MICRO-DOSING: A CONCEPTUAL FRAMEWORK FOR USE AS A PROGRAMMING STRATEGY FOR RESISTANCE TRAINING IN TEAM SPORTS

M. Cuthbert[1, 2], G.G. Haff[1, 3], J.J. McMahon[1], M. Evans[2], & P. Comfort[1, 3, 4].

[1]University of Salford, Greater Manchester, UK; [2]The Football Association, Burton Upon Trent, UK; [3]Edith Cowan University, Joondalup, Australia; [4]Leeds Beckett University, Leeds, UK

Matthew Cuthbert, PhD

"Current Position Bio": Matthew Cuthbert currently works for The Football Association where he is an England Women's Pathway Physical Performance Coach.

Corresponding author:
E-mail: m.cuthbert@edu.salford.ac.uk

ABSTRACT

Micro-dosing, in the context of resistance training has increased in popularity within sporting environments where it is frequently used amongst strength and conditioning professionals. While there is a clear definition for the concept within the literature it is still commonly incorrectly used, and the extent to which micro-dosing has been explicitly investigated in empirical research is limited. There are, however, 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 micro-dosing as an overarching concept. There are also misinterpretations about the term and what micro-dosing entails; for example, the term micro-dosing is often used interchangeably with the concept of the minimum effective dose. The aim of this review is, therefore, 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 micro-dosing requires further investigation. Although micro-dosing may be a relatively new term which is considered 'trendy' amongst practitioners, the underlying principles associated with micro-dosing have been expressed and investigated for a long time.

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

INTRODUCTION

Recently, the concept of 'micro-dosing' has become a popular topic of discussion and debate amongst strength and conditioning professionals (1). This concept originally appeared in clinical research regarding drug development during the 1990's, as a method of assessing pharmacokinetics (how a substance reacts when given to a living organism) prior to full Phase I clinical trials (60). In clinical environments micro-dosing involves the application of a dose that is sub-pharmacological and sub-therapeutic (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 micro-dose (83). Within this context a micro-dose stimulates metabolic reactions, but these effects are not perceived by the individual. Although mostly anecdotal, recommendations of these sub-perceptual 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 however, micro-dosing has commonly been misconceived to be synonymous with the 'minimal effective dose' (1, 94). This misconception is understandable as until recently no formal definition of exercise micro-dosing had been present in the literature. Based upon this recent definition micro-dosing has been clearly defined as "the division of total volume within a micro-cycle, across frequent, short duration, repeated bouts" (18).

More recently, Hansen (42) has proposed an alteration to the original naming of his approach to contextualize micro-dosing as 'micro-priming'. Whilst Hansen (42) rightly highlights that many practitioners continue to improperly label and apply the micro-dosing 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 "flavour-of-the-month" programming trends (42). Though the authors agree with the notion that a greater focus should be placed upon doing the basics consistently and at a greater frequency, where feasible, Hansen's (42) rationale for moving away from the term micro-dosing is in part due to the association with taking small yet more frequent dosages of stimuli (such as drugs) that require periods of 'cycling-off' to prevent/avoid habituation. When going beyond exercise programming, however, and considering a periodized approach to training, cyclical constructs are central to how we integrate, sequence and organize training that targets a specific outcome (103). Therefore, the application of micro-dosing may not always be appropriate or may need to be utilized 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 micro-dosing, 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.

Insert Figure 1

Therefore, the purpose of this review is to discuss how the concept of micro-dosing 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 micro-dosing may theoretically be used as a programming strategy across four 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.

Insert Figure 2

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 time period in which possible adaptations can take place (16). Training residuals are therefore separate to any delayed training effect driven by supercompensation and are often contextualised as short-, medium-, 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, stroke volume and decreased resting heart rate, as well as 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 maximal aerobic consumption and anaerobic thresholds, increased muscular strength, power, and endurance which may last for several weeks, but 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 individuals' training history and the volume and intensities of loading used prior to 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 focussed training of certain physical characteristics is omitted for predetermined period of time (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 non-collision sports (e.g., soccer, basketball) (Table 1). There are several reasons 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.

Insert Table 1

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). In contrast, international tournaments can last up to four weeks, however, as outlined by Issurin (53) within that time 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 to 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 competition, resistance training volumes can be reduced even further to prioritise recovery, exacerbating the loss of training residuals. Micro-dosing resistance training as an approach during these periods of dense competition schedules may be a feasible option to maintain appropriate strength and/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 post-activation performance enhancement (PAPE) or resistance priming stimuli (see *resistance priming* below), the accumulated volume across the whole microcycle may be maintained whilst potentially inducing less fatigue compared with traditional approaches to programming in-season training. It is possible that a micro-dosed 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)) due to 'recovery' being prioritised 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 of time is unrealistic due to 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). It is, however, important to note that periodization is the macro-management of the training process (17) and serves as the scaffold for planning the direction of programming, making both periodization and programming two distinctly different concepts.

Insert Table 2

As Cunanan et al. (17) have highlighted, programming includes the manipulation of training variables (e.g., frequency, density, volume, load etc.) but also the use of various advanced programming strategies that can include phase potentiation (22), planned overreaching (31) and tapering (112). One programming strategy that can be used in a periodised training plan is micro-dosing 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 (105)) 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 'mini-blocks' to enhance specific training factors. These mini-blocks have been suggested as a strategy to prolong the residual effects of a preceding mesocycle, providing a form of micro-dosing (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 two weeks (120, 121). Therefore, varying emphasis means that attributes being maintained require less dedicated training, which may be more appropriate for team sports (56, 103). Micro-dosing 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), whilst the primary focus of the training phase (e.g., maximal strength) can be applied through longer duration sessions. In contrast, a micro-dosing 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 result of micro-dosing, as well as the increased frequency of stimulation to combat the short residuals associated with this characteristic.

Insert Figure 3

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 a concentrated loads in a relatively short durations and then integrate micro-dosed strength training sessions, where warranted, to provide an increased 'readiness' for competition without inducing excessive fatigue, whilst 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 micro-dosing sessions performed much closer to competition to maximize recovery (Figure 3). Practitioners should be mindful that increased frequency of sessions may also increase monotony of training especially if suitable exercise variation is not provided.

Minimum Effective Dosing

Despite there being some commonalities, minimum effective dose is not synonymous with micro-dosing, as exercise prescription can be applied across a spectrum of minimum to maximum effective dosing (Figure 1). The utilization of the minimum effective dose for maintenance of performance (57) may be advantageous during periods of fixture congestion to minimize training induced fatigue whilst 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 ~85% of one 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 maximise development of hypertrophy or strength (11, 36, 58, 69). Knowledge of these loading paradigms may, however, provide guidance on the volume load (sets x repetitions x load) required for a minimum effective dose and how these loads can be micro-dosed 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. (101) suggested reductions in volume by 33-66% can be made whilst strength is maintained providing the load lifted remains high.

Rønnestad et al. (92) 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 two 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, while 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 (92). 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 vs once every two weeks, but whereby the more frequent training group (i.e., once per week) micro-dosed the volume across the two weeks (e.g., halving the volume of each session). This of course requires further investigation; however, it may suggest that micro-dosing 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, micro-dosing and minimum effective dosing are separate concepts, albeit that the minimum effective dose can be micro-dosed, despite authors of a recent commentary relating micro-dosing to minimal dosing (1). The same authors also describe micro-dosing as 'old wine in a new bottle' directly comparing it to motor learning theory of distributed practice (1). Whilst the authors of this current review do not disagree with the suggestion that micro-dosing is not a new concept, the links to motor learning will be outlined later in the review.

Insert Figure 4

ACUTE/CHRONIC PROGRAMMING

Post-Activation Performance Enhancement (PAPE)

Prior to their being a distinction between the term PAPE and 'post-activation 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 two approaches share some similarities including enhanced contractile force, a delay in observed benefits of potentiation and a greater response in muscles with a large proportion of fast-twitch fibres, the time-course of benefits, from both PAP and PAPE, on force production and other underpinning mechanisms (myosin regulatory light chain phosphorylation compared to muscle temperature, water content and activation) differ largely, making them two 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 two ways in which resistance training could be designed to take advantage of PAPE within a micro-dosing strategy. Firstly, dependent upon 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). Secondly, a micro-dosing session may be constructed of just two 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 mins, dependent 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 micro-dosed sessions creating the overall microcycle dose.

Insert Figure 5

There is currently no consensus on the underpinning mechanisms that provides a PAPE effect following a specific CA, with a combination of mechanisms likely providing the enhancement of performance (28,29). The proposed mechanisms span three 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, 117), however, the duration of the window will be impacted 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 inter-individual 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]) (104).

Insert Figure 6

An overview of PAPE related studies that utilize 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). Even though most CAs result in small acute effects, it is important to consider that in stronger individuals, consistent increases in "intensity" via PAPE may result in a sufficient stimulus for greater chronic adaptation (68). This may be of greater importance in well-trained individuals, as chronic adaptations to training have been reported to be smaller compared to untrained individuals (90). In 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 utilising PAPE. With that in mind such practices may be more applicable for stronger individuals as the period between CA and PAPE is shorter (~3-7 minutes) than weaker individuals (~7-10 minutes) (117). These observations are likely due to 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 (107).

