recognition within the training process. Periodization of training has expanded beyond its Ancient Greek origins [5] to encompass appropriate time periods, implementation of specific training stimuli, and recovery tactics largely aimed at the modern competitive sport structure. Although, mechanistically, periodization as a long-term concept describes a developmental system, it is firmly founded on an adaptive process. This adaptive process has been largely based on fundamental biological constructs such as Hans Selye's general adaptation syndrome (GAS) [6].

Recently, a review by Buckner et al. [1] attempted to refute the efficacy of applying the GAS as a conceptual framework to the training process; however, their review joined others by failing to consider the entirety of Selye's work and his evolution of the GAS concept. Thus, the purpose of this review is to provide greater clarity on how the GAS serves as an appropriate mechanistic model to conceptualize the periodization of training. It is the authors' aim in this brief review to present evidence and rationale supporting and linking these two conceptual paradigms.

2 Periodization

2.1 A Brief History of Planned Training

While the pillars of training periodization originated in Ancient Greece and Rome [5, 7, 8], the concept of structured planning in sport became a modern concern in the early twentieth century as a result of increased cultural popularity and importance of sport and the subsequent increased frequency of athletic competition. These factors drove the resultant need for long-term preparation. For instance, Kotov [9], later supported by Grantyn [10], introduced the concept of a phasically-divided annual plan comprised of general, preparatory, and specific stages that permitted the revisitation of training aspects and planned variation. This revelation diverted coaches from the previously accepted opinion that athletes should limit training to 8–10 weeks prior to competition to prevent exhaustion or physical harm. Pihkala [11] further developed Kotov's model, advocating that competitive preparation should include extensive to intensive workloads, planned rest, and balanced training that is staged to prevent overtraining and injury.

Diverging from previous adopters of periodization, Matveyev [12] advocated that training decisions should move beyond the calendar year. In short, he established the need to prioritize planning based on attaining the optimal sporting form, specifically, creating a level of competitive readiness characterized by a complex of physiological, medical-control, and psychological indices. Matveyev noted that sporting form is a "harmonious unity of all the components of the athlete's optimal readiness: physical, psychic, technical, and tactical [12].''

In many ways, Matveyev's work served as a catalyst for other pioneers to seek a scientific basis for training theory and methodology. The scientific staging for periodization was based on the thought that an athlete needs to receive an optimal exercise or training stimulus balanced with appropriate unloading to elicit favorable long-term training effects. In turn, the programming variations, including oscillations in volume and intensity, would serve to promote adaptation, leading to the realization of enhanced fitness characteristics. The phasic and cyclical nature of periodized training seemed to dually call for forecasting an athlete's individualized tolerance of exer- cise-derived stress in conjunction with fatigue-managing recovery tactics that prevent what is now considered overtraining or stress-induced injury [13].

To date, most definitions of periodization have retained the founding constructs related to enhancing sporting form, while also advancing planning strategies based on established physiological processes and adaptation windows. On that basis, practitioners have attempted to establish programming methodologies that are in accordance with the founding principles of periodization.

2.2 Periodization Versus Programming

As noted in Sect. 1, 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, speed).

In contrast, programming can be considered the micromanagement of those delineated stages of training (Fig. 1). Some components of programming include density of training load, volume of training, intensity of training, exercise selection and order, sets and repetitions, among others. When appropriately organized, decisions regarding programming variables differentiate the time continuum into identifiable patterns based on intended objectives. Excessive accumulative fatigue inhibits physiological

