Journal of Sports Sciences, February 1st 2009; 27(3): 195–202

INVITED COMMENTARY

Peaking for optimal performance: Research limitations and future directions

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(Accepted 26 September 2008)

Abstract
A key element of the physical preparation of athletes is the taper period in the weeks immediately preceding competition. Existing research has defined the taper, identified various forms used in contemporary sport, and examined the prescription of training volume, load, intensity, duration, and type (progressive or step). Current limitations include: the lack of studies on team, combative, racquet, and precision (target) sports; the relatively small number of randomized controlled trials; the narrow focus on a single competition (single peak) compared with multiple peaking for weekly, multi-day or multiple events; and limited understanding of the physiological, neuromuscular, and biomechanical basis of the taper. Future research should address these limitations, together with the influence of prior training on optimal tapering strategies, and the interactions between the taper and long-haul travel, heat, and altitude. Practitioners seek information on how to prescribe tapers from season to season during an athlete's career, or a team's progression through a domestic league season, or multi-year Olympic or World Cup cycle. Practical guidelines for planning effective tapers for the Vancouver 2010 and London 2012 Olympics will evolve from both experimental investigations and modelling of successful tapers currently employed in a wide range of sports.

Keywords: *Athlete, competition, environment, modelling, taper, training camps*

Introduction

The taper is a key element of the physical preparation of athletes in the weeks before a competition. Since the early 1990s, there has been substantial research interest in the taper and its importance in the transition of athletes from the preparatory to competitive phase of the season. A number of reviews of the physiological (Bosquet, Montpetit, Arvisais, & Mujika, 2007; Houmard & Johns, 1994; Mujika, Padilla, Pyne, & Busso, 2004) and performance (Mujika & Padilla, 2003; Mujika et al., 2004) aspects of the taper have been published. Similar to the general prescription of training throughout the season, the planning and execution of the taper immediately before competition is a combination of both art and science. The purpose of this commentary is to summarize current knowledge about the taper in contemporary sport, identify the limitations of existing research, and highlight areas for future investigation. These investigations should advance our understanding of the taper for athletes and coaching preparing for the Vancouver 2010 Winter and London 2012 Summer Olympic Games.

Current knowledge on the taper

Definitions

The taper has been defined by several researchers to encompass the underlying purpose of this training methodology and/or the actual manipulations of the basic factors used to prescribe training in the weeks leading up to competition. The primary question for coaches and athletes is how to manipulate the type, frequency, duration, and intensity of training to

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ISSN 0264-0414 print/ISSN 1466-447X online © 2009 Taylor & Francis
DOI: 10.1080/02640410802509136

enhance or optimize performance. Sports scientists are interested in these questions on training prescription and also the underlying physiological and non-physiological bases of the taper. An operational definition that encapsulates the various elements of training prescription is ‘‘a progressive linear or non-linear reduction of the training load during a variable period of time, to reduce the physiological and psychological stress of daily training and optimize sports performance’’ (Mujika & Padilla, 2000, 2003). Further work in the last decade has facilitated prescriptive recommendations on the degree of reduction in training loads, the manipulation of training intensity and frequency, and the time course of physiological and performance responses. The onset and duration of the taper are key elements for the coach and athlete in practice, and the researcher interested in quantifying the effects of various training interventions in the taper. The onset of the taper is difficult to operationalize, but the duration and completion of the taper are determined by the scheduling (first day) of competition. The taper can be conceptualized as the final period in a sequence of meso-cyclic patterns in the course of the training year or season.

Types of taper

Different types or patterns of taper have been described, including the linear taper, an exponential taper involving a fast or slow constant of decay (reduction) in training load, and a step taper (Mujika & Padilla, 2003). The step taper involves a sudden, standardized reduction of the training load for the duration of the taper, in comparison with progressive tapers where a more gradual change is observed (Figure 1). A fast constant of decay elicits a more rapid reduction in training load, whereas a slow constant is associated with tapers involving a more gradual reduction in the period before competition. Although terminology has varied, some but not all commentators make the distinction between linear and exponential tapers. A recent meta-analysis grouped the linear and exponential tapers together as progressive tapers (Bosquet et al., 2007). Some researchers consider that a fast decay taper is more likely to enhance subsequent competitive performance than a slow decay taper (Banister, Cartner, & Zarkadas, 1999). Presumably, a fast decay taper provides more time for overcoming the fatigue accumulated during the last few weeks of the intensive and extensive training prior to the taper. Mathematical modelling suggests that an advanced reduction in the training load followed by a subsequent increase in the lead up to competition could optimize performance. The rationale behind this design is that the athlete would take advantage of reduced fatigue to enhance training tolerance and respond effectively to the training undertaken during the taper (Thomas, Mujika, & Busso, 2008).

