Microdosing: A Conceptual Framework for use as Programming Strategy for Resistance Training in Team Sports

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Supplemental digital content is available for this article. Direct URL citations appear in the printed text and are provided in the HTML and PDF versions of this article on the journal's Web site (http://journals.lww.com/nsca-scj).
Video Abstract–SCJ Micro-dosing (Audio)–http://links.lww.com/SCJ/A366.

ABSTRACT

Microdosing, in the context of resistance training, has increased in popularity within sporting environments where it is frequently used among strength and conditioning professionals. Although there is a clear definition for the concept within the literature, it is still commonly incorrectly used, and the extent to which microdosing has been explicitly investigated in empirical research is limited. However, there are many related research areas or themes (including programming for acute and chronic responses, programming around competition schedules, motor learning, and individualization) that indicate the potential benefits of microdosing as an overarching concept. There are also misinterpretations about the term and what microdosing entails; for example, the term microdosing is often used interchangeably with the concept of the minimum effective dose. Therefore, the aim of this review is to outline and discuss where some of these theories and concepts may or may not be appropriate for use within team sports, while also highlighting areas in which the application of microdosing requires further investigation. Although microdosing may be a relatively new term, which is considered "trendy" among practitioners, the underlying principles associated with microdosing have been expressed and investigated for a long time.

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INTRODUCTION

Recently, the concept of "microdosing" has become a popular topic of discussion and debate among strength and conditioning professionals (1). This concept originally appeared in clinical research regarding drug development during the 1990s, as a method of assessing pharmacokinetics (how a substance reacts when given to a living organism) before full phase I clinical trials (60). In clinical environments, microdosing involves the application of a dose that is subpharmacological and subtherapeutic (59). More recently, the concept has also been associated with psychedelics whereby typically 10–20% of a recreational dose (most commonly lysergic acid diethylamide [LSD] or psilocybin) is ingested regularly as a microdose (83). Within this context, a microdose stimulates metabolic reactions, but these effects are not perceived by the individual. Although mostly anecdotal, recommendations of these subperceptual doses were first published in 2011 in a book entitled "*The psychedelic explorer's guide: safe, therapeutic, and sacred journeys*" (28). From a physical performance perspective (within sports), the term was initially introduced by Hansen (41) in a blog post regarding spring training; since then,

KEY WORDS:
strength training; fixture congestion; periodization; competition schedule; individualization

however, microdosing has commonly been misconceived to be synonymous with the "minimal effective dose" (1,93). This misconception is understandable because until recently no formal definition of exercise microdosing had been present in the literature. Based on this recent definition, microdosing has been clearly defined as "the division of total volume within a microcycle, across frequent, short duration, repeated bouts" (18).

More recently, Hansen (42) has proposed an alteration to the original naming of his approach to contextualize microdosing as "micropriming." Although Hansen (42) rightly highlighted that many practitioners continue to improperly label and apply the microdosing concept, without providing a full picture of the potential applications, benefits, and pitfalls of the concept, practitioners are likely to struggle to navigate between effective training practices and the "flavor-of-the-month" programming trends (42). Although the authors agree with the notion that a greater focus should be placed on doing the basics consistently and at a greater frequency, where feasible, Hansen's (42) rationale for moving away from the term microdosing is in part the result of the association with taking small yet more frequent dosages of stimuli (such as drugs) that require periods of "cycling off" to prevent/avoid habituation. However, when going beyond exercise programming and considering a periodized approach to training, cyclical constructs are central to how we integrate, sequence, and organize training that targets a specific outcome (102). Therefore, the application of microdosing may not always be appropriate or may need to be used in conjunction with traditional programming methods to emphasize the development of specific skills or physical characteristics that align with the periods and phases contained within the periodized training plan.

Following the pharmacological theme presented when defining microdosing, it is important to understand what a dose is and the relationship a dose has with a subsequent response. In medical research, a dose refers to the amount of a therapeutic agent. The interaction between the dose and the potency of that agent provides researchers with a dose-response relationship for a given population whereby practitioners (medical professionals) can be provided with what is referred to as a therapeutic index, which represents the range in which the drug or substance is effective but not lethal. There are clear parallels in terminology when considering resistance training, with a combination of the volume (dose) and load/"intensity" (potency) providing a physiological response. The response is dictated by the training prescription used within the training zones (therapeutic index) and can be anywhere from a "minimal effective dose," all the way up to a period of planned overreaching, with a lethal dose comparable to causing rhabdomyolysis or overtraining when consistently training beyond those zones (Figure 1). It is important to understand that the 'optimal" dose-response will differ and fluctuate for each exercise, session, training cycle, program, and individual based on a multitude of factors, which mitigate the athlete's internal load and adaptive responses.

Therefore, the purpose of this review is to discuss how the concept of microdosing resistance training in team sports may be applied, using inferences from related research findings. Within each section, we provide a definition of the subject area, outline the potential ways in which microdosing may theoretically be used as a programming strategy across 4 key areas (i.e., competition schedule, acute/chronic programming, motor learning, and individualization [Figure 2]) derived from findings of published literature, and highlight areas for future research.

COMPETITION SCHEDULE

TRAINING RESIDUALS

The residual effects of training, commonly referred to as "training residuals," have been defined as the retention of positive physical changes following the cessation of training beyond a period in which possible adaptations can take place (16). Therefore, training residuals are separate to any delayed training effect driven by supercompensation and are often contextualized as short-term, medium-term, and long-term responses (54). Long-term residuals include "almost irreversible" changes in the musculoskeletal and neuromuscular systems, such as coordinative abilities, movement skills, and event-specific techniques whereby the rate of loss is several years. Medium-term residuals include those associated with the cardiovascular system such as increased capillary density and stroke volume, decreased resting heart rate, and neuromuscular changes such as effort regulation and force differentiation in which the rate of loss can be several months. Finally short-term residuals include increased

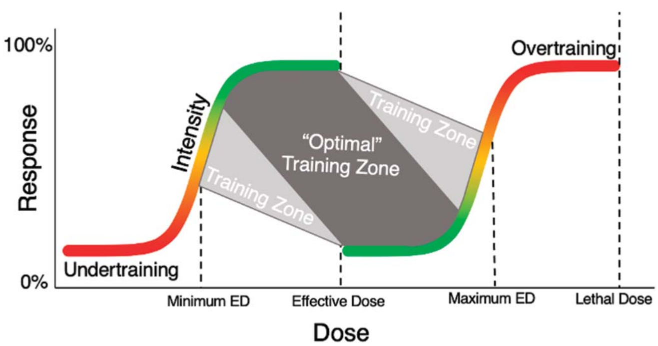

Figure 1. An illustration of the dose-response curve in relation to resistance training. ED = effective dose.

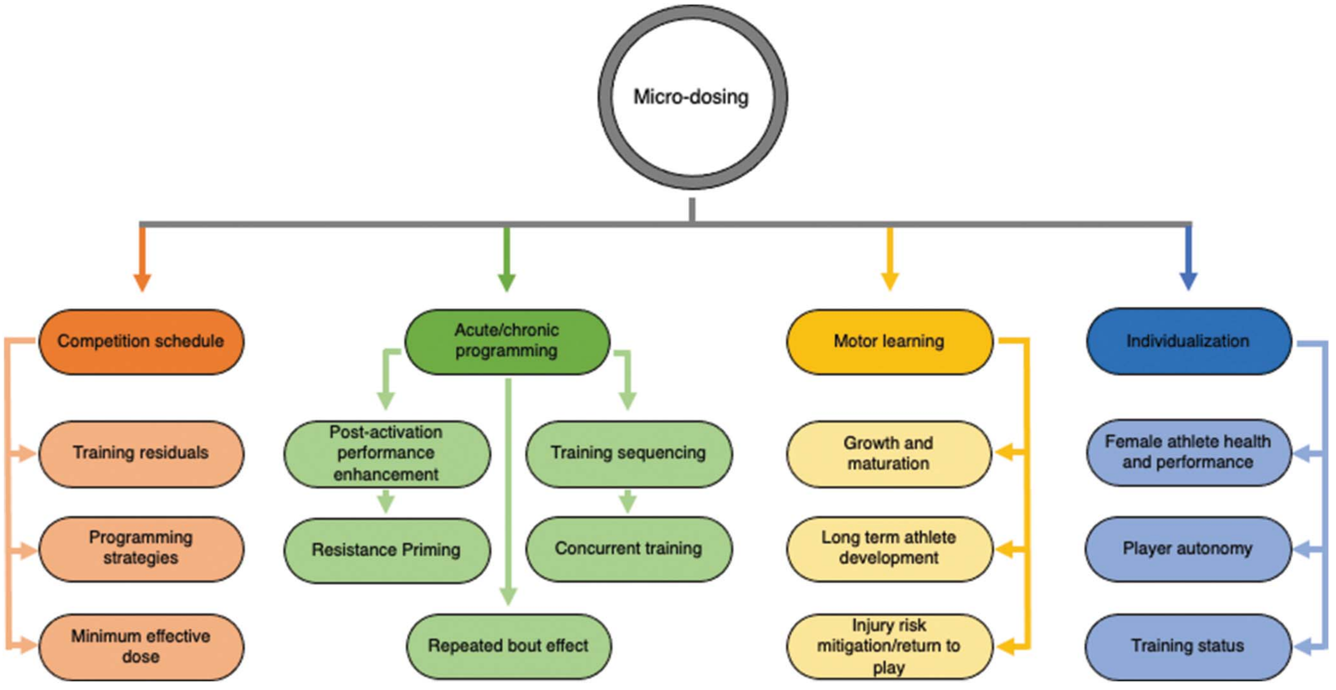

Figure 2. Illustration of key areas where microdosing resistance training may be advantageous.

maximal aerobic consumption and anaerobic thresholds and increased muscular strength, power, and endurance, which may last for several weeks, but it can also include anaerobic alactic, and glycolytic power, capacity, and efficiency, which can decay in a few weeks or days (51). The rate of loss for all residuals is heavily dependent on an individual's training history and the volume and intensities of loading used before the cessation of training that targets specific foci.