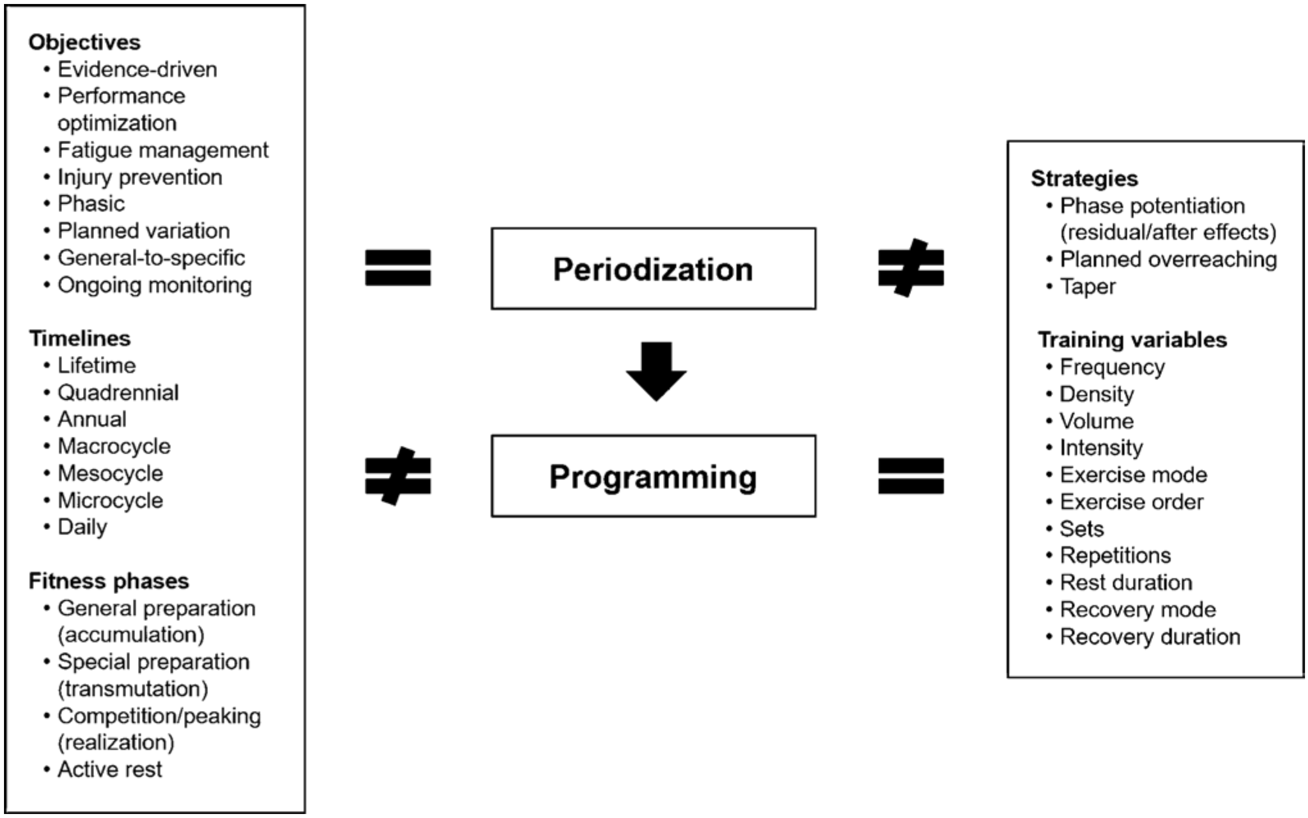

Fig. 1 The distinction and relationship between periodization and programming [157]

adaptation to training stimuli, produces non-beneficial psychological effects, and increases injury, illness, and overtraining potential [14–24]. Thus, a primary aim of programming is to structure the appropriate variation of training factors to modulate fatigue and optimize long-term adaptation.

While the constructs of modern periodization and programming were taking hold, Hans Selye was working to develop the GAS as a conceptual model, applicable to all biological systems, to explain the relationship between stress and adaptation. He envisaged broad applications of the GAS and called on other innovative thinkers to develop and apply it within their respective fields [25]. Selye went so far as to promote the purposeful undertaking of stress to direct the adaptive process stating, ‘‘The fruits of work must be cumulative and must provide a capital gain to meet future needs [26] (p. 12)’’. Indeed, pioneers of modern periodization recognized the applicability of the GAS and used it as a framework for the management of stress and fatigue to direct adaptation during sports training.

3 The General Adaptation Syndrome (GAS)

3.1 An Emergent Model of Adaptation to Stress

Selye first proposed the GAS to describe his observations of a systemic three-phase response—consisting of the alarm reaction, stage of resistance, and stage of exhaustion—to ‘diverse nocuous agents’ [27]. He integrated established concepts regarding the stress response, including Claude Bernard’s ‘milieu intérieur’ and Walter B. Cannon’s ‘homeostasis’, to provide a unifying model of stress and adaptation [25]. Selye’s early experiments detailed the predictable sequence of the GAS (Fig. 2) and the symptomatology of its phases. His subsequent work progressed to describe additional courses of the stress response (e.g. derailments/diseases of adaptation, foregoing the alarm reaction/stage of resistance) [28, 29]. Later, Selye developed his model to account for specific, local effects resulting from the GAS [25, 30]. He also suggested that the GAS has beneficial applications intended to induce adaptation and avoid exhaustion, including those related to exercise [31].