The PAPE approach may be beneficial to those with a higher training status, particularly during periods of training that are either focused on the 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 utilising a tapering strategy. The PAPE approach may, however, be limited or less effective with individuals of a lower training age (78, 98) 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 (108). Micro-dosing of PAPE stimuli may, therefore, be more appropriate for those of a greater training status (107, 117), in conjunction with other resistance training sessions. Those athletes of a lower training age should utilize micro-dosing 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 of time lasting 6-48 hrs after the completion of the priming activity (44). Due to the time-course of enhanced performance, adopting a micro-dosing 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 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 micro-dosing (18). Repeatedly utilising 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 to that previously described for PAPE. With the greater time-course for positive effect and dissipation (hours compared to minutes), some mechanisms such as muscle temperature and high-frequency motor neuron activation are unlikely to have an effect across a period of 48 hrs. 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 (114)) 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. There is, however, a lack of research directly examining potential mechanisms of resistance priming over the course of a 48-hr period following a CA.

Resistance priming strategies are typically implemented prior to competition to improve subsequent sporting performance (44). The prevalence of resistance priming in a pre-competition period (most frequently within an 8-hour window) has been reported to be evident across a range of different sports, the majority being multi-directional 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. (93) demonstrated a priming effect in a repeated sprint protocol, however, the enhancement in performance dissipated after two sprints (out of a total of six). 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, due to the chaotic nature, and the potential interference from aerobic stimuli, resistance priming is unlikely to benefit athletes across a whole fixture. In contrast, it may be worth considering micro-dosing 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 micro-dosing of training volume through both resistance priming and PAPE may provide consistent enhancements in training "intensity" whilst also providing an accumulation of training volume that may allow for continued development to chronic adaptations (Figure 7).

Insert 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 micro-dosing. This approach, as discussed in *programming strategies*, is observed during emphasis periodization approaches as 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, whilst 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 micro-dosed 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 "exercised-induced muscle damage". Exercised-induced muscle damage has been reported to acutely affect glucose metabolism, namely decreased glucose uptake and insulin sensitivity that impairs glucose synthesis (110). Such changes in glucose metabolism may also be detrimental to performance during periods of fixture congestion. While 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. Despite many RBE protocols utilising 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 to 6 eccentric repetitions, had no greater protective effect when a subsequent 24 eccentric repetitions were performed two 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, whilst producing far less damage in the initial bout. Whilst 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 upon these findings, utilising a micro-dosing 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 micro-doses, 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 micro-dosing 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 vs 5 repetitions 3 times per week). This example may allow the manifestation of a greater RBE while minimising 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 as well as 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 four 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 prior to 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 to that of complex and contrast training, respectively (see Figure 8).

Insert 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 inter-set rest periods but involves pre-planned rest intervals within the set (39). When performing traditional sets, movement velocity and therefore power output, tend to decline as more repetitions are performed (96). 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 minimising the effect of accumulated fatigue per 'bout' (43, 111). 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 micro-dosing (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, 111)), as with cluster training it would be theorized that greater improvements in strength and power may be achieved chronically when compared to 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 sessions.

When considering micro-dosing, the pre-planned rest periods may vary (much like in cluster training) dependent upon 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 in order to best exploit possible PAPE, resistance priming effects and even a RBE, with the definition of micro-dosing 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 demonstrates that higher training frequencies do not negatively impact strength adaptations providing volume is equated (18). The use of micro-dosing, however, 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.

Insert Figure 9

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, due to the importance of developing aerobic fitness congruently with strength and power, particularly in-season (118). 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 due to either excess fatigue, a greater catabolic state, differences in motor unit recruitment patterns or possible conflicts in fibre type shifts (24, 47), and inhibition of the mTOR pathway (118). The potential benefit of micro-dosing during unavoidable concurrent training could be the increase in 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 (95)) and emphasize motor unit recruitment and fibre types towards the desired adaptations. The reduction in session volume (but not total weekly volume) observed in micro-dosing may also combat the compromises of excess fatigue, as energy depletion has been described as contributing to the impairment of mTOR signal pathways mentioned previously (118).

Vechin et al. (115) 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 minimising an 'interference effect' (81). The HIIT protocols are based upon 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 s, ~90-110% vVO_2 max), short duration (< 60 s, ~110-130% vVO_2 max), repeated-sprint (3-10 s, ~140-170% vVO_2 max) and sprint interval (30-40 s, > 170% vVO_2 max). The suggestion based upon the interference model is that long duration HIIT sits within an 'interference zone' due to 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, as they are typically 3-5 minutes in duration. It is important to understand, however, that although different for each individual, within the 3–5-minute duration, there will be multiple short duration high intensity efforts (e.g., accelerations and decelerations) with periods of active rest in between (9). A duration ≥ 6 hrs, however, has been demonstrated to negate this conflict in a study that investigated 0 hrs, 6 hrs and 24 hrs (91), meaning the duration required could be less but further research would need to be conducted to demonstrate this. Vechin et al. (115) 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 two 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 due to an apparent lack of data around power training. In contrast to this view, however, Wilson et al. (118) 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 (97) published recently concurs with the findings of Wilson et al. (118), 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 as most team sports require rapid force production for efficient acceleration/deceleration type actions and there is therefore 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 (97). When considering implementing a micro-dosing 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 matchday (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 micro-dosed power stimulus. In terms of a power bias phase, micro-dosing 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 due to the reduction in session duration.

MOTOR LEARNING

Increased frequency of a stimuli with appropriate rest intervals, as induced via a micro-dosing 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 to "massed" practice (1, 100). 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 over exposure 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. Growth and maturation should therefore 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 due to interferences in motor skill execution (65). The use of micro-dosing 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 (119) 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 two sessions per week (one gym-based and one pitch-based) were compared to a group performing one 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 micro-dosing, 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 non-linear in nature, with periods of rapid growth development interspersed with periods of plateau (106). One problem typically experienced approximately six months prior to 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 due to technical deficiencies (65). Read et al. (88) have suggested in the realm of injury prevention during this period of peak height velocity, and the subsequent anthropometric changes including "adolescent awkwardness", that micro-dosing be a potential strategy for implementing a high frequency of low volume potent blocks of stimulus to accumulate a larger volume and/or compliance, in season.

The definition provided for maturation is progression toward a mature state which varies in timing, tempo and magnitude dependent upon 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 in order to provide performance benefits that are greater than the expected natural development. For instance, prior to 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 via 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). Micro-dosing may not only allow for increased frequency of sessions whilst maintaining acceptable volumes, but due to the subsequent reduction in duration, micro-dosing 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 to low (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 structural and architectural (increases in muscle cross-sectional area and pennation angle) (63). The structural and architectural development in skeletal muscle occurs due to rapidly increased circulating testosterone and growth hormone (116). At this point it is thought that strength training (the focus during pre-adolescence) 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, micro-dosing may not necessarily be appropriate. Considering that hypertrophy is predominately driven by volume, traditional resistance training sessions may end up being more suitable, particularly for large groups of athletes and bearing in mind age-related commitments in terms of education and potential participation in several sports. It is, however, worth considering that much like cluster-training, micro-dosing can be an opportunity to use high loads, considered optimal for increasing strength, whilst 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 of injury risk, and improvement of overall "athleticism" (61). Proposed LTAD models have typically been outlined for youth populations (64), focussing on the development of three key fundamental movement skills (FMS); (i) locomotion, (ii) stabilization, and (iii) 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 three FMS categories into eight, 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 due to the non-linear reduction of grey matter in the brain (33). As a result, high frequency exposure to motor learning is not commonly utilized to develop and refine skilled movements applied in resistance training; however, micro-dosing 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 females and males, 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 an integral part of the athlete's development across their entire athletic career. The LTAD model highlighted previously (64) does give a general indication of focus for adulthood (21+ years) which of course differs from the bias towards the motor skill competencies described for children and adolescents. There is a requirement for adults to constantly refine movement patterns to move towards 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 potentially skills that aid in the transfer between the two. Micro-dosing of resistance training may provide solutions for the development of physical capacities and potential enhancement of adaptation in comparison to traditional methods as described in previous sections. 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. There are also certain circumstances throughout a career, such as injury, that 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 micro-dosing 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, micro-dosing 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 micro-dosing (i.e., an increased frequency, but more importantly reduced duration of sessions) could also benefit the required motor learning as 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 (99). For those practitioners who separate injury risk mitigation (or "prevention") stimulus into a separate category of training, the definition provided for micro-dosing simply mention the division of total volume, so that 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, micro-dosing 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 produce positive benefits in terms of injury risk mitigation via improved motor control. Micro-dosing in this instance may therefore provide more opportunities for motor learning, but also allow a greater amount of time either for other sessions, such as traditional resistance sessions, or for recovery between sessions/training days. A form of injury risk mitigation has also been covered in the RBE section where the micro-dosing of unfamiliar or novel stimuli will provide an acute protection from similar stimulus following a period of recovery through the RBE. The micro-dosing of the RBE could also benefit return to play protocols with the introduction of new exercises but also some exercises executed during return to play are potentially atypical of those usually completed by athletes prior to injury, and therefore will be a novel stimulus.

In terms of return to play, Taberner et al. (109) have outlined a process for rehabilitation described as the 'control-chaos continuum', with that there is a progression from highly controlled and structured actions/behaviours/movements all the way to highly chaotic and unpredictable actions/behaviours/movements that appear to be both random and reactive. Although originally proposed for pitch-based protocols, resistance training can provide stimuli towards 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 micro-dosing 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 athletes return to play.