The shorter-term training residuals are of primary importance for programming, especially when considering periods of competition or the use of a block "periodization" approach where the focused training of certain physical characteristics is omitted for predetermined period (55). When designing periodized training programs, there are a variety of competition schedules across a range of team sports, many of which have some form of in-season fixture congestion, particularly sports that are deemed as noncollision sports (e.g., soccer, basketball) (Table 1). There are several reasons that some team sports have specific periods of in-season fixture congestion: for example, some European soccer teams will have multiple competitions running simultaneously, such as domestic leagues, domestic cup competitions, and European cup competitions. Both National Basketball Association (NBA) and National Hockey League (NHL) teams play multiple games back-to-back (one night after the other) typically to reduce travel requirements. Another example is demonstrated in team sports such as baseball or rugby sevens, whereby a "series" is played over 2–3 days, and multiple matches are played during these periods. Finally, international-based tournaments, such as the World Cup in soccer and rugby, or even the Olympics for team sports, such as field hockey and volleyball, also result in multiple fixtures in very quick succession with limited recovery time between each fixture.

Within short periods of fixture congestion where the duration of the congested period lasts the length of a microcycle or summated microcycle, fatigue management is generally the primary priority (depending on the competition and time of the season). By contrast, international tournaments can last up to 4 weeks; however, as outlined by Issurin (53), within that period, the residual effects of some physical qualities such, as maximal speed, may diminish if training targeting the development of this residual is not incorporated as part of the athlete's training program. It is important to remember that training residuals are usually based on the complete cessation of training that targets a particular capacity; therefore, competition may still provide some stimulus; however, based on the principle of specificity, the magnitude of certain stimuli is likely to be below the level required to allow for maintenance, development, or slowest decay (compared with opposition) of the training residual. Based on most periodization models, any period of competition is accompanied by a reduction of training volume and increase in intensity, which may result in the loss of specific training residuals. During periods of dense

Table 1
Examples of fixture schedules in a range of team sports

Sport	Standard/level	Competition type	Competition/season length	No. of games	Between-game turnaround time	Length of postseason[a]	No. of postseason[a] games
American football	Professional (NFL)	Season	18 wk	17	4–7 d	5 wk	3–4
Baseball	Professional (MLB)	Season/Series	~27 wk	162	0–1 d	~5 wk	3–22
Basketball	Professional (NBA)	Season	~26 wk	82	0–3 d	10 wk	4–28
Ice hockey	Professional (NHL)	Season	~26 wk	82	0–3 d	10 wk	4–28
Field hockey	Olympic games	Tournament	2 wk	10	0–2 d	—	—
Netball	Commonwealth games	Tournament	10 d	6–7	0–3 d	—	—
Rugby union	International	Tournament	~6 wk	7	~7 d	—	—
	Domestic	Season	~40 wk	~32–39	5–7 d	2 wk	2
Rugby league	International	Tournament	~7 wk	7	~7 d	—	—
	Domestic (super league)	Season	~32 wk	30–37	5–7 d	3 wk	3
	Domestic (NRL)	Season	26 wk	24	5–7 d	4 wk	4
Rugby sevens	International	Series	2 d	6	~3 h	—	—
Soccer	International	Tournament	~31 d	≤7	4–6 d	—	—
	Domestic (EPL)	Season	~40 wk	~38–62	3–7 d	—	—

[a]Postseason in this instance describes a period of play-off games leading to and including either promotion deciders or championship games.

EPL = England premier league; MLB = major league baseball; NBA = national basketball association; NFL = national football league; NHL = national hockey league; NRL = national rugby league.

competition, resistance training volumes can be reduced even further to prioritize recovery, exacerbating the loss of training residuals. Microdosing resistance training as an approach during these periods of dense competition schedules may be a feasible option to maintain appropriate strength or power stimuli. This may be accomplished through dividing the training volume typically seen in a microcycle so that more frequent shorter duration training sessions are encountered. Alternatively, through the utilization of specific programming strategies, such as postactivation performance enhancement (PAPE) or resistance priming stimuli (see *resistance priming* below), the accumulated volume across the whole microcycle may be maintained while potentially inducing less fatigue compared with traditional approaches to programming in-season training. It is possible that a microdosed approach can provide a sufficient stimulus to maintain or perhaps improve physical qualities, which typically deteriorate during periods of intensive competition (e.g., maximal speed (53)) because of "recovery" being prioritized over the application of resistance training.

PROGRAMMING STRATEGIES

There are various periods within certain team sports in-season where fixture congestion becomes prominent in the short term. On the other hand, the competition period for other team sports occurs over a prolonged duration (Table 1), with professional soccer, rugby, American football, basketball, and ice hockey all competing for large portions of the calendar year. In addition to a prolonged competitive season, a number of these team sports, including basketball and ice hockey (particularly in the NBA and NHL), are required to complete a competition schedule that is extremely dense/congested (Table 1). The requirement for sustained success throughout these prolonged periods is paramount to win championships or league titles. Sustaining a performance peak for prolonged periods is unrealistic because of the accumulation of fatigue and reductions in fitness, with these occurrences being a consistent argument as to why traditional periodization models (the transition from a high-volume low-intensity general preparation phase into a specialized, lower-volume, higher-intensity phase before leading into a competition phase) are "unsuitable" for team sports (53). However, it is important to note that periodization is the macromanagement of the training process (17) and serves as the scaffold for planning the direction of programming, making both periodization and programming 2 distinctly different concepts.

As Cunanan et al. (17) have highlighted, programming includes the manipulation of training variables (e.g., frequency, density, volume, load etc.) and also the use of various advanced programming strategies that can include phase potentiation (22), planned overreaching (31), and tapering (111). One programming strategy that can be used in a periodized training plan is microdosing, which can be applied as a standalone concept or in conjunction with several of these advanced programming strategies. For example, the use of concentrated volume loads (often termed planned overreaching (104)) that stimulates a delayed training effect or specific training residuals can stimulate what is referred to as phase potentiation (17,21,22). This concept is also aligned with the block periodization approach proposed by Issurin and Yessis (52), who referred to utilization of "miniblocks" to enhance specific training factors. These miniblocks have been suggested as a strategy to prolong the residual effects of a preceding mesocycle, providing a form of microdosing (51).

Alternative to sequential models, emphasis periodization whereby multiple training factors, such as strength, power, and endurance can be included simultaneously but with varying emphasis within each mesocycle may be a more appropriate periodization strategy. Emphasis periodization models cycle between stimulating loads (those that will elicit adaptation) and maintenance loads, with the emphasis typically rotating every 2 weeks (119,120). Therefore, varying emphasis means that attributes being maintained require less dedicated training, which may be more appropriate for team sports (56,102). Microdosing may assist in the application of maintenance loads (e.g., power during a strength bias phase), which can be distributed throughout the microcycle (Figure 3), whereas the primary focus of the training phase (e.g., maximal strength) can be applied through longer duration sessions. By contrast, a microdosing approach may permit more frequent exposure to the training emphasis/bias of the phase (e.g., a power stimulus), for those foci that would benefit more from reduced fatigue accumulation (Figure 3). As D'Emanuele et al. (19) demonstrate, rapid force production is one of the most sensitive physical characteristics to fatigue and experiences the greatest depression following training and therefore may benefit from the decreased volume load per session as a result of microdosing, as well as the increased frequency of stimulation to combat the short residuals associated with this characteristic.

When considering team sports with both a prolonged season and dense fixture schedules, it may be more appropriate to use a combination of traditional sessions when time permits, to generate concentrated loads in relatively short durations and then integrate microdosed strength training sessions, where warranted, to provide an increased 'readiness' for competition without inducing excessive fatigue, while maintaining training residuals. This approach could be front loaded within a training week, whereby the longer duration (higher volume) sessions are performed furthest away from competition and the microdosing sessions performed much closer to competition to maximize recovery (Figure 3). Practitioners should be mindful that increased frequency of sessions may

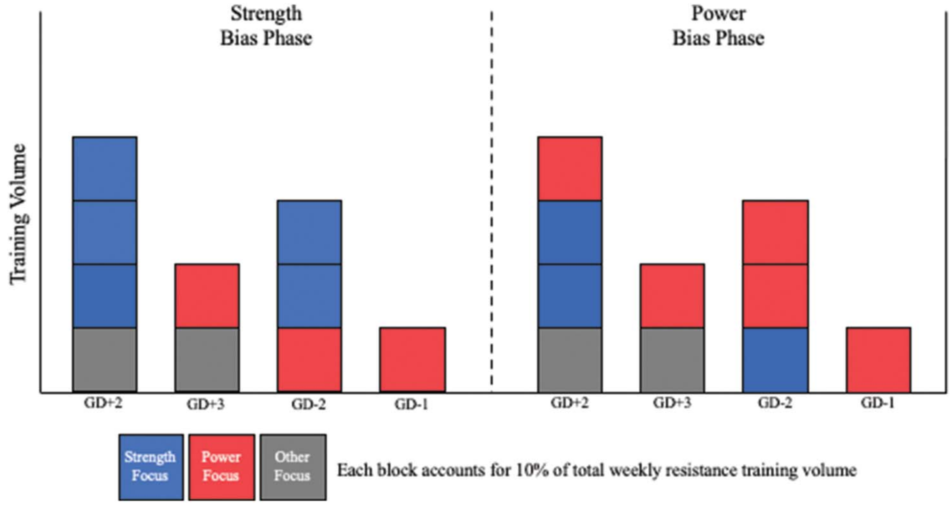

Figure 3. A schematic diagram illustrating an example of the distribution of resistance training volume and division of microdosing sessions for an in-season microcycle of either a strength bias or power bias. GD = game day.

also increase monotony of training especially if suitable exercise variation is not provided.