Although Selye’s earliest depictions of the GAS [29] (p. 123) included curves for both specific and ‘crossed’ (i.e. general) resistance, the GAS is commonly depicted as a

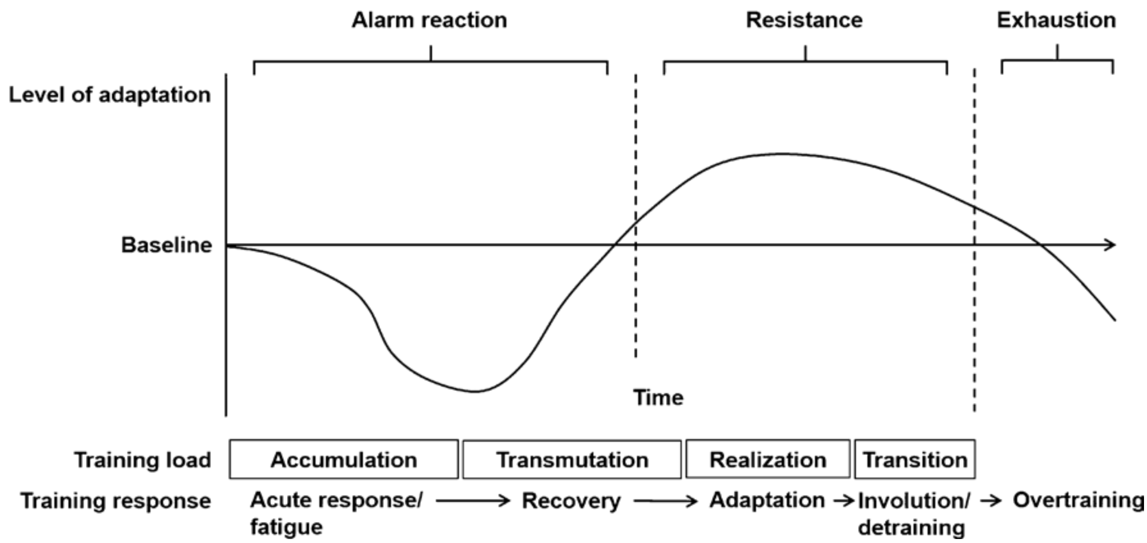

Fig. 2 Patterned response of the GAS begins with an initial decline, followed by an increase, in the organism's level of adaptation; prolonged application of a stressor or a dose too high in magnitude results in exhaustion. The training load and response can be viewed in relation to the GAS; overtraining results from improper load and fatigue management [29, 93]. *GAS* general adaptation syndrome

single curve representing either the general or a specific physiological state of an organism. However, it is likely overly simplistic to consider either aspect entirely in isolation since non-specific responses to stressors precede any specific adaptation [29, 32–36]. Viru [34, 35] explicated several non-specific physiological and biochemical responses (e.g. sympathoadrenal response, glucagon secretion) to accommodate training stress acutely, their functional relevance, and the molecular bases leading from these responses to specific protein synthesis and adaptation. The qualitative pattern of the functional response to training stress acutely and over the long-term exhibits high concordance with the GAS curve. The stimulus-fatigue-recovery-adaptation model based on the work of Yakovlev [37] is exemplary in this regard and provides additional clarity on the functional responses linking the training stimulus to adaptation. Additionally, Banister's fitness-fatigue model is a related extension of this concept, in which the potential change in performance is plotted as the interaction between fitness and fatigue after-effects of training, and mirrors the GAS curve [38, 39]. This point is borne out further by the conception of short-, medium-, long-term, and cumulative training effects. Practically speaking, these training effects constitute an athlete's performance potential, or level of adaptation, for an exercise, training session, phase, stage, or competition.