INDIVIDUALIZATION

Female Athlete Health and Performance

The authors believe 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 current sports science literature (26). There may therefore be numerous other areas to explore from a female athlete health perspective in relation to micro-dosing particularly when considering some of the points regarding motor learning. We have, however, focussed our attention on the implications of the menstrual cycle on training in this section, due to the high variation in duration of the menstrual cycle and associated phases, severity/presence of physical symptoms, and psycho-social 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. McNulty et al. (71), however, did recommend that a personalized approach should be taken based on individual responses to the menstrual cycle and the subsequent effect on performance. Whilst it is recommended that symptom management should be the priority, with the utilization of a micro-dosing approach, if training is required to be modified for a particular athlete, then depending on how the sessions are micro-dosed the athlete may only miss or reduce the planned training for a smaller percentage of the total weekly volume. For example, if two traditional resistance training sessions were micro-dosed equally into four 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 (102) 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, due to the disparity of literature tailored to female athletes, more research needs to be carried out to understand whether some of the previously highlighted benefits of micro-dosing, such as PAPE and resistance priming would also benefit female populations. Considering both PAPE and resistance priming are thought to benefit athletes with a higher training status, it is important to know if these results are present with females, particularly considering that both Russell et al. (93) and Cook et al. (14) have discussed the potential resistance priming effect to be due to 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 micro-dosing methods is the intent and motivation of the athletes completing the programme. Micro-dosing may offer an alternative approach to assist in the enhancement of some athletes' intent/motivation within a group. Motivation is reported to be a key element of an athletes' 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 behaviour (113). Intrinsic motivation refers to performing an activity for the pleasure and satisfaction derived from participation and with no other apparent rewards (20) and has been shown to be an important determinant of sport performance (67). Although a lot of 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, 113)) 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 (113)). Extrinsic motives can therefore either 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 behaviour or activity originates from and expresses their true selves rather than being a response to external pressures or demands (13). Mageau and Vallerand (113) have proposed a list of coaching behaviours 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 quite limited due to coaches planning and prescribing their training programs and schedules. Coaches could therefore potentially provide several options, that include traditional and micro-dosing 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 a greater level of ownership based on what their preferences are 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 has a preference towards spending less time in the gym during each training occasion but is willing to attend more frequent training sessions, the use of micro-dosing may be more appropriate based on their own preferences (see Option *B* in Table 2). It is important in these cases, however, that players understand the overall process and have an idea of where optionality is perhaps limited in order 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 whereby 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's day in, day out. It is worth considering, however, that dependent upon 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 which will increase training load. This may not be a negative consequence, as it may be a way of providing additional volume for weaker/lesser trained athletes without explicitly programming it, or alternatively the additional warm up sets could be viewed as additional power training (38).

Insert Table 3

Training Status

Unlike the other sections included in this review whereby micro-dosing is utilized 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 micro-dosing is best utilized 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 (89) also highlights 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 towards increasing the intensity of exercises rather than the total volume, micro-dosing 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. Outside of the competitive season, however, 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.

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 there may be some players who have come up through an academy system or attended a well-resourced school, some players may move to an organization having limited experience in resistance training and be of a much lower training status, despite being extremely proficient at their sport. Micro-dosing 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, however, 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 individualisation.

Insert Table 3

CONCLUSION

Micro-dosing 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 micro-dosing of resistance training could influence the enhancement of athletic development and performance have been outlined, as a conceptual framework. Although micro-dosing may not be a new concept, there are still many aspects of the framework provided that need further investigation to determine whether micro-dosing works in certain situations or populations, so practitioners can understand when it is and is not appropriate to utilize this programming strategy. In addition, this review has focussed 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 micro-dosing is here to stay or not, 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 micro-dosing is a convincing strategy to navigate these challenges.

REFERENCES:

1. Afonso J, Nakamura FY, Baptista I, Rendeiro-Pinho G, Brito J, and Figueiredo P. Microdosing: Old Wine in a New Bottle? Current State of Affairs and Future Avenues. *Int J Sports Physiol Perform*: 1-4, 2022.
2. Androulakis-Korakakis P, Fisher JP, and Steele J. The Minimum Effective Training Dose Required to Increase 1RM Strength in Resistance-Trained Men: A Systematic Review and Meta-Analysis. *Sports Med* 50: 751-765, 2020.
3. Bartolomei S, Malagoli Lanzoni I, and Di Michele R. Two vs. One Resistance Exercise Sessions in One Day: Acute Effects on Recovery and Performance. *Res Q Exerc Sport*: 1-6, 2022.
4. Behringer M, Vom Heede A, Matthews M, and Mester J. Effects of strength training on motor performance skills in children and adolescents: a meta-analysis. *Pediatr Exerc Sci* 23: 186-206, 2011.
5. Bickel CS, Cross JM, and Bamman MM. Exercise dosing to retain resistance training adaptations in young and older adults. *Med Sci Sports Exerc* 43: 1177-1187, 2011.
6. Blazevich AJ and Babault N. Post-activation Potentiation Versus Post-activation Performance Enhancement in Humans: Historical Perspective, Underlying Mechanisms, and Current Issues. *Frontiers in Physiol* 10, 2019.
7. Bondarchuk AP and Yessis M. *Transfer of Training in Sports.* Ultimate Athlete Concepts, 2007.
8. Brown N, Knight CJ, and Forrest LJ. Elite female athletes' experiences and perceptions of the menstrual cycle on training and sport performance. *Scandi J Med Sci Sports* 31: 52-69, 2021.
9. Buchheit M and Laursen PB. High-intensity interval training, solutions to the programming puzzle: Part I: cardiopulmonary emphasis. *Sports Med* 43: 313-338, 2013.
10. Bullock N and Comfort P. An investigation into the acute effects of depth jumps on maximal strength performance. *J Strength Cond Res* 25: 3137-3141, 2011.
11. Carroll KM, Bazyler CD, Bernards JR, Taber CB, Stuart CA, DeWeese BH, Sato K, and Stone MH. Skeletal Muscle Fiber Adaptations Following Resistance Training Using Repetition Maximums or Relative Intensity. *Sports* 7, 2019.
12. Chen TC, Yang TJ, Huang MJ, Wang HS, Tseng KW, Chen HL, and Nosaka K. Damage and the repeated bout effect of arm, leg, and trunk muscles induced by eccentric resistance exercises. *Scand J Med Sci Sports* 29: 725-735, 2019.
13. Conroy DE and Coatsworth JD. Assessing Autonomy-Supportive Coaching Strategies in Youth Sport. *Psychol Sport Exerc* 8: 671-684, 2007.
14. Cook CJ, Kilduff LP, Crewther BT, Beaven M, and West DJ. Morning based strength training improves afternoon physical performance in rugby union players. *J Sci Med Sport* 17: 317-321, 2014.
15. Cormier P, Freitas TT, Loturco I, Turner A, Virgile A, Haff GG, Blazevich AJ, Agar-Newman D, Henneberry M, Baker DG, McGuigan M, Alcaraz PE, and Bishop C. Within Session Exercise Sequencing During Programming for Complex Training: Historical Perspectives, Terminology, and Training Considerations. *Sports Med* 52: 2371-2389, 2022.
16. Counsilman B and Counsilman J. The residual effects of training. *J swim res* 7: 5-12, 1991.
17. Cunanan AJ, DeWeese BH, Wagle JP, Carroll KM, Sausaman R, Hornsby WG, 3rd, Haff GG, Triplett NT, Pierce KC, and Stone MH. The General Adaptation Syndrome: A Foundation for the Concept of Periodization. *Sports Med* 48: 787-797, 2018.
18. Cuthbert M, Haff GG, Arent SM, Ripley N, McMahon JJ, Evans M, and Comfort P. Effects of Variations in Resistance Training Frequency on Strength Development in Well-Trained Populations and Implications for In-Season Athlete Training: A Systematic Review and Meta-analysis. *Sports Med* 51: 1967-1982, 2021.
19. D'Emanuele S, Maffiuletti NA, Tarperi C, Rainoldi A, Schena F, and Boccia G. Rate of Force Development as an Indicator of Neuromuscular Fatigue: A Scoping Review. *Front Hum Neurosci* 15, 2021.