MINIMUM EFFECTIVE DOSING

Despite their being some commonalities, minimum effective dose is not synonymous with microdosing because exercise prescription can be applied across a spectrum of minimum to maximum effective dosing (Figure 1). The utilization of the minimum effective dose for the maintenance of performance (57) may be advantageous during periods of fixture congestion to minimize training-induced fatigue while maintaining physical characteristics. The length of time where the minimum effective dose is targeted with training will be heavily influenced by the time course of residual decay for specific physical qualities and the athlete's current training status.

A number of researchers have recently investigated the minimum effective dose for various populations with the view of preventing detraining (5), increasing strength (2,57), or for stimulating hypertrophy (57). For example, Iversen et al. (57) have suggested prescriptions to improve maximal strength capacity, ≥4 sets per muscle group should be completed for a 4–6 repetition range at approximately 85% of 1 repetition maximum (RM) per week. Regardless of the sets, repetitions, and frequencies suggested in this research, the authors concluded that working to volitional fatigue is required, which is impractical for in-season exercise prescription, particularly during dense competition schedules, and is not necessary to maximize the development of hypertrophy or strength (11,36,58,69). Knowledge of these loading paradigms may, however, provide guidance on the volume load (sets × repetitions × load) required for a minimum effective dose, and how these loads can be microdosed throughout a microcycle, without the need to induce additional fatigue by training to failure, as used in the aforementioned studies. Alternatively, guidance could also be provided for the reduction of a relative percentage of overall training for a minimum effective dose to be applied: for example, Spiering et al. (100) suggested that reductions in volume by 33–66% can be made while strength is maintained provided the load lifted remains high.

Rønnestad et al. (91) investigated the effect that frequency of strength training has on the in-season maintenance of strength and athletic performance in team sports. A comparison was made between a group performing strength training once per week and a group performing the same session once every 2 weeks. In effect, the latter group performed half the volume across the 12-week season. The group performing resistance training once every second week demonstrated a decrease in maximal strength, whereas the group performing the same session volume once every week (in effect doubling the dose) maintained performance, demonstrating that once per week of the programmed volume was the minimal effective dose for maintenance of strength over 12 weeks (91). As an extension of this study, it may be interesting to determine if the same effect would be present had the groups' training volume been equated, with frequency remaining once per week versus once every 2 weeks, but whereby the more frequent training group (i.e., once per week) microdosed the volume across the 2 weeks (e.g., halving the volume of each session). This of course requires further investigation; however, it may suggest that microdosing is not necessarily appropriate if already applying a minimum effective dose but could be used as a tool to increase the in-season volume or maintain a volume higher than that of a minimum effective dose in periods of dense competition schedules or fixture congestion (Figure 4). Either way,

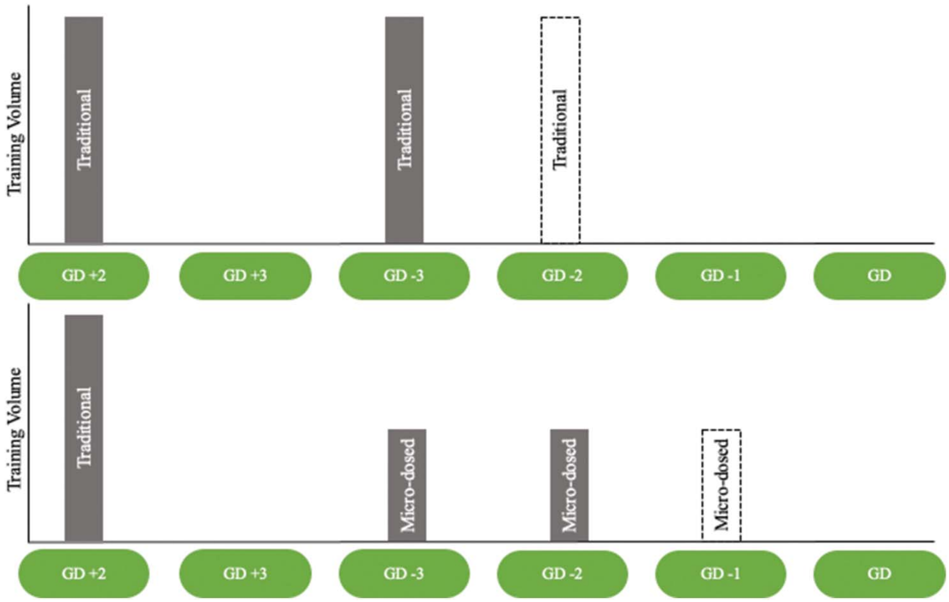

Figure 4. A schematic diagram illustrating a comparison of a traditional, 2-session, resistance training week (in-season) and an example a front-loaded training week whereby a higher-volume, longer-duration (traditional) session is performed furthest away from game day (GD) in conjunction with microdosed sessions closer to competition. The dashed lines indicate the possible movement of sessions based on the configuration of rest days in a microcycle and not any additional sessions, for example, the sessions seen on GD-3 may be scheduled on either GD-2 or GD-1 for traditional or microdosing, respectively.

microdosing and minimum effective dosing are separate concepts, albeit that the minimum effective dose can be microdosed, despite authors of a recent commentary relating microdosing to minimal dosing (1). The same authors also describe microdosing as "old wine in a new bottle" directly comparing it with motor learning theory of distributed practice (1). Although the authors of this current review do not disagree with the suggestion that microdosing is not a new concept, the links to motor learning will be outlined later in the review.

ACUTE/CHRONIC PROGRAMMING

POSTACTIVATION PERFORMANCE ENHANCEMENT (PAPE)

Before there being a distinction between the term PAPE and "postactivation potentiation" (PAP) (defined as the increase in force/torque following an electrically evoked twitch contraction, rather than a voluntary contraction), PAP was used as an umbrella term for both (6). Although the 2 approaches share some similarities including enhanced contractile force, a delay in observed benefits of potentiation, a greater response in muscles with a large proportion of fast-twitch fibers, the time course of benefits, from both PAP and PAPE, on force production and other underpinning mechanisms (myosin regulatory light chain phosphorylation compared with muscle temperature, water content, and activation) differ largely, making them 2 distinctly different approaches (6). For a more detailed discussion on the differences between PAP and PAPE, see reviews by Blazevich and Baubault (6), and Prieske et al. (84).

By definition PAPE is the acute enhancements in voluntary dynamic force production after a bout (defined as a short period of intense activity) or conditioning activity (CA) typically viewed as a single prescribed exercise sometimes with as little as one set performed (6,74,84). There are 2 ways in which resistance training could be designed to take advantage of PAPE within a microdosing strategy. First, depending on the configuration of a training day, it may be possible that the first bout of exercise is a high-intensity CA (e.g., 1 set of 3 repetitions at ~90% 1RM (66)), whereby the subsequent PAPE effect could increase the intensity of the first few actions of the following technical training session (e.g., sprint training (66)) or resistance training session (10) (Figure 5). Second, a microdosing session may be constructed of just 2 exercises as a contrast set/session, whereby the time course in between the CA and the subsequent exercise (e.g., jumping or plyometric task) is long enough (i.e., 3–12 minutes, depending on training status) to elicit a PAPE effect. The second option is likely to be more feasible and can be applied more frequently throughout a microcycle, with the accumulative volume of multiple CAs in addition to other microdosed sessions creating the overall microcycle dose.

Currently, there is no consensus on the underpinning mechanisms that

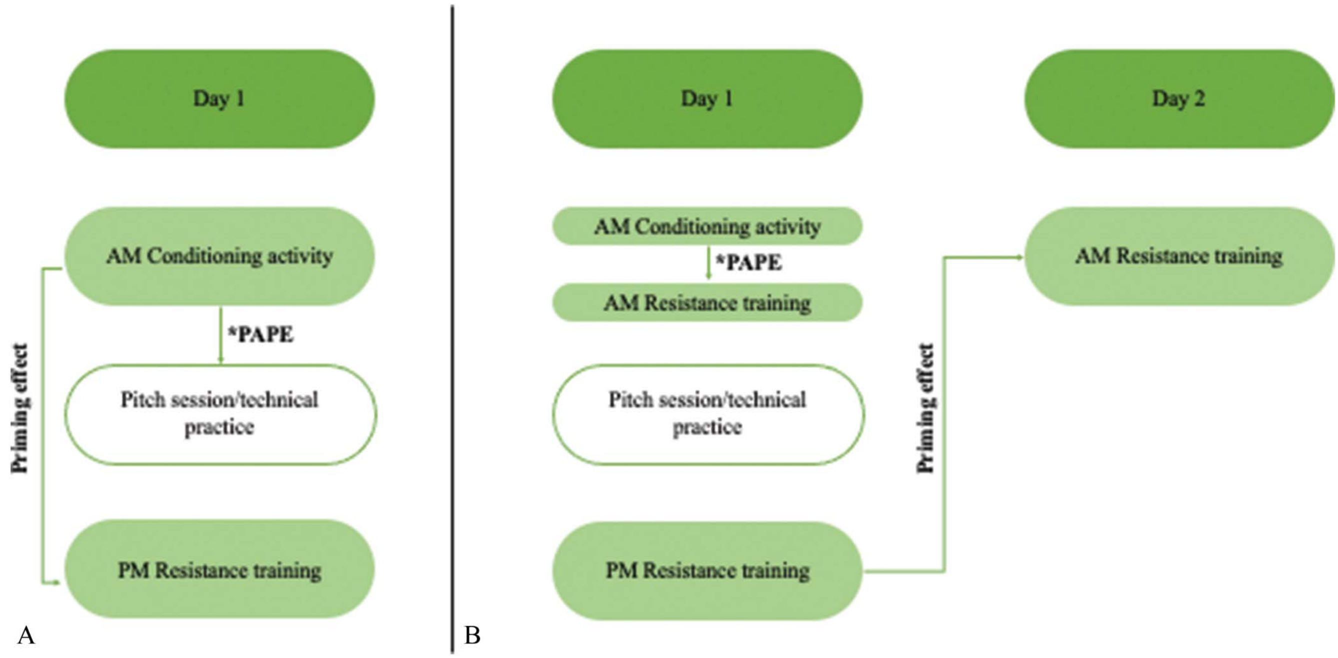

Figure 5. An example of 2 different session configurations across (A) 1 day and (B) 2 days to take advantage of both postactivation performance enhancement and priming effects. *PAPE = postactivation performance enhancement. In this instance, performance enhancement is most likely to influence the first couple of actions in the subsequent pitch session/technical practice or resistance training session.