The practice of potentiation provides further examples to conceptualize the qualitative scalability of the GAS curve suggested by Selye [29] and Garhammer [40] across short- and long-term applications in which 'conditioning' activities are performed to facilitate the enhancement of functional outcomes (performance or adaptation) beyond that which would be attained by performing the target activity alone. Research has demonstrated the possibility of potentiation acutely through proper warm-up preceding exercise and post-activation potentiation strategies, provided that the qualitative and impulse (magnitude 9 duration) characteristics of the conditioning activity are appropriate [41–50]. Conversely, conditioning activities lacking appropriate specificity or sufficient impulse may result in no change in performance, while too large of an impulse may cause a performance decrement analogous to 'exhaustion' [48, 49, 51, 52]. Additionally, the period between the conditioning and target activities must be sufficient to allow for the dissipation of fatigue and the expression of potentiating effects [48, 49, 51–54] illustrative of Selye's statements on the role of rest in the GAS [30]. Likewise, too much time between a conditioning and target activity may result in the 'detraining' or 'involution' of any potentiating effects [48, 49, 51, 53]. Evidence is also suggestive of both the efficacy of phase potentiation as a long-term programming construct of potentiation [55–59] and the potentially negative effects of improper phase sequencing and content [59–62]. Thus, the GAS concept provides a conceptual framework for understanding the causal link between stress and adaptation within the context of sports training, as well as the resultant practical effects of training stimuli.

3.2 A Conceptual Framework for Sports Training

Selye noted that the GAS, and thus adaptation, only occurs if ''an organism is exposed to a stimulus to the quality or intensity of which it is not adapted [63] (p. 758).''

Moreover, he demonstrated the specificity of adaptation to a causative agent [33, 63], which holds true for musculoskeletal, neuromuscular, and metabolic adaptations in relation to exercise (e.g. intracellular signal activation leading to hypertrophic adaptation [34, 64, 65]). Thus, the training stimulus must be of both an appropriate type and magnitude to elicit desired adaptations. This point also implies a necessary intensification and more precise and exacting manipulation of training variables as an athlete progresses to higher levels of adapted motor potential. Selye promoted the concept that an organism possesses a finite capacity to accommodate stress by documenting the cumulative effect of individual and multiple stressors [27, 33, 63]. He reiterated the chronology of the stress response and highlighted the periodicity of the decrement and recovery of one's faculties following bouts of stress and rest, respectively [30], thus implying the need for planned variation and rest in training. Furthermore, Selye characterized the GAS as the sum of multiple, concurrent reactions [29] and described the influence of genetics and a myriad of 'conditioning' factors, such as nutrition, psychological state, and other stressors, on the course and specific effects of the GAS [29, 33, 63, 66–68]. Therefore, the cumulative training effect may be conceptualized as the integration of multiple reactions and adaptations, subject to the influence of conditioning factors.

These ideas are realized in the 'creation' of increased maximum strength and power, which involves a complex interaction of multiple mechanisms. For example, resistance training (acute and chronic stimuli) mechanistically imparts tension, tissue damage, and metabolic responses. The resultant alterations to the intracellular environment lead to the activation of many different biochemical cascades. These reactive adjustments include, but are not limited to, the mechanistic target of rapamycin (mTOR) pathway, AMP-activated protein kinase (AMPK) activation, changes in inflammatory responses encompassing leukocyte invasion of tissue [69–74], increased interleukin concentrations [65, 75, 76], and alterations in cortical activation [77–81]. These responses collectively dictate increased connective tissue size, increased muscle cross-sectional area, architectural changes, and neural input and output alterations, with the cumulative adaptations ultimately leading to enhanced maximum strength and related characteristics such as rate of force development and power [55, 56, 80, 82–86]. During the training process, all of these effects are modulated by appropriate manipulations of training variables, nutrition, sleep, and other factors [87, 88]. Poor load and fatigue management and insuffi- cient recovery strategies may lead to suboptimal or maladaptation, immunosuppression, injury, or overtraining [17–24, 64, 89, 90]. These points underscore the need for the consideration and management of the frequency,