20. Deci EL. Effects of externally mediated rewards on intrinsic motivation. *J Pers Soc Psychol* 18: 105, 1971.
21. DeWeese BH, Hornsby G, Stone M, and Stone MH. The training process: Planning for strength–power training in track and field. Part 1: Theoretical aspects. *J Sport Health Sci* 4: 308-317, 2015.
22. DeWeese BH, Hornsby G, Stone M, and Stone MH. The training process: Planning for strength–power training in track and field. Part 2: Practical and applied aspects. *J Sport Health Sci* 4: 318-324, 2015.
23. Dick TJM and Wakeling JM. Shifting gears: dynamic muscle shape changes and force-velocity behavior in the medial gastrocnemius. *J Appl Physiol (1985)* 123: 1433-1442, 2017.
24. Docherty D and Sporer B. A proposed model for examining the interference phenomenon between concurrent aerobic and strength training. *Sports Med* 30: 385-394, 2000.
25. Dos'Santos T, Thomas C, McBurnie A, Comfort P, and Jones PA. Biomechanical Determinants of Performance and Injury Risk During Cutting: A Performance-Injury Conflict? *Sports Medicine* 51: 1983-1998, 2021.
26. Emmonds S, Heyward O, and Jones B. The challenge of applying and undertaking research in female sport. *Sports Med Open* 5: 1-4, 2019.
27. Eston RG, Finney S, Baker S, and Baltzopoulos V. Muscle tenderness and peak torque changes after downhill running following a prior bout of isokinetic eccentric exercise. *J Sports Sci* 14: 291-299, 1996.
28. Fadiman J. The psychedelic explorer's guide : safe, therapeutic, and sacred journeys. 2011.
29. Findlay RJ, Macrae EHR, Whyte IY, Easton C, and Forrest LJ. How the menstrual cycle and menstruation affect sporting performance: experiences and perceptions of elite female rugby players. *Br J Sports Med* 54: 1108, 2020.
30. Francis C. *Structure of Training for Speed.* CharlieFrancis.com, 2008.
31. Fry AC and Kraemer WJ. Resistance exercise overtraining and overreaching. Neuroendocrine responses. *Sports Med* 23: 106-129, 1997.
32. Gentil P and Bottaro M. Influence of supervision ratio on muscle adaptations to resistance training in nontrained subjects. *J Strength Cond Res* 24: 639-643, 2010.
33. Gogtay N, Giedd JN, Lusk L, Hayashi KM, Greenstein D, Vaituzis AC, Nugent TF, 3rd, Herman DH, Clasen LS, Toga AW, Rapoport JL, and Thompson PM. Dynamic mapping of human cortical development during childhood through early adulthood. *Proc Natl Acad Sci U S A* 101: 8174-8179, 2004.
34. Gould D, Dieffenbach K, and Moffett A. Psychological Characteristics and Their Development in Olympic Champions. *J Appl Sport Psychol* 14: 172-204, 2002.
35. Grgic J, Schoenfeld BJ, Davies TB, Lazinica B, Krieger JW, and Pedisic Z. Effect of Resistance Training Frequency on Gains in Muscular Strength: A Systematic Review and Meta-Analysis. *Sports Med* 48: 1207-1220, 2018.
36. Grgic J, Schoenfeld BJ, Orazem J, and Sabol F. Effects of resistance training performed to repetition failure or non-failure on muscular strength and hypertrophy: A systematic review and meta-analysis. *J Sport Health Sci* 11: 202-211, 2022.
37. Haff GG. Periodization and Power Integration, in: *Developing Power*. M McGuigan, ed. Champaign, IL: Human Kinetics, 2017, pp 33-62.
38. Haff GG and Nimphius S. Training Principles for Power. *Strength Cond J* 34: 2-12, 2012.
39. Haff GG, Whitley A, McCoy LB, O'Bryant HS, Kilgore JL, Haff EE, Pierce K, and Stone MH. Effects of Different Set Configurations on Barbell Velocity and Displacement During a Clean Pull. *J Strength Cond Res* 17, 2003.
40. Häkkinen K and Kallinen M. Distribution of strength training volume into one or two daily sessions and neuromuscular adaptations in female athletes. *Electromyogr Clin Neurophysiol* 34: 117-124, 1994.
41. Hansen DM. Micro-dosing with speed and tempo sessions for performance gains and injury prevention. https://www.strengthpowerspeed.com/micro-dosing-speed-tempo/, 2015.
42. Hansen DM. Let's make a case for boring. https://sprintcoach.com/wp-content/uploads/2018/08/Lets-Make-a-Case-for-Boring-Derek-M-Hansen.pdf, 2018.
43. Hardee JP, Triplett NT, Utter AC, Zwetsloot KA, and McBride JM. Effect of interrepetition rest on power output in the power clean. *J Strength Cond Res* 26: 883-889, 2012.
44. Harrison PW, James LP, McGuigan MR, Jenkins DG, and Kelly VG. Resistance Priming to Enhance Neuromuscular Performance in Sport: Evidence, Potential Mechanisms and Directions for Future Research. *Sports Med* 49: 1499-1514, 2019.
45. Harrison PW, James LP, McGuigan MR, Jenkins DG, and Kelly VG. Prevalence and application of priming exercise in high performance sport. *J Sci Med Sport* 23: 297-303, 2020.
46. Herrington L. The Effects of 4 Weeks of Jump Training on Landing Knee Valgus and Crossover Hop Performance in Female Basketball Players. *J Strength Cond Res* 24, 2010.

47. Hickson RC. Interference of strength development by simultaneously training for strength and endurance. *Eur J Appl Physiol Occup Physiol* 45: 255-263, 1980.
48. Hody S, Croisier J-L, Bury T, Rogister B, and Leprince P. Eccentric Muscle Contractions: Risks and Benefits. *Front Physiol* 10: 536-536, 2019.
49. Howatson G, Van Someren K, and Hortobágyi T. Repeated bout effect after maximal eccentric exercise. *Int J Sports Med* 28: 557-563, 2007.
50. Impellizzeri FM, McCall A, and van Smeden M. Why methods matter in a meta-analysis: a reappraisal showed inconclusive injury preventive effect of Nordic hamstring exercise. *J Clin Epidemiol* 140: 111-124, 2021.
51. Issurin V and Thome M. *Building the Modern Athlete: Scientific Advancements & Training Innovations.* Ultimate Athlete Concepts, 2015.
52. Issurin V and Yessis M. *Block Periodization: Breakthrough in Sports Training.* Ultimate Athlete Concepts, 2008.
53. Issurin VB. Block periodization versus traditional training theory: a review. *J Sports Med Phys Fitness* 48: 65-75, 2008.
54. Issurin VB. Generalized training effects induced by athletic preparation. A review. *J Sports Med Phys Fitness* 49: 333-345, 2009.
55. Issurin VB. New horizons for the methodology and physiology of training periodization. *Sports Med* 40: 189-206, 2010.
56. Issurin VB. Benefits and Limitations of Block Periodized Training Approaches to Athletes' Preparation: A Review. *Sports Med* 46: 329-338, 2016.
57. Iversen VM, Norum M, Schoenfeld BJ, and Fimland MS. No Time to Lift? Designing Time-Efficient Training Programs for Strength and Hypertrophy: A Narrative Review. *Sports Medicine* 51: 2079-2095, 2021.
58. Izquierdo M, Ibañez J, González-Badillo JJ, Häkkinen K, Ratamess NA, Kraemer WJ, French DN, Eslava J, Altadill A, Asiain X, and Gorostiaga EM. Differential effects of strength training leading to failure versus not to failure on hormonal responses, strength, and muscle power gains. *J Appl Physiol (1985)* 100: 1647-1656, 2006.
59. Lappin G and Garner RC. Big physics, small doses: the use of AMS and PET in human microdosing of development drugs. *Nat Rev Drug Discov* 2: 233-240, 2003.
60. Lappin G, Noveck R, and Burt T. Microdosing and drug development: past, present and future. *Expert Opin Drug Metab Toxicol* 9: 817-834, 2013.
61. Lloyd RS, Cronin JB, Faigenbaum AD, Haff GG, Howard R, Kraemer WJ, Micheli LJ, Myer GD, and Oliver JL. National Strength and Conditioning Association Position Statement on Long-Term Athletic Development. *J Strength Cond Res* 30, 2016.
62. Lloyd RS, Dobbs IJ, Wong MA, Moore IS, and Oliver JL. Effects of Training Frequency During a 6-Month Neuromuscular Training Intervention on Movement Competency, Strength and Power in Male Youth. *Sports Health*: 19417381211050005, 2021.
63. Lloyd RS, Faigenbaum AD, Stone MH, Oliver JL, Jeffreys I, Moody JA, Brewer C, Pierce KC, McCambridge TM, Howard R, Herrington L, Hainline B, Micheli LJ, Jaques R, Kraemer WJ, McBride MG, Best TM, Chu DA, Alvar BA, and Myer GD. Position statement on youth resistance training: the 2014 International Consensus. *Br J Sports Med* 48: 498-505, 2014.
64. Lloyd RS and Oliver JL. The Youth Physical Development Model: A New Approach to Long-Term Athletic Development. *Strength Cond J* 34, 2012.
65. Lloyd RS, Oliver JL, Faigenbaum AD, Myer GD, and De Ste Croix MBA. Chronological Age vs. Biological Maturation: Implications for Exercise Programming in Youth. *J Strength Cond Res* 28, 2014.
66. Low D, Harsley P, Shaw M, and Peart D. The effect of heavy resistance exercise on repeated sprint performance in youth athletes. *J Sports Sci* 33: 1028-1034, 2015.
67. Mageau GA and Vallerand RJ. The coach–athlete relationship: a motivational model. *J Sports Sci* 21: 883-904, 2003.
68. Marshall J, Bishop C, Turner A, and Haff GG. Optimal Training Sequences to Develop Lower Body Force, Velocity, Power, and Jump Height: A Systematic Review with Meta-Analysis. *Sports Med* 51: 1245-1271, 2021.
69. Martorelli S, Cadore EL, Izquierdo M, Celes R, Martorelli A, Cleto VA, Alvarenga JG, and Bottaro M. Strength Training with Repetitions to Failure does not Provide Additional Strength and Muscle Hypertrophy Gains in Young Women. *Eur J Transl Myol* 27: 6339-6339, 2017.
70. McHugh MP, Connolly DA, Eston RG, and Gleim GW. Exercise-induced muscle damage and potential mechanisms for the repeated bout effect. *Sports Med* 27: 157-170, 1999.