provide a PAPE effect following a specific CA, with a combination of mechanisms likely providing the enhancement of performance (28,29). The proposed mechanisms span 3 areas: neural, mechanical, and cellular. More specifically these potential mechanisms are likely related to increased calcium ion (Ca^{2+}) sensitivity, muscle-tendon stiffness, and increased muscle temperatures (6). It is generally considered that the time course of PAPE following a CA occurs within a window of 3–10 minutes but may also last >15 minutes in some scenarios (6,116); however, the duration of the window will be affected by the magnitude of the load applied during the CA and the relative strength of the individual (stronger individuals recover more quickly). Although this seems like a large window, it is important to highlight that the recovery duration, whereby fatigue following the CA diminishes but the "potentiation" effect remains (Figure 6A), can demonstrate large interindividual variation as a result of a number of factors, including training experience, strength level, and myotypology (6). This phenomenon has previously been contextualized as an acute version of the traditional fitness-fatigue paradigm (supercompensation [Figure 6C]) (103).

An overview of PAPE-related studies that use a range of CAs (e.g., free weight exercises, resisted sprints, variable resistance exercises, isometric tasks, and plyometrics) and their effect on a variety of different performance measures has been provided in a comprehensive review by Ng et al. (74). Interestingly, the magnitude of PAPE effects in stronger individuals may be comparable to the improvements observed following an entire phase of training (e.g., 4-week mesocycle). Although most CAs result in small acute effects, it is important to consider that in stronger individuals, consistent increases in "intensity" through PAPE may result in a sufficient stimulus for greater chronic adaptation (68). This may be of greater importance in well-trained individuals because chronic adaptations to training have been reported to be smaller compared with untrained individuals (89). By contrast, the time course for manifestation of PAPE is longer for weaker individuals and therefore may not be realistic to permit a sufficient training stimulus to elicit a chronic adaptation, and greater focus should be spent increasing the underpinning capacities (i.e., strength) before using PAPE. With that in mind, such practices may be more applicable for stronger individuals because the period between CA and PAPE is shorter (~3–7 minutes) for them than for weaker individuals (~7–10 minutes) (116). These observations are likely because of greater relative strength in individuals with a longer training history/experience, in line with previous recommendations regarding greater and more rapid potentiation in stronger individuals (106).

The PAPE approach may be beneficial to those with a higher training status, particularly during periods of training that are either focused on the

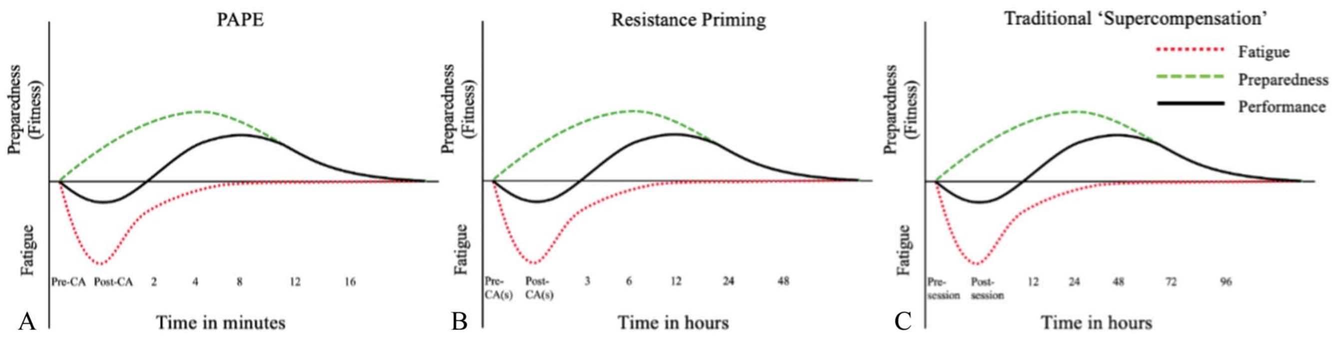

Figure 6. A comparison of the time-course of the fitness-fatigue paradigm following postactivation performance enhancement (PAPE), resistance priming, and traditional supercompensation conditioning activities. CA = conditioning activity; CA(s) = conditioning activity of multiple sets/a small number of high-load, low-volume conditioning activities.

development of power (providing overall training volume does not diminish), when PAPE is not the only stimulus provided in a training week or when athletes are using a tapering strategy. However, the PAPE approach may be limited or less effective with individuals of a lower training age (78,97), whereby greater improvements will likely be observed from other approaches focused on developing the amount of force they can produce rather than trying to enhance the rate at which they produce it (107). Therefore, microdosing of PAPE stimuli may be more appropriate for those of a greater training status (106,116), in conjunction with other resistance training sessions. Those athletes of a lower training age should use microdosing in other ways to benefit in-season resistance training without focusing on trying to induce a PAPE effect.

RESISTANCE PRIMING

"Resistance" priming, occasionally referred to as delayed potentiation, is the enhancement of neuromuscular performance following a low-volume strength (e.g., squat, 3 sets, 3 repetitions, ≥85% 1RM) or power (e.g., jump squats, 3–4 sets, 5 repetitions, 30–40% 1RM) CA that manifests beyond the window traditionally associated with PAPE (44). For example, the beneficial effects of priming have been reported to occur for periods lasting 6–48 hours after the completion of the priming activity (44). Because of the time course of enhanced performance, adopting a microdosing approach with appropriate volumes and intensities will likely elicit a priming response and provide some benefit during subsequent resistance, skill-based or technical training session. In some cases, this may be between sessions during a single day, particularly in some environments where training might be split into morning and evening, or otherwise the priming effect is likely to benefit training on subsequent days (Figure 5). Provided that the priming stimuli are repeated throughout the microcycle, as mentioned within the previous section, the cumulative volume can equal the planned training prescription of a more traditional approach to resistance training, in line with the definition of microdosing (18). Repeatedly using a priming effect may also increase the intensity in which that prescribed volume is executed.

Theoretically, resistance priming is a more chronic form of PAPE and acute representation of the traditional fitness-fatigue paradigm (Figure 6), although the underpinning mechanisms may differ from that previously described for PAPE. With the greater time course for positive effect and dissipation (hours compared with minutes), some mechanisms such as muscle temperature and high-frequency motor neuron activation are unlikely to have an effect across a period of 48 hours. It has also been hypothesized that acute changes in architecture and water content can contribute to an increased ability for "muscle gearing" (see Van Hooren and Bosch (113)), which could result in an acute enhancing effect for resistance priming. Although this has predominately been demonstrated in animals, Dick and Wakeling (23) have provided a comprehensive set of in vivo data, which support theorized mechanisms of muscle gearing in human subjects. However, there is a lack of research directly examining potential mechanisms of resistance priming over the course of a 48-hour period following a CA.

Resistance priming strategies are typically implemented before competition to improve subsequent sporting performance (44). The prevalence of resistance priming in a precompetition period (most frequently within an 8-hour window) has been reported to be evident across a range of different sports, the majority being multidirectional team sports (45). Both resistance priming and PAPE have been assessed using an outcome measure of neuromuscular performance, such as a ballistic jump, plyometric exercise, sprint, or maximum voluntary contraction. Although a resistance priming effect has been demonstrated in the outcome measures mentioned, the increases in performance may be limited to the action and number of repetitions being measured. For example, Russell et al. (92) demonstrated a priming effect in a repeated sprint protocol; however, the enhancement in performance dissipated after 2 sprints (out of a total of 6). The dissipation of performance enhancement highlights the suitability of resistance priming on competition in strength-power sports, whereby a low number of actions are completed typically with long rest periods. The authors are not suggesting that the approach is unsuitable for that of team sports; however, because of the chaotic nature, and the potential interference from aerobic stimuli, resistance priming is unlikely to benefit athletes across a whole fixture. By contrast, it may be worth considering microdosing resistance training in appropriate volumes that will elicit a regular resistance priming response that increases the intensity of work in subsequent training sessions/days, rather than influencing match performance. In combination with the PAPE approach described above, the microdosing of training volume through both resistance priming and PAPE may provide consistent enhancements in training "intensity" while also providing an accumulation of training volume that may allow for continued development to chronic adaptations (Figure 7).

REPEATED BOUT EFFECT

The repeated bout effect (RBE), predominantly but not exclusively observed as a result of eccentric exercise, is a phenomenon whereby the muscle damage and subsequent symptoms caused by an initial bout of unfamiliar exercise becomes minimal when the same bout is repeated following a period of recovery (70). Initial symptoms include loss of muscle force production characteristics, range of motion, increase in muscle proteins in the blood, and development of muscle soreness that are detrimental to performance (48,76,79). Although it may not be possible to completely eradicate the initial symptoms associated with the introduction of a novel stimuli, it may be possible to reduce them through microdosing. This approach, as discussed in *programming strategies*, is observed during emphasis periodization approaches because all physical components are performed simultaneously, which means that when the emphasis changes, the "system stiffness" associated with the change in training focus is reduced (30). Dividing the volume of unfamiliar and/or eccentric bias stimuli may allow for the magnitude of disruption caused to be considerably lower, while still providing the protective characteristics of the repeated bout effect required to increase the volumes at a later point within a training cycle (77). As such, a new or novel stimuli may be microdosed when first introduced and then implemented in a traditional format allowing the smooth transition between vertically integrated and horizontally sequenced mesocycles (7,37).