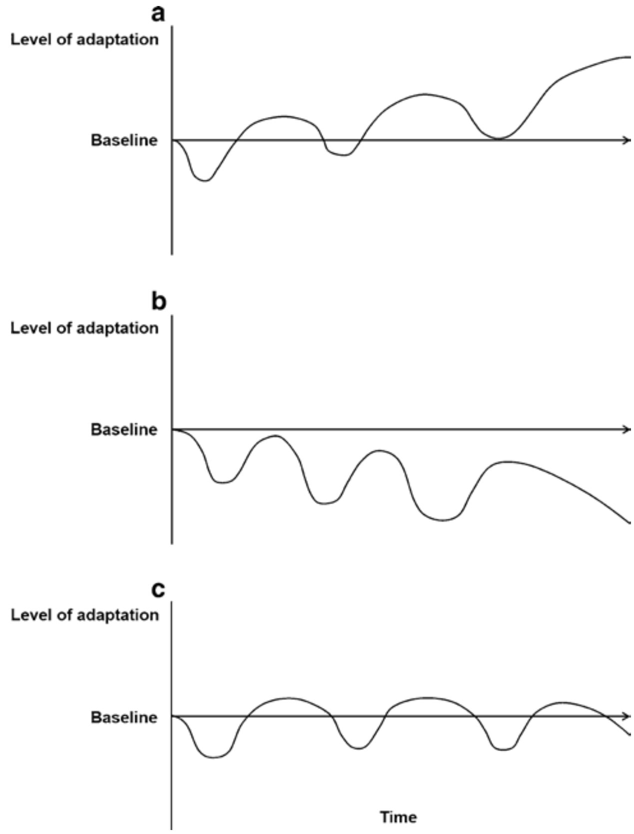

Fig. 3 a Optimal loading results in continual improvements over time; b loading that is too frequent or too high in magnitude does not allow adequate recovery, and therefore maladaptation/overtraining occurs; c infrequent or insufficient loading results in stagnation or decline in an athlete's level of adaptation [92, 93, 151]

magnitude, and duration of all stressors to ensure optimal loading to promote adaptation (Fig. 3). Furthermore, stress tolerance, finite adaptive ability, conditioning factors, and cumulative training effects concomitantly dictate the need for periodization.

Periodization of training is a long-term approach [91] that can span several years [92]. While the precise time courses and regulation of specific adaptations to exercise are not fully clear, it is apparent that variable time courses exist [65]. Therefore, one must consider the course of training adaptations on multiple timescales. The consideration of time allows for systematic planning that integrates short-, medium-, and long-term training effects into cumulative training effects [93]. The GAS model is applicable across the multiple functional units of time contained in a periodized plan whereby cumulative effects subsume preceding responses. Thus, training periodization represents a fractal process [94] owing to the cyclic nature of the GAS. This perspective reinforces Verkhoshansky's suggestion that periodization allows for continuity between successive stages of training by exploiting the cyclic nature of the stress response and considering changes in the athlete's state over time [92]. Exercise and sport scientists continue to explicate the influence of exercise variables—namely exercise mode, contraction type, contraction velocity, volume, and intensity—on training adaptations. Considerable research also explores the effects of so-called conditioning factors (e.g. genetics, age, sex, nutrition, training history) on training adaptations [95–108]. Such work provides the scientific basis for programming intended to develop the physical characteristics ascribed to each fitness phase of the periodized training plan. Training adaptations occur in response to a series of workouts constituting loads that stimulate the translation of the specific proteins underlying the desired adaptation(s). Planned variation and rest are required to modulate fatigue to optimize adaptation and reduce the risk of illness, injury, or overtraining, which are functionally equivalent to the stage of exhaustion [55, 56, 109–124]. The logical staging of fitness phases promotes a time-dependent integration of discrete physical characteristics (i.e. adaptations) into a cumulative training effect, thus maximizing training goals in a timelier fashion.

4 Criticism of the GAS Model and Periodization

Matveyev was one of the earliest critics of the use of Selye's model in the periodization of training. He based this rejection on an interpretation that the GAS was inherently pathological [125], despite Selye's characteri- zation of the GAS as ''a useful, normal physiological reaction to stress'' [30]. Matveyev acknowledged the importance of the stress response and the time courses of adaptation, but believed that such processes played a lim- ited role in the planning of training [125]. Matveyev favored a pedagogical lens and viewed training as a developmental process rather than an adaptive one. It should be noted that the political environment strongly shaped the development of scientific discourse in the Soviet Union [126], and may have magnified any philo- sophical differences that led to Matveyev's partial rejection of the GAS model.