71. McNulty KL, Elliott-Sale KJ, Dolan E, Swinton PA, Ansdell P, Goodall S, Thomas K, and Hicks KM. The Effects of Menstrual Cycle Phase on Exercise Performance in Eumenorrheic Women: A Systematic Review and Meta-Analysis. *Sports Med* 50: 1813-1827, 2020.
72. Moody JA, Naclerio F, Green P, and Lloyd RS. Motor skill development in youths, in: *Strength and conditioning for young athletes: science and application*. RS Lloyd, JL Oliver, eds.: Routledge, 2014.
73. Myer GD, Kushner AM, Faigenbaum AD, Kiefer A, Kashikar-Zuck S, and Clark JF. Training the developing brain, part I: cognitive developmental considerations for training youth. *Curr Sports Med Rep* 12: 304-310, 2013.
74. Ng CY, Chen SE, and Lum D. Inducing Postactivation Potentiation With Different Modes of Exercise. *Strength Cond J* 42, 2020.
75. Nimphius S. Exercise and Sport Science Failing by Design in Understanding Female Athletes. *Int J Sports Physiol Perform*: 1-2, 2019.
76. Nosaka K and Clarkson PM. Muscle damage following repeated bouts of high force eccentric exercise. *Med Sci Sports Exerc* 27: 1263-1269, 1995.
77. Nosaka K, Sakamoto K, Newton M, and Sacco P. The repeated bout effect of reduced-load eccentric exercise on elbow flexor muscle damage. *Eur J Appl Physiol* 85: 34-40, 2001.
78. Okuno NM, Tricoli V, Silva SB, Bertuzzi R, Moreira A, and Kiss MA. Postactivation potentiation on repeated-sprint ability in elite handball players. *J Strength Cond Res* 27: 662-668, 2013.
79. Peñailillo L, Blazevich A, Numazawa H, and Nosaka K. Rate of force development as a measure of muscle damage. *Scand J Med Sci Sports* 25: 417-427, 2015.
80. Peterson MD, Rhea MR, and Alvar BA. Applications of the dose-response for muscular strength development: a review of meta-analytic efficacy and reliability for designing training prescription. *J Strength Cond Res* 19: 950-958, 2005.
81. Petré H, Löfving P, and Psilander N. The Effect of Two Different Concurrent Training Programs on Strength and Power Gains in Highly-Trained Individuals. *J Sports Sci Med* 17: 167-173, 2018.
82. Philippaerts RM, Vaeyens R, Janssens M, Van Renterghem B, Matthys D, Craen R, Bourgois J, Vrijens J, Beunen G, and Malina RM. The relationship between peak height velocity and physical performance in youth soccer players. *J Sports Sci* 24: 221-230, 2006.
83. Polito V and Stevenson RJ. A systematic study of microdosing psychedelics. *PLoS One* 14: e0211023, 2019.
84. Prieske O, Behrens M, Chaabene H, Granacher U, and Maffiuletti NA. Time to Differentiate Postactivation "Potentiation" from "Performance Enhancement" in the Strength and Conditioning Community. *Sports Med* 50: 1559-1565, 2020.
85. Radnor JM, Moeskops S, Morris SJ, Mathews TA, Kumar NTA, Pullen BJ, Meyers RW, Pedley JS, Gould ZI, Oliver JL, and Lloyd RS. Developing Athletic Motor Skill Competencies in Youth. *Strength Cond J* 42, 2020.
86. Ralston GW, Kilgore L, Wyatt FB, Buchan D, and Baker JS. Weekly Training Frequency Effects on Strength Gain: A Meta-Analysis. *Sports Med Open* 4: 36, 2018.
87. Ramsay JA, Blimkie CJ, Smith K, Garner S, MacDougall JD, and Sale DG. Strength training effects in prepubescent boys. *Med Sci Sports Exerc* 22: 605-614, 1990.
88. Read PJ, Oliver JL, and Lloyd RS. Seven Pillars of Prevention: Effective Strategies for Strength and Conditioning Coaches to Reduce Injury Risk and Improve Performance in Young Athletes. *Strength Cond J* 42: 120-128, 2020.
89. Rhea MR. Determining the magnitude of treatment effects in strength training research through the use of the effect size. *J Strength Cond Res* 18: 918-920, 2004.
90. Rhea MR, Alvar BA, Burkett LN, and Ball SD. A meta-analysis to determine the dose response for strength development. *Med Sci Sports Exerc* 35: 456-464, 2003.
91. Robineau J, Babault N, Piscione J, Lacome M, and Bigard AX. Specific Training Effects of Concurrent Aerobic and Strength Exercises Depend on Recovery Duration. *J Strength Cond Res* 30: 672-683, 2016.
92. Rønnestad BR, Nymark BS, and Raastad T. Effects of in-season strength maintenance training frequency in professional soccer players. *J Strength Cond Res* 25: 2653-2660, 2011.
93. Russell M, King A, Bracken RM, Cook CJ, Giroud T, and Kilduff LP. A Comparison of Different Modes of Morning Priming Exercise on Afternoon Performance. *Int J Sports Physiol Perform* 11: 763-767, 2016.
94. Sabag A, Lovell R, Walsh NP, Grantham N, Lacome M, and Buchheit M. Upper-Body Resistance Training Following Soccer Match Play: Compatible, Complementary, or Contraindicated? *Int J Sports Physiol Perform* 16: 165-175, 2021.

95. Sabag A, Najafi A, Michael S, Esgin T, Halaki M, and Hackett D. The compatibility of concurrent high intensity interval training and resistance training for muscular strength and hypertrophy: a systematic review and meta-analysis. *J Sports Sci* 36: 2472-2483, 2018.
96. Sánchez-Medina L and González-Badillo JJ. Velocity loss as an indicator of neuromuscular fatigue during resistance training. *Med Sci Sports Exerc* 43: 1725-1734, 2011.
97. Schumann M, Feuerbacher JF, Sünkeler M, Freitag N, Rønnestad BR, Doma K, and Lundberg TR. Compatibility of Concurrent Aerobic and Strength Training for Skeletal Muscle Size and Function: An Updated Systematic Review and Meta-Analysis. *Sports Med*, 2021.
98. Seitz LB, de Villarreal ES, and Haff GG. The temporal profile of postactivation potentiation is related to strength level. *J Strength Cond Res* 28: 706-715, 2014.
99. Shaw I, Shaw B, Brown G, and Shariat A. Review of the role of resistance training and musculoskeletal injury prevention and rehabilitation. *J Orthop Res Ther* 2016: 1-5, 2016.
100. Smith CD and Scarf D. Spacing Repetitions Over Long Timescales: A Review and a Reconsolidation Explanation. *Front Psychol* 8, 2017.
101. Spiering BA, Mujika I, Sharp MA, and Foulis SA. Maintaining Physical Performance: The Minimal Dose of Exercise Needed to Preserve Endurance and Strength Over Time. *J Strength Cond Res* 35: 1449-1458, 2021.
102. Staron RS, Karapondo DL, Kraemer WJ, Fry AC, Gordon SE, Falkel JE, Hagerman FC, and Hikida RS. Skeletal muscle adaptations during early phase of heavy-resistance training in men and women. *J ApplPhysiol*76: 1247-1255, 1994.
103. Stone MH, Hornsby WG, Haff GG, Fry AC, Suarez DG, Liu J, Gonzalez-Rave JM, and Pierce KC. Periodization and block periodization in sports: emphasis on strength-power training— a provocative and challenging narrative. *J Strength Cond Res* 35: 2351-2371, 2021.
104. Stone MH, Sands WA, Pierce KC, Ramsey MW, and Haff GG. Power and Power Potentiation Among Strength–Power Athletes: Preliminary Study. *Int J Sports Physiol and Perform* 3: 55-67, 2008.
105. Stone MH, Stone M, Sands WA, and Sands B. *Principles and Practice of Resistance Training.* Human Kinetics, 2007.
106. Stratton G and Oliver JL. The impact of growth and maturation on physical performance, in: *Strength and conditioning for young athletes: science and application*. RS Lloyd, JL Oliver, eds.: Routledge, 2014.
107. Suchomel TJ, Lamont HS, and Moir GL. Understanding Vertical Jump Potentiation: A Deterministic Model. *Sports Med* 46: 809-828, 2016.
108. Suchomel TJ, Nimphius S, and Stone MH. The Importance of Muscular Strength in Athletic Performance. *Sports Med* 46: 1419-1449, 2016.
109. Taberner M, Allen T, and Cohen DD. Progressing rehabilitation after injury: consider the 'control-chaos continuum'. *Br J Sports Med* 53: 1132, 2019.
110. Tee JC, Bosch AN, and Lambert MI. Metabolic consequences of exercise-induced muscle damage. *Sports Med* 37: 827-836, 2007.
111. Tufano JJ, Conlon JA, Nimphius S, Brown LE, Seitz LB, Williamson BD, and Haff GG. Maintenance of Velocity and Power With Cluster Sets During High-Volume Back Squats. *Int J Sports Physiol Perform* 11: 885-892, 2016.
112. Turner A. The Science and Practice of Periodization: A Brief Review. *Strength Cond J*33, 2011.
113. Vallerand RJ. Intrinsic and extrinsic motivation in sport and physical activity: A review and a look at the future. 2007.
114. Van Hooren B and Bosch F. Is there really an eccentric action of the hamstrings during the swing phase of high-speed running? part I: A critical review of the literature. *J Sports Sci* 35: 2313-2321, 2017.
115. Vechin FC, Conceição MS, Telles GD, Libardi CA, and Ugrinowitsch C. Interference Phenomenon with Concurrent Strength and High-Intensity Interval Training-Based Aerobic Training: An Updated Model. *Sports Med* 51: 599-605, 2021.
116. Viru A, Loko J, Harro M, Volver A, Laaneots L, and Viru M. Critical Periods in the Development of Performance Capacity During Childhood and Adolescence. *Eur J Phys Educ* 4: 75-119, 1999.
117. Wilson JM, Duncan NM, Marin PJ, Brown LE, Loenneke JP, Wilson SM, Jo E, Lowery RP, and Ugrinowitsch C. Meta-analysis of postactivation potentiation and power: effects of conditioning activity, volume, gender, rest periods, and training status. *J Strength Cond Res* 27: 854-859, 2013.
118. Wilson JM, Marin PJ, Rhea MR, Wilson SM, Loenneke JP, and Anderson JC. Concurrent training: a meta-analysis examining interference of aerobic and resistance exercises. *J Strength Cond Res* 26: 2293-2307, 2012.
119. Winstein CJ. Knowledge of results and motor learning--implications for physical therapy. *Phys Ther* 71: 140-149, 1991.