Although the initial symptoms described previously are predominantly observed following eccentric exercises, they also occur in response to concentric, concentric and eccentric combined, and isometric muscle actions and are occasionally referred to as "exercise-induced muscle damage." Exercise-induced muscle damage has been reported to acutely affect glucose metabolism, namely, decreased glucose uptake and insulin sensitivity that impairs glucose synthesis (109). Such changes in glucose metabolism may also be detrimental to performance during periods of fixture congestion. Although the RBE has been demonstrated to provide a protective effect upon a subsequent bout of exercise, this does not necessarily remain task specific, whereby the protective effect only applies to the task that induced the RBE, but with specificity of the muscle group and action required. An example of this could be the eccentric action of the hamstrings during a Nordic hamstring exercise, which could subsequently provide protection of an eccentric action during sprinting (27). Although the evidence of the Nordic hamstring exercise protecting against injury is equivocal (50), appropriate prescription may provide enough of a protective effect to reduce the magnitude of exercise-induced muscle damage.

Within-group responses to eccentric bouts become more homogenous following the initial exposure (49,77), which may be advantageous when working within a setting whereby individualization is more challenging.

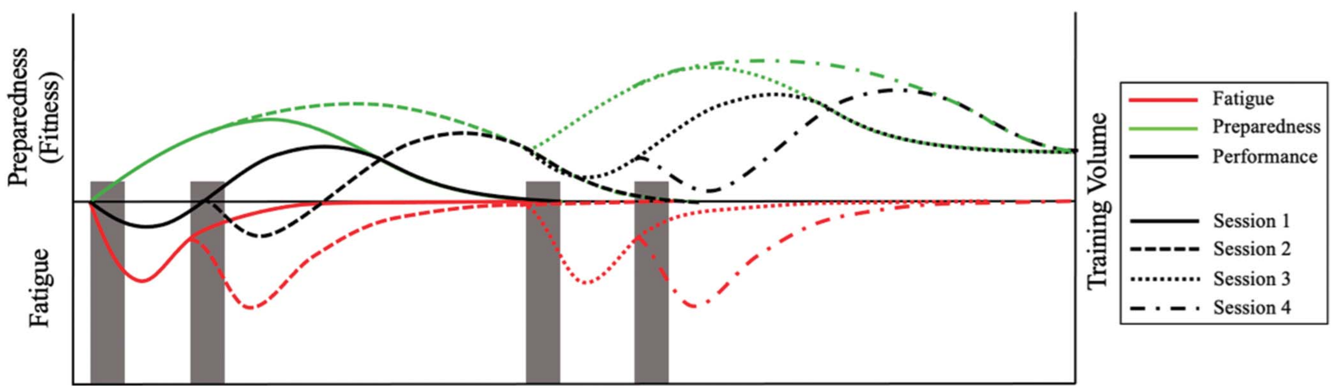

Figure 7. An example of the use of resistance priming on the fitness-fatigue paradigm and the theoretical benefit on increased preparedness and performance.

Despite many RBE protocols using high doses of eccentric actions (e.g., 5 sets of 10 repetitions (12)), Nosaka et al. (77) have demonstrated that performing 24 eccentric repetitions, compared with 6 eccentric repetitions, had no greater protective effect when a subsequent 24 eccentric repetitions were performed 2 weeks later (whereby plasma creatine kinase activity and myoglobin concentration were not significantly greater in either group), highlighting the benefits of low doses of an eccentric stimulus. Within the same study, a group performed 2 eccentric repetitions, which demonstrated a partial but significant protective effect, while producing far less damage in the initial bout. Although a significant protective effect has been demonstrated following a single eccentric bout, Hody et al. (48) have also described observations of a greater protective effect following several sessions. Based on these findings, using a microdosing strategy when introducing an unfamiliar or eccentric stimulus could minimize fatigue and exercise-induced muscle damage following the initial bout, while also providing a protective effect for subsequent bouts of exercise. Following these initial microdoses, gradual increases in volume can be prescribed without inducing the same level of muscle damage that would occur without the protection provided by the RBE. Appropriate introduction of unfamiliar stimuli in-season is essential to reduce or negate some of the negative effects (actual or perceptual) on performance. Considering the study conducted by Nosaka et al. (77), the microdosing strategy can be applied to eccentric exercises whereby the total volume equates to the larger volumes of ≥6 repetitions but divided into smaller doses across a week (e.g., 15 repetitions once per week versus 5 repetitions 3 times per week). This example may allow the manifestation of a greater RBE while minimizing symptoms that are detrimental to performance.

TRAINING SEQUENCING

The principles of training sequencing, be that acutely (i.e., within-session), chronically (i.e., between mesocycle), or anywhere within that continuum, appear to be consistent but with differing terminology. For example, Marshall et al. (68) reviewed acute training sequencing, investigating both the acute responses and the chronic responses from acute strategies (sequencing of sets and exercises), such as "contrast" and "complex" training. Since publication of the review by Marshall et al. (68), further detail around within-session training sequencing has been outlined, whereby complex training is referred to as an umbrella term for 4 other sequencing methods, including, contrast, ascending, descending, and French contrast (15). When considering all forms of complex training further along the acute-chronic continuum, parallels can be drawn to the principles of PAPE and priming, as described in the sections before this when looking at the sequencing of training sessions. Even further along the continuum, with the sequencing of microcycles, approaches such as a conjugated successive system and weekly undulations in training volume (as opposed to load where the focus on developing a specific physical capacity varies each week) can also be compared with that of complex and contrast training, respectively (Figure 8).

Another sequencing method highlighted by Marshall et al. (68) is cluster training. Cluster training is a global term for a number of different set structures that include basic cluster sets, equal work-to-rest ratio and the rest pause method, and is defined as a set structure that includes the normal interset rest periods but involves preplanned rest intervals within the set (39). When performing traditional sets, movement velocity and therefore power output tend to decline as more repetitions are performed (95). Cluster training facilitates superior maintenance of repetition velocity and power output, while also allowing for the potential to perform a greater number of repetitions, increased loads, or a combination of the two through minimizing the effect of accumulated fatigue per "bout" (43,110). All variations highlighted as a form of cluster training on an acute scale (i.e., within set) can also be applied in principle on a chronic scale, as microdosing (Figure 9). If the division of volume across a microcycle allows for superior maintenance of movement velocity and power, or even increased load (suggested above by (43,110)), as with cluster training, it would be theorized that greater improvements in strength and power may be achieved chronically when compared with a traditional approach. Häkkinen and Kallinen (40) demonstrated that the division of resistance training volume into 2 daily sessions over a 3-week period significantly improved strength in female athletes. Further evidence of this strategy providing faster recovery responses and higher training intensities has also been outlined by Bartolomei (3) with a 4-hour rest period between the sessions.

When considering microdosing, the preplanned rest periods may vary (much like in cluster training) depending on the chosen variation, to gain the benefits discussed within the PAPE and resistance priming sections, highlighting the links demonstrated in Figure 8. Variations in volume per session is also likely to occur to best exploit possible PAPE, resistance priming effects, and even a RBE, with the definition of microdosing provided by Cuthbert et al. (18) as frequent, short-duration, repeated bouts and not that these bouts are required to be equal. This approach may also allow for reduced volumes closer to match-day. Providing that the entire training volume prescribed is completed, findings from a recent systematic review and meta-analyses demonstrate that higher training frequencies do not negatively impact strength adaptations, providing equated volume (18). However, the use of microdosing in a variety of sequences (e.g., complex, PAPE, or priming) may allow for the enhancement of various training stimuli to allow for a greater training response because of reduced amounts of fatigue following each session.

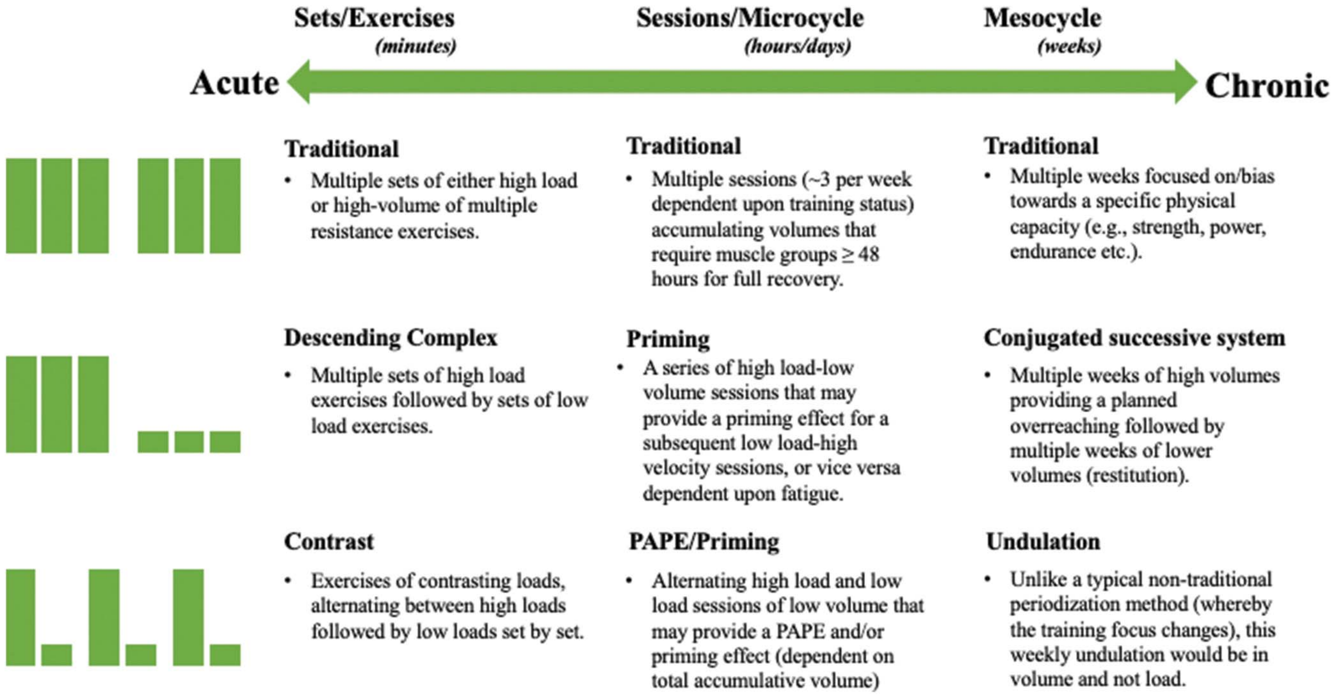

Figure 8. A comparison of terminology used for different set, session, microcyle, and mesocyles across the acute-chronic continuum.