Magnitude of performance improvements

The expected mean improvement in individual performance time with an effective taper is about 2–3%, ranging from 0 to 6% in trained athletes (Mujika & Padilla, 2003). The underlying improvements in power output to elicit these magnitudes of improvement vary according to the specific demands of the sport. In running, an increase in mean power

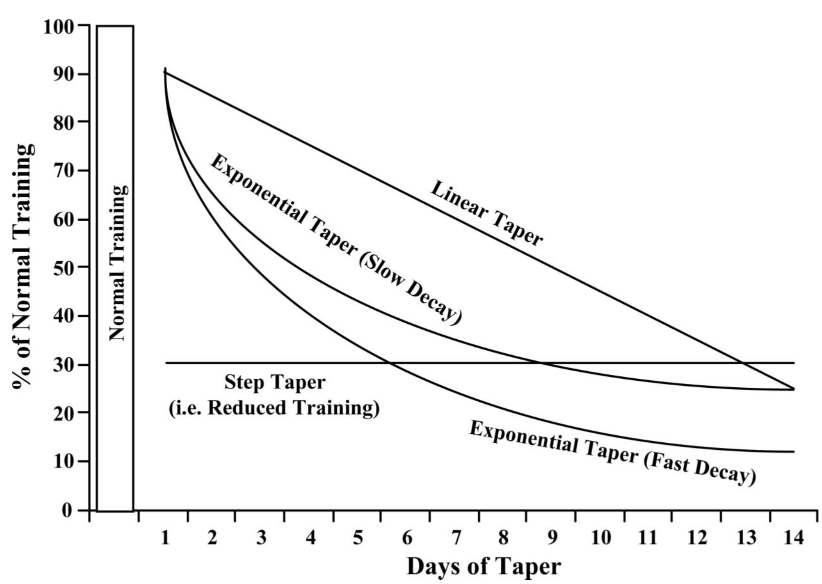

Figure 1. Schematic representation of the different types of tapers: linear taper, exponential taper with slow or fast time constants of decay of the training load, and step taper. Reproduced with permission from Mujika and Padilla (2003).

of 2–3% will elicit the desired increase in performance. In cycling, a slightly larger increase in power output is required given that aerodynamic resistance increases exponentially with velocity. In swimming, in contrast, an 8% improvement in mean power is needed (given that change in power is the cube of the change in velocity) to elicit a 2% improvement in performance (Toussaint & Truijens, 2006). A worthwhile improvement in top-ranked athletes is in the order of 0.5–3.0% from sprint to endurance events in individual sports like running, swimming, and cycling (Hopkins, Hawley, & Burke, 1999; Pyne Trewin, & Hopkins, 2004). On this basis, an effective taper of the order of 1–2% can make a substantial difference to the outcome of competition performance in many sports. Mujika and colleagues (Mujika, Padilla, & Pyne, 2002) reported that the differences between the gold medallist and fourth-placed athlete (1.6%), and between the third- and eighth-placed athletes (2.0%), at the Sydney 2000 Olympics swimming events were smaller than the mean improvement in performance obtained with the taper (2.2%) by 99 athletes. The absolute level of performance after the taper will depend on both the initial level of fitness and performance and the magnitude of adaptation and improvement. The magnitude of individual variation is such that some athletes are likely to perform more poorly than their previous best performance, while others show substantial improvement. Gender, event duration, and level of performance do not appear to be conditioning factors in the types of tapers that coaches could employ (Mujika et al., 2002). More work is required to identify the effect of tapers in sports determined by other dimensions such as mass, distance or points scored. At present, our understanding of the factors contributing to the individual responses to various types of taper is rudimentary, and trial and error in the field are still the primary means of managing this process.

Key elements of the taper

The key elements of the taper are the magnitudes of reduction in training volume, prescription of training intensity, duration and pattern of the taper, and interaction of the taper with the preceding phase of training. In many sports, particularly Summer and Winter Olympic endurance sports, training volume is the main currency of the training programme. Manipulation of training volume is understood intuitively by most coaches and athletes, although many of them fear a potential loss of fitness when training volume is markedly reduced. The importance of reducing training volume was confirmed in a meta-analysis (Bosquet et al., 2007), which indicated that performance improvement was more sensitive to reductions in training volume than manipulation of other training variables. After controlling for all other variables, a reduction in training volume elicited a moderate [effect size 0.72 ± 0.36 (±95% confidence limits)] improvement in performance (Table I). This magnitude of improvement was approximately twice that of modifying training intensity (0.33 ± 0.14) or training frequency (0.35 ± 0.17) (Bosquet et al., 2007). The practical application of these findings is that coaches should give the highest priority to prescription of training volume during the taper. The reduction in training volume is likely to have a moderate, but meaningful, effect on performance, whereas modifying training intensity or training frequency may have only a small effect.

Scientific bases for taper-induced performance gains

The scientific bases for enhancement of performance through a taper can be categorized into physiological and non-physiological factors. The physiological factors underpinning the taper-induced enhancement of performance include cardiorespiratory, metabolic, biochemical, hormonal, and neuromuscular factors (Mujika et al., 2004). A substantial part of the experimental work on the taper has focused on changes in submaximal and maximal oxygen consumption and related factors such as hypervolaemia, erythropoiesis, oxidative enzyme activity, muscle fibre recruitment, energy stores, and substrate utilization (for reviews, see Bosquet et al., 2007; Mujika et al., 2004).