120. Zatsiorsky VM. *Timing in Strength Training, in: Science and Practice of Strength Training.* Champaign, IL: Human Kinetics, 1995.
121. Zatsiorsky VM and Kraemer WJ. *Timing in Strength Training, in: Science and Practice of Strength Training.* Champaign, IL: Human Kinetics, 2006.

Figures

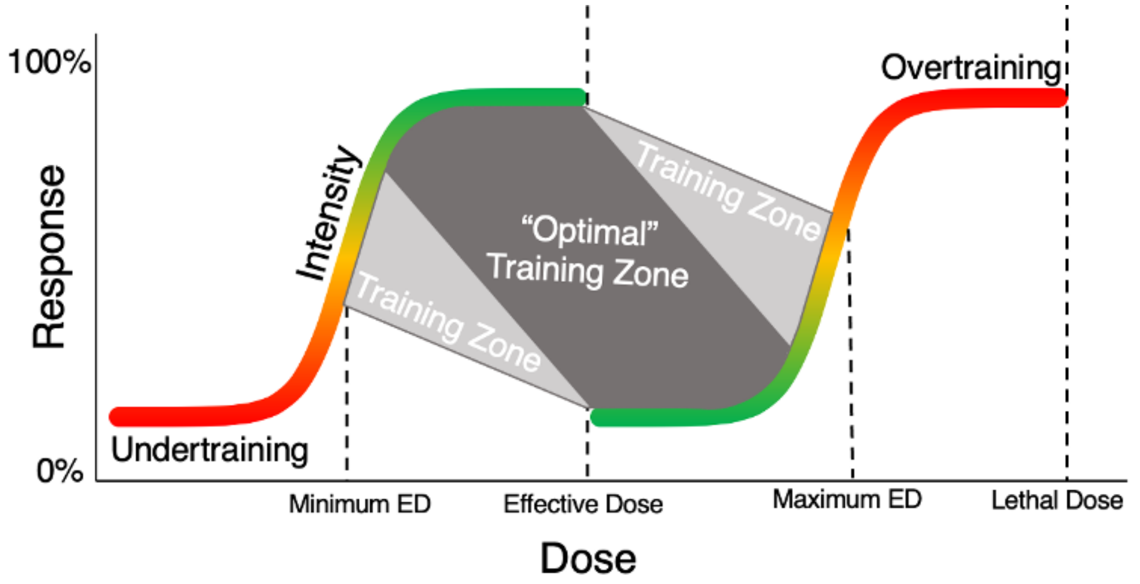

Figure 1. An illustration of the dose-response curve in relation to resistance training
ED = Effective Dose

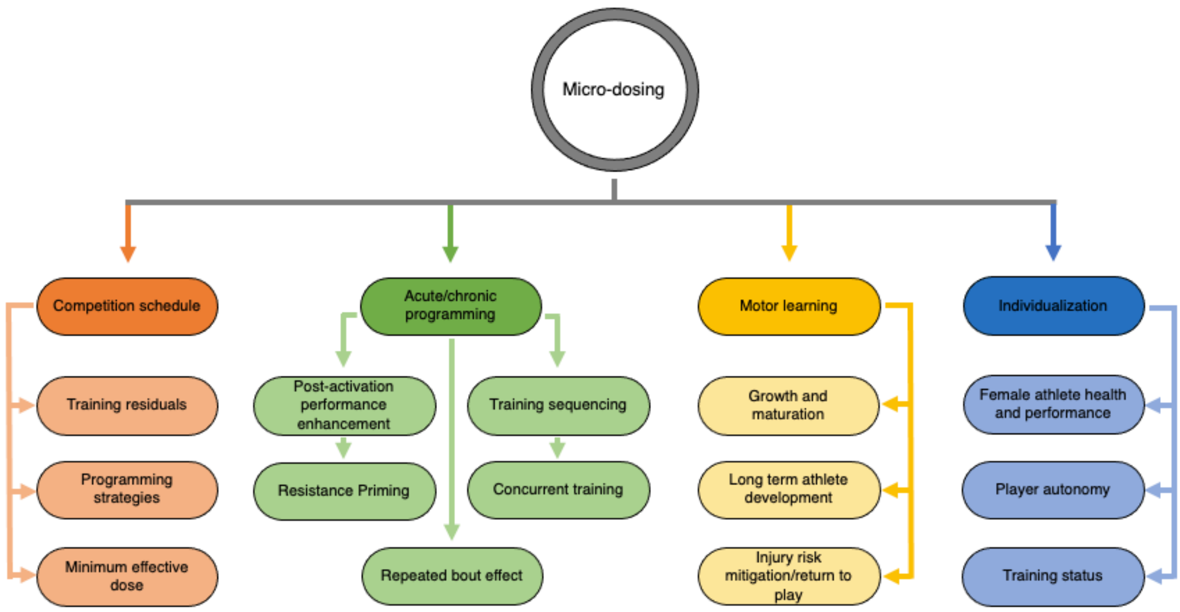

Figure 2. Illustration of key areas where micro-dosing training may be advantageous

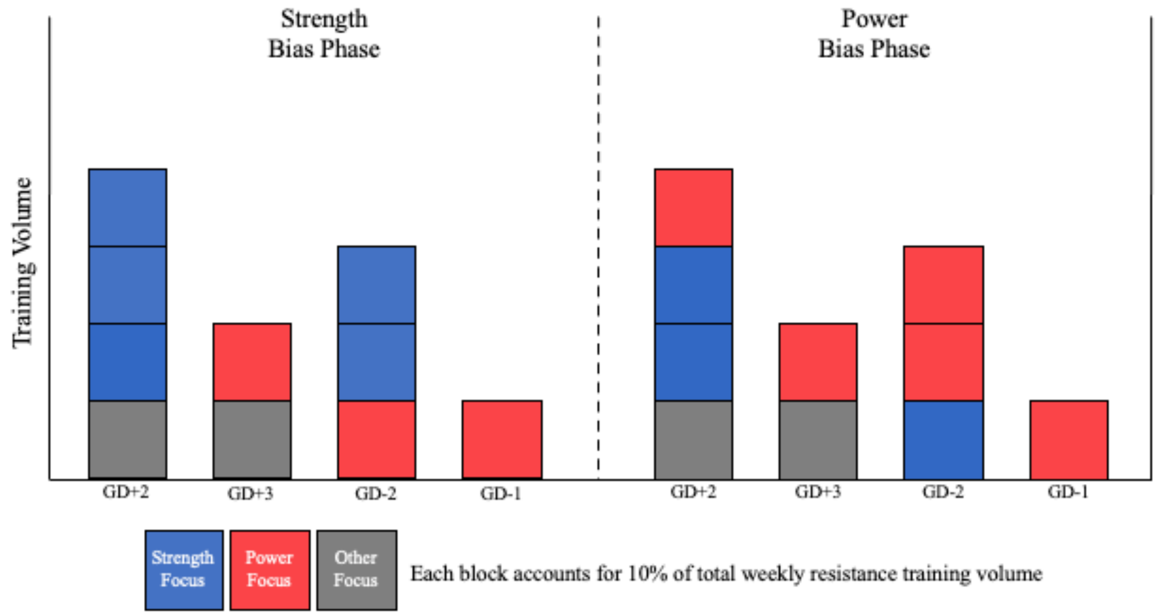

Figure 3. A schematic diagram illustrating an example of the distribution of resistance training volume and division of micro-dosing sessions for an in-season microcycle of either a strength bias or power bias.
GD = Game day