CONCURRENT TRAINING

Concurrent training is the combination of resistance training and aerobic exercise in a single program/training cycle and is observed particularly in multidirectional team sports, because of the importance of developing aerobic fitness congruently with strength and power, particularly in-season (117). Concurrent performance of aerobic and resistance training has been suggested to create an "interference phenomenon" or "interference effect," where adaptations to resistance training are compromised because of excess fatigue, a greater catabolic state, differences in motor unit recruitment patterns or possible conflicts in fiber type shifts (24,47), and inhibition of the mTOR pathway (117). The potential benefit of microdosing during unavoidable concurrent training could be the increase in the number of exposures to strength/power stimulus, which may reduce the inhibition of mTOR pathways (although the evidence of this in human populations is equivocal (94)) and emphasize motor unit recruitment and fiber types toward the desired adaptations. The reduction in session volume (but not total weekly volume) observed in microdosing may also combat the compromises of excess fatigue because energy depletion has been described as contributing to the impairment of mTOR signal pathways mentioned previously (117).

Vechin et al. (114) have presented an updated model of the interference effect, which describes how interference between aerobic and resistance training can be reduced or negated through the use of high-intensity interval training (HIIT), in line with previous findings regarding the beneficial effects of HIIT in minimizing an "interference effect' (81). The HIIT protocols are based on the work by Buchheit and Laursen (9) who refer to velocity at maximal oxygen consumption (vVO_2 max), which is referred to as maximal aerobic speed when completed in the field rather than in a laboratory setting. The protocols include long duration (>60 seconds, ~90–110% vVO_2 max), short duration (<60 seconds, ~110–130% vVO_2 max), repeated sprint (3–10 seconds, ~140–170% vVO_2 max), and sprint interval (30–40 seconds, >170% vVO_2 max). The suggestion based on the interference model is that long-duration HIIT sits within an "interference zone" because of conflicting peripheral adaptations, particularly when little to no recovery is given between the HIIT protocol and resistance training. Long-duration HIIT, being within the interference zone, may lead practitioners to assume that small-sided games and associated technical drills are encompassed within that category because they are typically 3–5 minutes in duration. However, it is important to understand that although different for each individual, within the 3- to 5-minute duration, there will be multiple, short-duration, high-intensity efforts (e.g., accelerations and decelerations) with periods of active rest in between. A duration of ≥6 hours, however, has been demonstrated to negate this conflict in a study that investigated 0, 6, and 24 hours (90), meaning that the duration required could be less, but

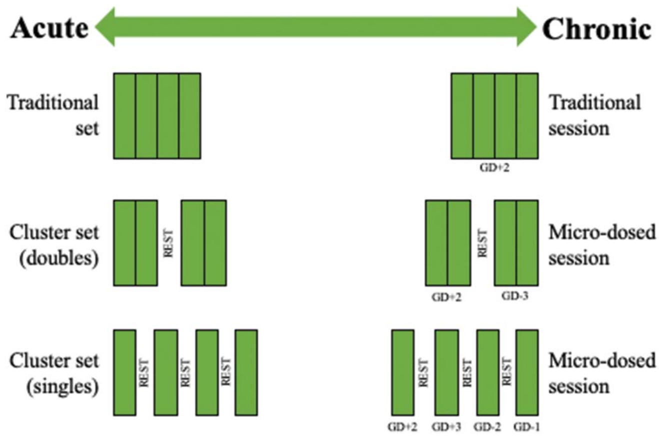

Figure 9. A comparison of the structure of cluster training and microdosing and where they fit across the acute-chronic continuum. GD = game day.

further research would need to be conducted to demonstrate this. Vechin et al. (114) have also suggested that short-duration HIIT may be included within a "slight interference zone," but further research needs to be conducted to affirm that statement. The other 2 HIIT protocols (repeated sprint and sprint interval) would be recommended if the interference effect is required to be completely avoided.

The interference effect has been reported mainly in relation to strength and hypertrophy bias training because of an apparent lack of data around power training. In contrast to this view, however, Wilson et al. (117) concluded in a meta-analysis investigating concurrent training studies that power is the major variable affected by concurrent training. The conclusions in an updated meta-analysis (96) published recently concur with the findings of Wilson et al. (117), suggesting that "combining aerobic and strength training in close proximity attenuates adaptations in explosive strength regardless of exercise order." The attenuation of "explosive" strength or more accurately, rapid force production, in-season is problematic because most team sports require rapid force production for efficient acceleration/deceleration type actions, and therefore, there is a need to develop this quality throughout the season. It has also been concluded that there is little to no interference effect on maximal strength (96). When considering implementing a microdosing strategy, if an athlete requires additional long-duration aerobic stimuli, it is likely to be more beneficial to schedule those on days where there is a greater strength training stimulus. An example of this can be observed in Figure 3, whereby the additional aerobic stimulus could be added on match day (MD) +2 and MD −2 (match day may be referred to as game day in some team sports) during the strength bias phase to allow isolation of the microdosed power stimulus. Regarding a power bias phase, microdosing could assist in alleviating some of the interference effect, allowing the potential for a greater rest period between the resistance training and additional aerobic work because of the reduction in session duration.

MOTOR LEARNING

Increased frequency of a stimuli with appropriate rest intervals, as induced through a microdosing approach, is the primary theme throughout this section, similar to the concept of distributed learning over time or "the spacing effect" whereby better learning and retention of skilled tasks is achieved compared with "massed" practice (1,99). Based on a long-term athlete development (LTAD) perspective, Moody et al. (72) have recommended 2–3 structured, integrated, neuromuscular training sessions to allow recovery and prevent disinterest from overexposure to formalized training; however, some of these effects may be related to the lack of variation in the application of stimuli. We propose that this could potentially go further than just 2–3 structured sessions for numerous reasons, including attention retention, regularity of feedback, and skill recall.

GROWTH AND MATURATION

Although both growth and maturation and LTAD typically go hand in hand, the authors want to highlight that LTAD should span the whole journey that an athlete needs to navigate. Therefore, growth and maturation should be viewed as an important part of the journey that needs greater appreciation and emphasis on motor learning during the period of childhood through to adolescence because of interferences in motor skill execution (65). The use of microdosing during these important periods could provide a solution to enhance motor learning, by increasing the frequency of motor skill development and therefore increase the opportunities and availability of feedback, which has been demonstrated to aid both performance and learning (118) without simultaneously increasing the total volume. Unfortunately, it is common that when frequency increases, so does the volume. An example can be observed in a recent 6-month intervention investigating the effect of neuromuscular training frequencies on motor skill competencies, strength, and power in male youth (62). Within the intervention, a group performing 2 sessions per week (1 gym based and 1pitch based) were compared with a group performing 1 session per week (pitch based), which, in effect, doubled the weekly volume and did not truly investigate the frequency of exposures as the title suggests (62). With the same total volume load across a microcycle being maintained through microdosing, there would be a reduction in daily volume load, which is sometimes necessary during this stage of development as we discuss below.

Within the National Strength and Conditioning Association's LTAD position stand, growth is clearly defined as the increase in the size attained by specific parts of the body or alternatively the body as a whole (61). Growth has also been described as nonlinear in nature, with periods of rapid growth development interspersed with periods of plateau (105). One problem typically experienced approximately 6 months before an adolescents' "peak height velocity" (the maximum rate of growth in stature) is a phenomenon known as "adolescent awkwardness" (82). Adolescent awkwardness is the temporary disruption of basic motor skills execution because of a growth spurt rather than any training-induced performance decrements. Although the recommendation has been made to modify training volume loads during this phase of rapid skeletal growth, to avoid excessive loading, there also needs to be ample opportunity provided for individuals to relearn motor skills and reintroduce some physical literacy to limit the potential for injuries because of technical deficiencies (65).

The definition provided for maturation is progression toward a mature state, which varies in timing, tempo, and magnitude depending on the different biological systems (i.e., skeletal or sexual) (61). Lloyd et al. (65) have highlighted the importance of assessing biological maturity, particularly when considering appropriate exercise prescription to provide performance benefits that are greater than the expected natural development. For instance, before puberty, the primary mechanism underlying improvements in muscular strength and related characteristics is through neural adaptations (87). Myer et al. (73) have summarized how the formulation and fine tuning of specific skills during childhood corresponds with the high degree of plasticity in neuromuscular function and brain development through synaptic pruning, in which critical subsystems (cognitive, sensory, emotional, perceptual, and motor control) are developing optimally. Considering that increases in strength during childhood are typically neurological, training prescription should be focused on higher relative loads with 'mean intensity (% of 1RM)" being highlighted as demonstrating a significantly positive correlation with gains in motor performance skills in a meta-analysis by Behringer et al. (4). Microdosing may not only allow for increased frequency of sessions while maintaining acceptable volumes, but because of the subsequent reduction in duration, microdosing may also allow for smaller groups and therefore a higher supervision ratio. Particularly, during childhood, whereby regular constructive feedback is required, working with smaller groups more frequently may provide greater opportunities for feedback, with Gentil and Bottaro (32) demonstrating greater strength increases in both upper- and lower-body muscles under a high supervision ratio (1:5) compared with low supervision ratio (1:25).