In a recent review, Buckner et al. [1] challenged the applicability of the GAS to sport and exercise, restricting their examination to the earliest perspective of Selye's work. This restricted perspective inexplicably omits substantive developments of the GAS concept that evolved from Selye's original experiments, and leads the authors to argue against isolated components of the GAS removed from scientific and practical context. For example, Buckner et al. [1] advance a model of the GAS founded on the use of 'toxic' doses of stressing agents to suggest that the GAS model has no correspondence to typical resistance training protocols. It is unclear whether the authors use the term toxic to mean lethal or injurious as indicated in Selye's work. Regardless, their argument is somewhat unfounded considering that Selye based his early findings on the use of both uniform and incremental sublethal doses [27, 32, 33, 63]. Buckner et al. [1] also seem to suggest that the GAS model does not suppose periods of rest for resistance training programs. This suggestion neglects Selye's remarks on the value of rest in the recovery from stress, and his proposition that such periodicity may have therapeutic value.

In another review from this group, Mattocks et al. [2] imprecisely characterized exercise as an acute stress that poorly corresponds to the chronic nature of Selye's model. This suggestion is especially curious considering that exercise was one of the original stressors Selye employed in his discovery of the GAS [27]. Moreover, even the earliest practitioners who applied the GAS to sports training understood the summative nature of systematic training (i.e. planned series of workouts) [127, 128]. Mattocks et al. [2] also questioned the role of periodization to increase muscle hypertrophy and strength; however, their issues appear to stem from a conflation of the concepts of periodization and programming. As discussed in Sect. 2.2, these are two distinct, although related, concepts. Periodization relates to the division of the training plan into discrete repeatable phases aimed at developing and maturing specific fitness characteristics (e.g. strength-endurance, strength, power), whereas programming relates to the selection of exercise variables to provide a training stimulus that elicits the desired adaptations (e.g. muscle hypertrophy, metabolic and neural alterations) [87, 88]. Several studies particularly illustrate the distinction between periodization (i.e. planning) and programming [60–62, 129]. Furthermore, these and additional studies demonstrate that the order of periodized phases influences physical and performance outcomes [60–62, 129–132]. Two major practical implications of these studies are that (1) phases should be logically and strategically sequenced, and (2) programming decisions must be congruent with the objectives of each phase and the overall plan. It is also worth noting that meta-analyses have confirmed the efficacy of periodized training for strength and power development compared with more traditional protocols [133, 134]. Despite their criticisms, both Mattocks et al. [2] and Buckner et al. [1] acknowledge that training peri- odization may be useful for sports training and that the principles of the GAS provide a plausible framework for training periodization.

In a separate essay, Kiely [3] claimed that the GAS does not account for the potential psychogenesis of the stress response and the influential role of factors such as psychological or emotional state during the stress response. Selye [135] admitted that during his original conception of the stress concept in 1936 he ‘‘gave little thought to its psychological or sociological implications for [he] saw stress as a purely physiological and medical phenomenon”. However, Selye came to consider these additional factors and their relationship to stress response over the course of his work [25, 26, 30, 31, 67, 136–138]. Furthermore, Selye grew to recognize that stress research would continue in biology and medicine “alongside the study of psychology and sociology’’ [135]. Nevertheless, the fact remains that disturbance to the state of an organism is the driving force for biological adaptation, which is the central thesis of the GAS model and the primary basis for its application to the athlete’s training process.

5 The GAS and Periodization in the Twenty-First Century

The GAS model provides a mechanistic framework for contextualizing adaptation within a periodized training model. Practitioners thus attempt to construct a plan to direct adaptation in accordance with the competitive schedule. Kiely [139] highlighted that such planning assumes the predictability of adaptation and the ability to forecast appropriate training. Kiely [139] cautioned that the ‘mechanistic logic’ underpinning traditional periodization leads to prescriptive planning that fails to accommodate the apparent variability of individual responses. He suggested that training should be an emergent process that is responsive to the ongoing changes of a complex system identified through assessment and monitoring [139]. However, the implication that the practice of periodization involves strict adherence to immutable planning is inaccurate on several levels. Namely, it confuses, at least partially, periodization paradigms with programming. Although, once planned, fitness phases and other respective timelines are largely static, it is the programming that ‘drives’ these phases. Indeed, the programming can be quite static, such as has been used in some research para- digms, or it can be quite dynamic. As an example, many studies use repetition maximum (RM) zones as part of their programming. RM zones inevitably require one or more sets to proceed to failure, thus always producing a relative maximum effort, regardless of the set and repetition scheme. Other authors and researchers use a more fluid process by prescribing loads based on percentages contingent on the subject/athlete’s readiness [16, 140], and have also prescribed true heavy and light days [87, 88, 93].