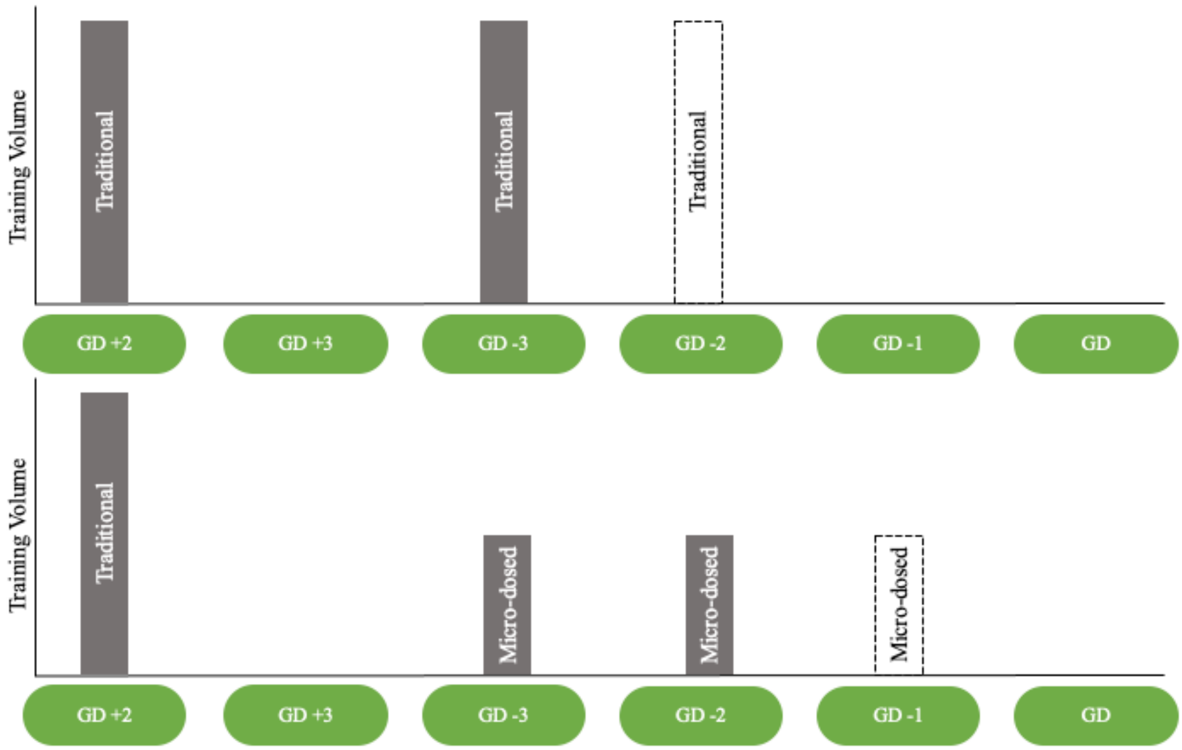

Figure 4. A schematic diagram illustrating a comparison of a traditional two-session resistance training week in-season, and an example a front-loaded training week whereby a higher volume, longer duration (traditional) session is performed furthest from a game day (GD) in conjunction with micro-dosed 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 e.g., the sessions seen on GD-3 may be scheduled on either GD-2 or GD-1 for traditional or micro-dosing, respectively.

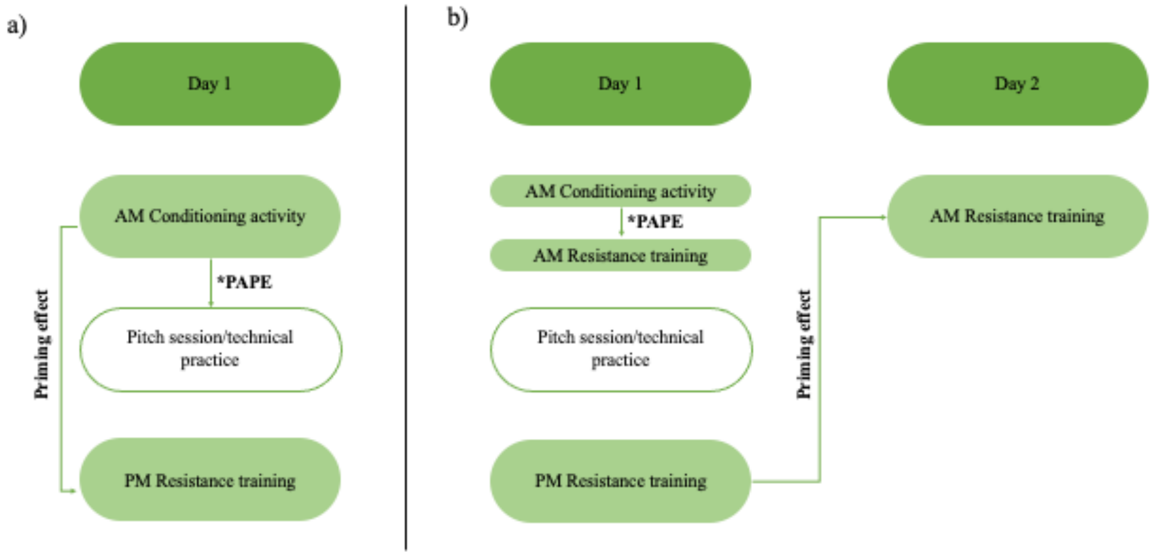

Figure 5. An example of two different session configurations across (a) one and (b) two days to take advantage of both post-activation performance enhancement and priming effects.
**PAPE = Post-activation performance enhancement.* In this instance performance enhancement is most likely to influence the first couple of actions in the subsequent pitch session/technical practice or resistance training session.

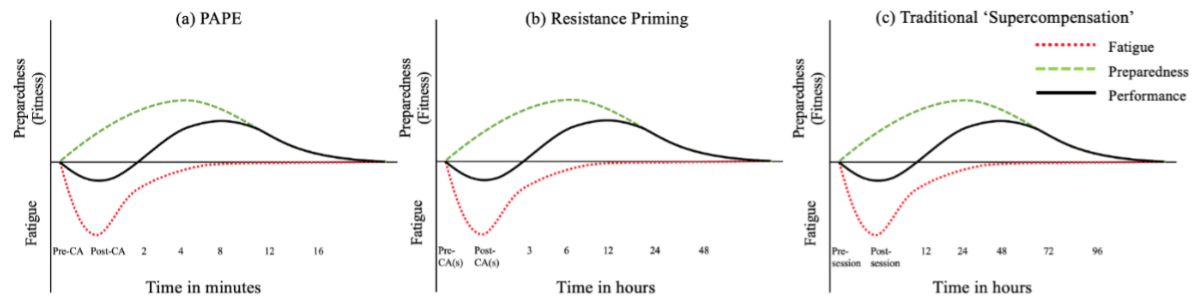

Figure 6. A comparison of the time-course of the fitness-fatigue paradigm following post-activation performance enhancement (PAPE), resistance priming and traditional supercompensation conditioning activities.
CA = Conditioning Activity; CA(s) = Conditioning activity of multiple sets/a small number of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

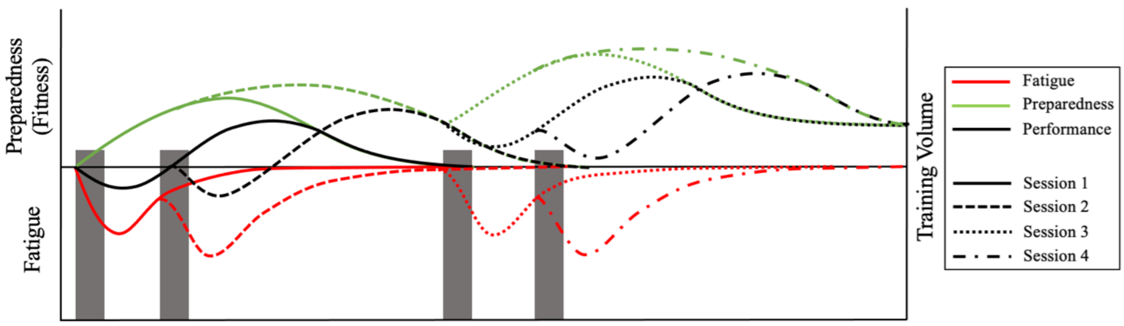

Figure 7. An example of the use of resistance priming on the fitness-fatigue paradigm and the theoretical benefit on increased preparedness and performance.

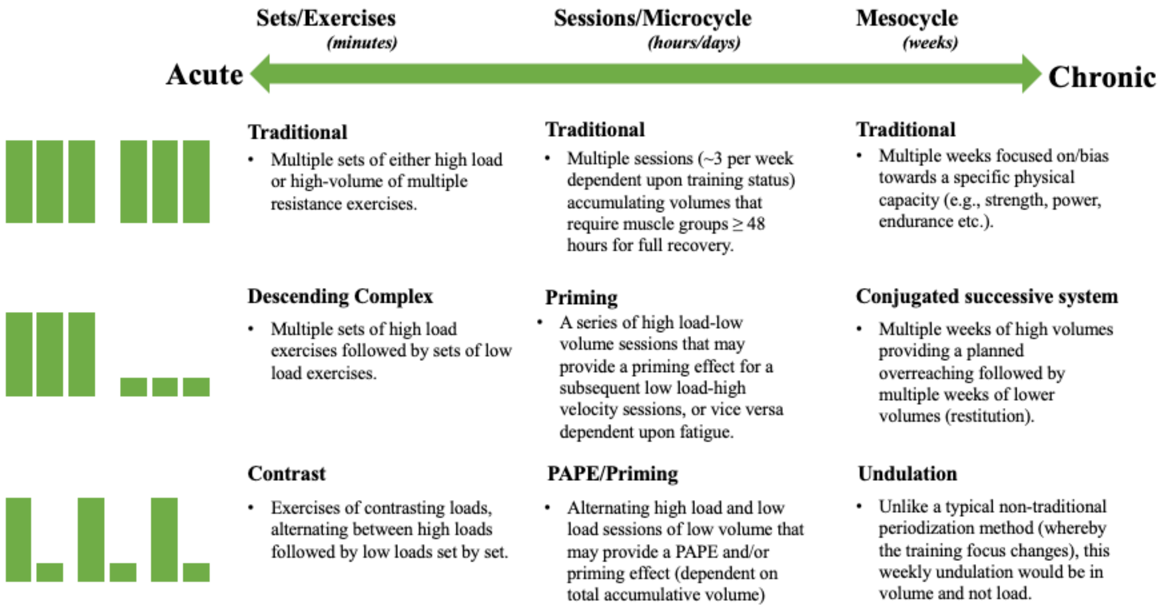

Figure 8. A comparison of terminology used for different set, session, microcycle and mesocycles across the acute-chronic continuum.