Following the onset of puberty and typically after peak height velocity, improvements in strength are not only attributable to neurological changes but also to structural and architectural changes (increases in muscle cross-sectional area and pennation angle) (63). The structural and architectural development in skeletal muscle occurs because of rapidly increased circulating testosterone and growth hormone (115). At this point, it is thought that strength training (the focus during preadolescence) can begin to be interspersed with bouts of hypertrophy-based training to maintain increases in both strength and overall performance (64). During these bouts of hypertrophy-based training, microdosing may not necessarily be appropriate. Considering that hypertrophy is predominately driven by volume, traditional resistance training sessions may be more suitable, particularly for large groups of athletes and bearing in mind age-related commitments regarding education and potential participation in several sports. However, it is worth considering that much like cluster training, microdosing can be an opportunity to use high loads, considered optimal for increasing strength, while also incurring hypertrophic effects.

LONG-TERM ATHLETE DEVELOPMENT

Long-term athlete development has been defined as the habitual development of health and fitness characteristics that contribute to enhanced physical performance, reduction in injury risk, and improvement in overall "athleticism" (61). Proposed LTAD models have typically been outlined for youth populations (64), focusing on the development of 3 key fundamental movement skills (FMS): (a) locomotion, (b) stabilization, and (c) manipulation, in conjunction with phased and integrated strength and power development where appropriate. More recently, Radnor et al. (85) expanded the FMS concept, outlining the use of athletic motor skill competencies, which breaks the 3 FMS categories into 8, more specific skills. Regardless of the model used, effective motor skill execution, governed by the combination of efficient cognitive processing, movement patterns, and force production, is paramount (72). Although covered in greater detail in the previous section, one of the reasons that the LTAD models typically focus on the youth populations is that older populations are less susceptible to learning new motor skills because of the nonlinear reduction of grey matter in the brain (33). As a result, high-frequency exposure to motor learning is not commonly used to develop and refine skilled movements applied in resistance training; however, microdosing may provide more focused and frequent opportunities to enhance motor learning during such tasks.

Once athletes reach the end of adolescence (~20 and 21 years for women and men, respectively), they are typically within professional or elite environments; however, this should not be the end of their LTAD. In the authors' opinion, a focus on LTAD should remain integral to the athlete's development throughout their athletic career. The LTAD model highlighted previously (64) gives a general indication of focus for adulthood (21+ years), which differs from the bias toward the motor skill competencies described for children and adolescents. There is a requirement for adults to constantly refine movement patterns to move toward mastery. The refinement may be to master skills specific to their sport; it could be mastery of exercises that elicit improvements in the underpinning physical capacities for those sport-specific skills or potential skills that aid in the transfer between the two. Microdosing of resistance training may provide solutions for developing physical capacities and potential enhancement of adaptation compared with traditional methods, as described previously. There is an argument that, for the most part, this can be achieved with the range of movements associated with the earlier stages of LTAD (e.g., squat, lunge, hinge, jumping, landing, etc). As athletes become masterful of these foundation movements, more complex tasks are required to further challenge learning. Certain circumstances throughout a career, such as injury, may require adjustment to a previously developed motor skill or to rebuild the physical capacities, much like with untrained individuals, without incurring too much fatigue.

Another benefit to microdosing is the increased frequency of feedback; through dividing resistance training volume throughout a week, athletes will gain a greater number of opportunities to receive feedback be that intrinsic or extrinsic. As described in the *growth and maturation* section, microdosing can also aid in reducing the coach-to-athlete ratio, which means those who benefit from greater extrinsic feedback may also benefit in this instance. In addition, whether athletes are within a full-time organization or not, there will be an increased demand on their time, be that other departments (e.g., technical/tactical), media commitments, or life outside of their sporting environment, which may mean that the utilization of microdosing (i.e., an increased frequency, but more importantly reduced duration of sessions) could also benefit the required motor learning because this approach may aid greater compliance to the prescribed protocols. Shorter duration sessions may also benefit those individuals with shorter levels of concentration, increasing the overall quality of the work done.

INJURY RISK MITIGATION/ RETURN TO PLAY

Typically, injury risk mitigation and return to play are viewed as entirely different entities; however, principally, they both aim to stimulate positive adaptations to musculoskeletal structures (e.g., muscle cross-sectional area, pennation angle, fascicle length, etc.) and increased neuromuscular control (98). For those practitioners who separate injury risk mitigation (or "prevention") stimulus into a separate category of training, the definition provided for microdosing simply mentions the division of total volume, so that it could be considered as total volume of a planned dose of whatever stimuli has been planned for. In this regard, if a traditional approach to resistance training is appropriate, microdosing can still be of benefit when it comes to accessory stimuli that comes under an injury risk mitigation banner. Herrington (46) has demonstrated this approach with regular, short-duration, progressive, jump training that positively benefits injury risk mitigation through improved motor control. Microdosing in this instance may therefore provide more opportunities for motor learning, but it also allows a greater amount of time for other sessions, such as traditional resistance sessions or recovery between sessions/training days. A form of injury risk mitigation has also been covered in the RBE section where the microdosing of unfamiliar or novel stimuli will provide an acute protection from similar stimulus following a recovery period through the RBE. The microdosing of the RBE could also benefit return-to-play protocols with the introduction of new exercises. Some exercises executed during return to play are potentially atypical of those usually completed by athletes before injury and therefore will be a novel stimulus.

Regarding return to play, Taberner et al. (108) have outlined a process for rehabilitation described as the "control-chaos continuum," with that there is a progression from highly controlled and structured actions/behaviors/movements all the way to highly chaotic and unpredictable actions/behaviors/movements that appear to be both random and reactive. Although originally proposed for pitch-based protocols, resistance training can provide stimuli toward one end of the continuum that is highly controlled in nature and directly translates to the increased capacity of tissues required to produce or tolerate the forces required during chaotic and unplanned situations described by Dos'Santos et al. (25). One reason for applying a microdosing approach in a return to play/rehabilitation situation would be to allow the doses of highly controlled but potentially fatiguing actions to be divided in a way that the fatigue levels during the highly chaotic actions are lower than if they were to follow a larger volume of controlled work. This in turn will allow exercises to be performed across the full spectrum of control to chaos, throughout each microcycle, when at an appropriate stage of an athlete's return to play.

INDIVIDUALIZATION

FEMALE ATHLETE HEALTH AND PERFORMANCE

The authors believe that it is important to recognize that there is much more to female athlete health and performance than the menstrual cycle and also understand the current disparity in the current sports science literature (26). Therefore, there may be numerous other areas to explore from a female athlete health perspective in relation to microdosing particularly when considering some of the points regarding motor learning. However, we have focused our attention on the implications of the menstrual cycle on training in this section because of the high variation in duration of the menstrual cycle and associated phases, severity/presence of physical symptoms, and psychosocial experiences between individuals and therefore potential requirement for individualization of training (29). Although a recent systematic review and meta-analyses presented a trivial effect of the menstrual cycle on performance, no general guidance was provided for modulating exercise across the cycle (71). The between-study variance and poor methodological quality of the included studies resulted in the lack of guidance regarding manipulation of training. However, McNulty et al. (71) did recommend that a personalized approach should be taken based on individual responses to the menstrual cycle and the subsequent effect on performance. Although it is recommended that symptom management should be the priority, with the utilization of a microdosing approach, if training is required to be modified for a particular athlete, then depending on how the sessions are microdosed, the athlete may only miss or reduce the planned training for a smaller percentage of the total weekly volume. For example, if 2 traditional resistance training sessions were microdosed equally into 4 sessions, rather than missing 50% of the weekly volume, only 25% would be missed/adapted. Although relatively low absenteeism in training has been reported previously (29), within the week leading up to menses evidence indicates that some individuals do require adjustments to training (8).

Further to just the menstrual cycle, Nimphius (75) has highlighted previously that although strength and neuromuscular adaptations are broadly similar in male and female athletes of comparable training status (101), the influence that sporting and societal systems have on motor skill development/attainment may ultimately influence the transfer of improved strength to sport-specific skills. Despite some of these issues, because of the disparity of the literature tailored to female athletes, more research needs to be performed to understand whether some of the previously highlighted benefits of microdosing, such as PAPE and priming, would also benefit female populations. Considering that both PAPE and resistance priming are believed to benefit athletes with a higher training status, it is important to know if these results are present with female athletes, particularly considering that both Russell et al. (92) and Cook et al. (14) have discussed the

Table 2
An example of 3 variations of traditional and micro-dosed approaches to a strength training block

Training day	Option A	Option B	Option C
Monday (game day +2)	Back squat (3 × 5)	Back squat (1 × 5)	Back squat (3 × 5)
	Push press (3 × 5)	Push press (1 × 5)	Romanian deadlift (3 × 5)
	Bulgarian split squat (3 × 5)	Bulgarian split squat (1 × 5)	
	Romanian deadlift (3 × 5)	Romanian deadlift (1 × 5)	
	Depth jump (3 × 5)	Depth jump (1 × 5)	
	Calf raise (3 × 5)	Calf raise (1 × 5)	
Wednesday (game day −3)		Back squat (1 × 5)	Bulgarian split squat (3 × 5)
		Push press (1 × 5)	Calf raise (3 × 5)
		Bulgarian split squat (1 × 5)	
		Romanian deadlift (1 × 5)	
		Depth jump (1 × 5)	
		Calf raise (1 × 5)	
Thursday (game day −2)		Back squat (1 × 5)	Push press (3 × 5)
		Push press (1 × 5)	Depth jump (3 × 5)
		Bulgarian split squat (1 × 5)	
		Romanian deadlift (1 × 5)	
		Depth jump (1 × 5)	
		Calf raise (1 × 5)	

Intensity at 80–85% 1RM.