Fluid programming also takes into consideration the athlete’s relative state of preparedness for a given session by prescribing training ranges (based on percentages). Thus, if there is some indication that an athlete is below par, potentially through subjective feedback [141–143] or measuring physical or physiological parameters [144–146], adjustments can be made in the loading for that (or subsequent) training session(s). In addition, true heavy and light days and recovery or unload weeks are often built into the programming, which may allow not only fatigue recovery but also additional adaptation when coupled with planned overreaching or intensification paradigms [17, 57, 58, 86–88, 90, 147–149]. Furthermore, if the periodization and programming are carefully integrated into an annual plan, the plan always includes a monitoring process.

Although many theorists and practitioners have advocated, and implemented, various methods of scientific monitoring to inform the training process [86, 93, 141, 142, 144–146, 150–153], DeWeese et al. [154] noted that formal definitions of periodization embodied regimented plans that excluded ongoing monitoring. Advancements in science and technology have created a wellspring of information that enables coaches to make dynamic, evidence-based decisions to optimize training. Therefore, DeWeese et al. [154] proposed a revised definition of periodization that incorporates ongoing monitoring to permit an individualized and responsive training process. In this way, the concept of periodization has been updated to better reflect the reality of sport performance training in the twenty-first century. In practice, the inclusion of a monitoring process reaffirms the foundation of periodization on the GAS to model individual responses to training, thereby enabling coaches to validate and optimize the training process.

6 Conclusions

GAS is widely considered as the basis for modern periodization [6, 155]. Advances in the scientific understanding of stress and adaptation, as well as technology, have led some authors to question the validity of both the GAS and periodization. Within this context, many have recognized the need to update the definition of periodization to reflect such advancements [86, 150, 154]. Thus, this modernized definition of periodization emphasizes the importance of scientifically driven practice and evidence-based decision making that considers the individual. Selye repeatedly addressed controversy [136] and misconceptions [31] regarding the GAS. Given Selye’s continual work to clarify the GAS and its related concepts, it is not surprising that occasional clarification is necessary to address similar issues in the specific application of the GAS to sport performance training.

While it is reasonable to critically evaluate any paradigm, critics of the GAS have not dismantled the link between stress and adaptation, which is the crux of the

GAS model and the primary basis for its application to sports training. Additionally, they fail to offer alternative models to explain the process of adaptation. The authors of the current review recognize that the GAS does not account for all reactions or processes related to stress. However, no model is complete or fully accurate. Nevertheless, notable reviews have related the GAS directly to the bio- logical and physiological responses and adaptations to exercise [34, 35], and many theorists have detailed the conceptual application of the GAS to training [40, 127, 128, 156]. Many other models regarding the training process are complementary to, rather than incompatible with, the GAS [38]. For example, the fitness– fatigue paradigm does not consider the mechanisms of adaptation. Rather, it depicts an athlete's state of pre- paredness and ability to express his or her current level of adapted motor potential as a function of the levels of fitness and fatigue resulting from training.

Despite its imprecisions, the GAS has proven to be an instructive framework for understanding the mechanistic process of providing a training stimulus to induce specific adaptations that result in functional enhancements. This framework can guide coaches in the planning of the training process and the selection of programming tactics that aid in the execution of the plan. However, additional research is necessary to further elucidate the precise application of the GAS model to sports training, as well as to refine the practices of periodization and programming. Furthermore, it is incumbent upon the coach to maintain current scientific knowledge to ensure sound practice, and to adjust the programming based on individual responses to optimize the training process.

Compliance with Ethical Standards

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Conflict of interest Aaron Cunanan, Brad DeWeese, John Wagle, Kevin Carroll, Robert Sausaman, W. Guy Hornsby III, G. Gregory Haff, N. Travis Triplett, Kyle Pierce, and Michael Stone declare that they have no conflicts of interest relevant to the content of this review.

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