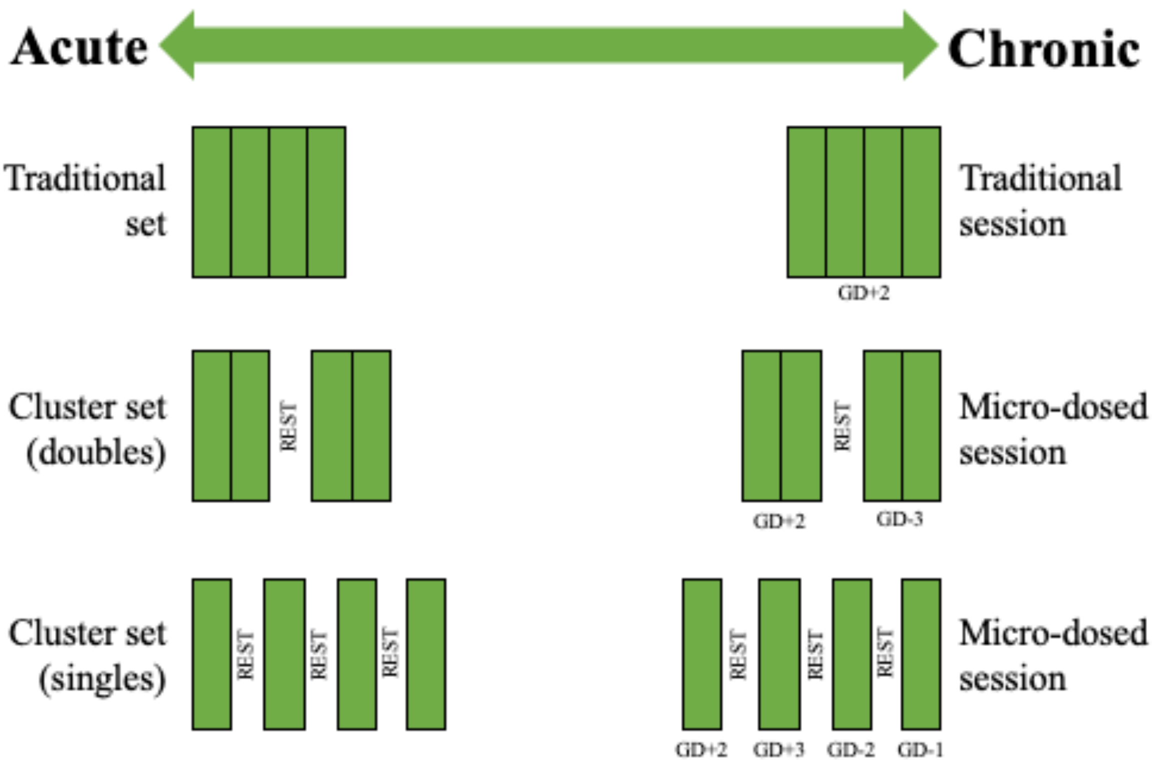

Figure 9. A comparison of the structure of cluster training and micro-dosing and where they fit across the acute-chronic continuum.
GD = Game day

Tables

Table 1. Characteristics of the training frequency interventions used for the upper body in the studies included within this review.

Sport	Standard/Level	Competition type	Competition/ season length	Number of games	Between game turnaround time	Length of post-season*	Number of post-season* games
American Football	Professional (NFL)	Season	18 weeks	17	4-7 days	5 weeks	3-4
Baseball	Professional (MLB)	Season/Series	~27 weeks	60	0-3 days	~5 weeks	26-43
Basketball	Professional (NBA)	Season	~26 weeks	82	0-3 days	10 weeks	4-28
Ice Hockey	Professional (NHL)	Season	~26 weeks	82	0-3 days	10 weeks	4-28
Field Hockey	Olympic Games	Tournament	2 weeks	10	0-2 days	-	-
Netball	Commonwealth Games	Tournament	10 days	6-7	0-3 days	-	-
Rugby Union	International	Tournament	~6 weeks	7	~7 days	-	-
	Domestic	Season	~40 weeks	~32-39	5-7 days	2 weeks	2
Rugby League	International	Tournament	~7 weeks	7	~7 days	-	-
	Domestic (Super League)	Season	~32 weeks	30-37	5-7 days	3 weeks	3
	Domestic (NRL)	Season	26 weeks	24	5-7 days	4 weeks	4
Rugby Sevens	International	Series	2 days	6	~3 hours	-	-
Soccer	International	Tournament	~31 days	≤ 7	4-6 days	-	-
	Domestic (EPL)	Season	~40 weeks	~38-62	3-7 days	-	-

NFL = National Football League; MLB = Major League Baseball; NBA = National Basketball Association; NHL = National Hockey League; NRL = National Rugby League; EPL = England Premier League

*Post-season in this instance describes a period of play-off games leading to and including either promotion deciders or championship games.

Table 2. An example three 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 (3x5) Push Press (3x5) Bulgarian Split Squat (3x5) Romanian Deadlift (3x5) Depth Jump (3x5) Calf Raise (3x5)	Back Squat (1x5) Push Press (1x5) Bulgarian Split Squat (1x5) Romanian Deadlift (1x5) Depth Jump (1x5) Calf Raise (1x5)	Back Squat (3x5) Romanian Deadlift (3x5)
Wednesday (Game day -3)		Back Squat (1x5) Push Press (1x5) Bulgarian Split Squat (1x5) Romanian Deadlift (1x5) Depth Jump (1x5) Calf Raise (1x5)	Bulgarian Split Squat (3x5) Calf Raise (3x5)
Thursday (Game day -2)		Back Squat (1x5) Push Press (1x5) Bulgarian Split Squat (1x5) Romanian Deadlift (1x5) Depth Jump (1x5) Calf Raise (1x5)	Push Press (3x5) Depth Jump (3x5)

Intensity at 80-85% 1RM

Table 3. Practical application of micro-dosing, summarised

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. • Due to the flexibility in session frequency and duration (resulting in minimal fatigue) micro-dosing 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	• Micro-dosing is a programming strategy itself but can be used in conjunction with other strategies such as distributing volume during a period of planned overreaching. • Micro-dosing can also be used within emphasised periodization models either to distribute a maintenance load or help enhance the primary focus of the phase. • Micro-dosing could be used to assist in the reduction of volume during tapering at both a micro- (i.e., game preparation) and macro-level (i.e., step, linear or exponential tapering).
Minimum effective dose	• While a separate concept to micro-dosing, minimum effective dosing can potentially be applied using micro-dosing. • Micro-dosing can be applied throughout the full dose-response spectrum and while minimum effective dosing is not appropriate for prolonged periods.
Acute/Chronic Programming	
Post-activation performance enhancement (PAPE)	• A PAPE stimulI should be used in addition to other micro-dosed 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 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)	• Micro-dosing 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 micro-dosing being likened to cluster training (Figure 8). • The sequencing of micro-dosed resistance training will allow practitioners to best utilise concepts previously discussed such as PAPE, resistance priming, and RBE.
Concurrent training	• Due to the flexibility in scheduling associated with micro-dosing, 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 micro-dosing 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. • Micro-dosing could also help appropriately increase frequency and total volume to take advantage of normal responses without putting athletes at increased risk.
Long term athlete development (LTAD)	• Micro-dosing 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	• Micro-dosing will permit increased opportunities for motor learning during return to play protocols. • The use of micro-dosing could allow for doses of highly controlled but potentially fatiguing actions to be completed in a relatively safe manner whilst having less impact on the more chaotic actions.
Individualization	
Female athlete health and performance	• Micro-dosing could increase compliance particularly if training requires modification or adjustment due to the flexibility of moving short duration sessions without causing excessive fatigue. • Micro-dosing research should be completed in female populations as well as further investigation into PAPE and resistance priming due to a lack of investment into the application of these principles in females.
Player autonomy	• Micro-dosing 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 programme or are not full-time professionals.
Training status	• Some of the principles discussed such a PAPE and resistance priming are of greater benefit or only applicable to athletes of greater training status or relative strength. • Micro-dosing may provide opportunities to divide squads into smaller groups of similar training statuses to allow for the various ranges within the whole group.