Table 3
Practical application of microdosing, summarized

Competition schedule	
Training residuals	Fixture congestion can reduce resistance training frequency, and therefore, load to a point whereby the residual effects of training are lost and detraining occurs Because of the flexibility in session frequency and duration (resulting in minimal fatigue), microdosing could be used to maintain a sufficient frequency and volume to ensure an appropriate stimuli in comparison to what may typically be executed in congested competition schedules
Programming strategies	Microdosing is a programming strategy itself but can be used in conjunction with other strategies such as distributing volume during a period of planned overreaching Microdosing can also be used within emphasized periodization models either to distribute a maintenance load or help enhance the primary focus of the phase Microdosing could be used to assist in the reduction of volume during tapering at both a microlevel (i.e., game preparation) and macrolevel (i.e., step, linear, or exponential tapering)
Minimum effective dose	Although a separate concept to microdosing, minimum effective dosing can potentially be applied using microdosing Microdosing can be applied throughout the full dose-response spectrum and while minimum effective dosing is not appropriate for prolonged periods
Acute/chronic programming	
Postactivation performance enhancement (PAPE)	PAPE stimuli should be used in addition to other microdosed sessions to accumulate appropriate volumes With careful planning based on session timings and training status of individuals, the PAPE stimuli can potentially enhance the first couple of actions of a pitch session/technical practice or the first exercise of a subsequent resistance training session
Resistance priming	Greater volume than a PAPE stimulus with a subsequently longer duration between stimulus and response. This may lend itself to more consistent use, making it easier to both accumulate appropriate total volume and to plan for within a training schedule More likely to influence subsequent training sessions than competition in team sports
Repeated bout effect (RBE)	Microdosing could be used to introduce a new or novel stimulus while providing minimal disruption to other aspects of training and athlete readiness A RBE can be induced with a small volume and provide protection for subsequently higher volumes
Training sequencing	Training sequences have the same “look” when approached acutely and chronically (but with differing terminology and desired mechanisms), with an acute form of microdosing being likened to cluster training (Figure 8) The sequencing of microdosed resistance training will allow practitioners to best use concepts previously discussed such as PAPE, resistance priming, and RBE
Concurrent training	Because of the flexibility in scheduling associated with microdosing, the approach could be used to alleviate some of the “interference effect” associated with completing traditional resistance training sessions in close proximity to aerobic-based training
Motor learning	
Growth and maturation	The reduction in acute volume, maintenance of total volume, and increased frequency of exposure through microdosing can potentially assist with the reduction of injury risk related to “adolescent awkwardness” and anthropometric changes associated with peak height velocity Shorter-duration sessions can also allow for an increased number of groups and subsequently a lower coach-to-athlete ratio, potentially increasing feedback opportunities and therefore learning Microdosing could also help appropriately increase frequency and total volume to take advantage of normal responses without putting athletes at an increased risk

Table 3 (continued)

Long term athlete development (LTAD)	Microdosing may provide more focused and frequent opportunities to refine and enhance motor learning to effectively combine efficient cognitive processing, movement patterns, and force production capabilities, no matter the stage of LTAD Increased frequency of feedback and benefit for individuals with short levels of attention/concentration to increase the quality of work done
Injury risk mitigation/return to play	Microdosing will permit increased opportunities for motor learning during return-to-play protocols The use of microdosing could allow for doses of highly controlled but potentially fatiguing actions to be completed in a relatively safe manner while having less impact on the more chaotic actions
Individualization	
Female athlete health and performance	Microdosing could increase compliance particularly if training requires modification or adjustment because of the flexibility of moving short-duration sessions without causing excessive fatigue Microdosing research should be completed in female populations as well as further investigation into PAPE and resistance priming because of a lack of investment into the application of these principles in female population
Player autonomy	Microdosing could enhance player motivation/intent through autonomy support, providing an element of choice to the athlete within some specific guidelines set by the practitioner Allowing players to have a say in elements of their schedule and some level of flexibility may also benefit compliance in athletes who are part of a decentralized program or are not full-time professionals
Training status	Some of the principles discussed such as PAPE and resistance priming are of greater benefit or only applicable to athletes of greater training status or relative strength Microdosing may provide opportunities to divide squads into smaller groups of similar training statuses to allow for the various ranges within the whole group

potential resistance priming effect to be because of hormonal changes.

PLAYER AUTONOMY

Based on several meta-analytical observations (18,35,86), as previously highlighted, there are no meaningful differences between training frequencies when volume load is equated. One factor that is likely to make a difference between the success of both traditional and microdosing methods is the intent and motivation of the athletes completing the program. Microdosing may offer an alternative approach to enhance some athletes' intent/motivation within a group. Motivation is reported to be a key element of an athlete's success in sports (34) and has been clearly described as the internal (intrinsic) and/or external (extrinsic) forces that influence the initiation, direction, intensity, and persistence of a person's behavior (112). Intrinsic motivation refers to performing an activity for the pleasure and satisfaction derived from participation and with no other apparent rewards (20) and is an important determinant of sport performance (67). Although many team sport athletes are intrinsically motivated when it comes to the technical and tactical development of their sport, not all athletes will experience the same motivation when it comes to resistance training and may require a greater level of extrinsic motivation. Extrinsic motivation has been proposed to be either self-determined (e.g., internal acceptance of the value of resistance training for sports performance and engaging out of choice even if it perceived as unpleasant (67,112)) or non–self-determined (e.g., feeling obligated or pressured to take part in resistance training either externally by a coach or internally through a feeling of guilt (112)). Extrinsic motives can therefore be imposed and coercive or fully endorsed by the athlete (67).

One possible method of enhancing the intrinsic and self-determined extrinsic motivation or altering non–self-determined motivation is through autonomy support. Autonomy-supportive environments allow individuals to feel that a behavior or activity originates from and expresses their true selves rather than being a response to external pressures or demands (13). Mageau and Vallerand (112) have proposed a list of coaching behaviors that allow for autonomy support, the first of which is "providing as much choice as possible within specific limits and rules." Athletes' choice in sport is generally limited because of coaches planning and prescribing their training programs and schedules. Coaches could potentially provide several options, including traditional and microdosing approach(es), which players can choose from, that are still within the coaches' control to maintain appropriate planning and periodization. Optionality could also give the players greater ownership based on their preferences to maximize the quality, intent, and overall compliance of their weekly outputs. For example, a player may have the attitude that they would rather get all the work done in larger less frequent chunks and follow more traditional approaches to training (see option *A* in Table 2). Alternatively, if a player prefers spending less time in the gym during each training occasion but is willing to attend more frequent training sessions, microdosing may be more appropriate based on their preferences (see Option *B* in Table 2). However, it is important in these cases that players understand the overall process and have an idea of where optionality is perhaps limited for the practitioner to guide the desired training outcome.

Providing an alternative approach, to increase player autonomy, may also have benefits within organizations that work in a decentralized format where athletes are either spread across a country or even across countries, and motivation becomes key if they are not in face-to-face contact with their coach day in and day out. However, it is worth considering that depending on the training status of the athletes, option *B* in Table 2 will potentially increase the number of warm-up sets executed across a training cycle, increasing training load. This may not be a negative consequence because it may provide additional volume for weaker/lesser trained athletes without explicitly programming it or the additional warm-up sets could be viewed as additional power training (38).

TRAINING STATUS

Unlike the other sections included in this review where microdosing is used as a method that should ultimately enhance the effectiveness, feasibility, or flexibility of resistance training in-season, training status is more likely to dictate how microdosing is best used with a given athlete. Peterson et al. (80) has identified that the rate of improvement in muscular strength following a given training stimulus decreases with greater training status and previous level of muscular strength. Rhea (88) also highlighted that smaller magnitudes of improvement should be expected in athletes of a higher training status. As a result of the findings by Peterson et al. (80), the potency (intensity) or dose (volume) of an exercise, or in some cases both, must increase to elicit a similar magnitude of adaptation over a chronic period of training (i.e., progressive overload). In-season, when the training focus is likely to be weighted toward increasing the intensity of exercises rather than the total volume, microdosing with athletes of a higher resistance training status may be more appropriate for many of the reasons covered in previous sections such as eliciting a PAPE or resistance priming response. However, outside of the competitive season, the volumes that those of higher training status require will likely make a traditional approach to training more appropriate as time constraints are not as limiting (Table 3).

Within team sports, there can be a large variation in the training status of a squad, particularly in team sports such as soccer, where the culture around physical development can differ greatly. Although some players may have come up through an academy system or attended a well-resourced school, some players may move to an organization with limited experience in resistance training and be of a much lower training status, despite being extremely proficient at their sport. Microdosing may provide a greater opportunity to divide the team into smaller groups that train more frequently, particularly for those of a lower training status to benefit from concepts highlighted previously such as the RBE, a reduced amount of fatigue per session, and greater number of learning opportunities.

PRACTICAL APPLICATIONS

A whole range of practical applications have been suggested throughout this manuscript. A summary of these has been provided in Table 3 for each of the four key areas suggested, including competition schedule, acute/chronic programming, motor learning, and individualization.

CONCLUSION

Microdosing is not necessarily a new concept, even within resistance training, or at least it is derived from numerous other strategies and models. Within this review, however, the ways in which microdosing of resistance training could influence the enhancement of athletic development and performance have been outlined, as a conceptual framework. Although microdosing may not be a new concept, many aspects of the framework still need further investigation to determine whether microdosing works in certain situations or populations, so practitioners can understand when it is and is not appropriate to use this programming strategy. In addition, this review has focused on team sports, but it is also worth considering how the concept would apply to individual athletes or for tactical strength and conditioning (military or emergency response personnel). Whether the term microdosing is here to stay, the underpinning theories provided to solve constraints around competition scheduling or enhance the acute/chronic programming, individualization, and motor learning of athletes will remain applicable, and microdosing is a convincing strategy to navigate these challenges.

Conflicts of Interest and Source of Funding: The authors report no conflicts of interest and no source of funding.

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