Table I. Effects of moderator variables on effect size for taper-induced changes in performance.

Categories	Effect size[a] ± 95% CI	*P*-value
Decrease in training volume		
< 20%	−0.02 ± 0.30	0.88
21-40%	0.27 ± 0.23	0.02
41-60%	0.72 ± 0.36	0.0001
> 60%	0.27 ± 0.30	0.07
Decrease in training intensity		
Yes	−0.02 ± 0.35	0.91
No	0.33 ± 0.14	0.0001
Decrease in training frequency		
Yes	0.24 ± 0.27	0.08
No	0.35 ± 0.17	0.0001
Duration of the taper		
< 7 days	0.17 ± 0.22	0.14
8–14 days	0.59 ± 0.23	0.0005
15–21 days	0.28 ± 0.30	0.07
> 22 days	0.31 ± 0.45	0.18
Pattern of the taper		
Step taper	0.42 ± 0.53	0.12
Progressive taper	0.30 ± 0.14	0.0001

Notes: [a]Effect size: trivial < 0.2; small 0.2–0.6; moderate 0.6–1.2. Reproduced with permission from Bosquet et al. (2007).

Other non-physiological factors of the taper likely include psychological states, psychophysiological functions such as tolerance to pain (see review by Mujika et al., 2004), and biomechanical and neuromuscular factors such as development of muscular power, muscle elastic properties, and the stretch–shortening cycle of muscle contraction (Noakes, 2000; Papoti, Martins, Cunham, Zagatto, & Gobatto, 2007). Neural and biomechanical factors of the taper are important (D'Acquisto et al., 1992; Houmard, Scott, & Justice, 1994) and influence adaptations to physical training and the outcome of competitive performance itself. A multidisciplinary approach can provide a holistic view of the mechanisms that promote performance gains via tapering. In essence, the aim of the taper is to maximize the physiological adaptations realized through the training process and to reduce the cumulative effects of fatigue.

Research limitations and future directions

Individual and team sports

Most experimental and observation research on tapering in the scientific literature has been conducted in individual (predominantly endurance) sports and events. Individual sports where taper has been examined include running (Houmard et al., 1990, 1994; Houmard, Hortobagyi, & Johns, 1992; Mujika et al., 2000; Shepley et al., 1992), swimming (Anderson, Hopkins, Roberts, & Pyne, 2007; Houmard & Johns, 1994; Mujika et al., 2002; Trinity, Pahnke, Reese, & Coyle, 2006), cycling (Halson, Bridge, & Meeusen, 2002; Jeukendrup, Hesselink, Snyder, Kuipers, & Keizer, 1992; Neary, Bhambani, & McKenzie, 2003), rowing (Kubukeli, Noakes, & Dennis, 2002; Steinacker, Lormes, Lehmann, & Altenburg, 1998), and triathlon (Banister et al., 1999; Margaritis, Palazzetti, Rousseau, Richard, & Favier, 2003). There are two main reasons for the focus on individual sports: first, in individual sports there are moderate to large correlations between physiological capacities, basic training factors such as volume and intensity, and competitive performance; second, these factors are much easier to isolate and quantify in comparison with the multi-faceted nature of team sports physiological demands, training, and performance (Mujika, 2007a).

In contrast, there is little information available on winter Olympic sports (e.g. cross-country skiing and biathlon), team sports (field and court sports), combat sports (boxing, wrestling, and martial arts), racquet sports (tennis, squash, and badminton), and target or precision sports (shooting and archery). A literature search in PubMed and SportsDiscus in publications to the end of 2007 using the keywords "taper" and "football" yielded only three studies. The scarcity of published studies highlights the potential for team sports to gain a competitive advantage if they can develop effective strategies for tapering before competition. In contrast, it seems that professional soccer players competing for their clubs in the lead up to major international tournaments such as the World Cup, and therefore having reduced opportunities to taper, are among those most likely to underperform when representing their countries (Ekstrand, Walden, & Hagglund, 2004). Team sports clearly involve a combination of physical, physiological, psychological, technical, and tactical factors that contribute to performance. Given that most team sports require well-developed speed, acceleration, power, endurance, and agility, it is likely that an effective taper would improve many or all of these attributes (Mujika, 2007a). The area of tapering in team sports is certainly ripe for scientific investigation. A key concern will be optimizing the taper for a single match versus league and tournament play.

Another issue confronting sporting authorities is the emergence of lucrative commercial sponsorships, which are creating new events and competitions in a busy sporting calendar. The emergence of these commercial opportunities means that many athletes now attempt to taper for several events in a given season or year, where previously they focused on one or two major national or international competitions.

Experimental approaches

No study has directly examined the taper in the context of multiple peaking. In most individual sports, the major competition involves a series of heats, semi-finals, and finals that can stretch over several days or more in major international competition. In team sports, in particular the popular codes of football, most national and regional competitions involve one or more games per week over a 4- to 8-month season. It is not known how often an athlete or team can obtain the performance benefits of an efficient taper, making it difficult to provide definitive recommendations. Another key consideration in team sports is preparation of national teams for major international competitions like the World Championships, World Cup or the Summer and Winter Olympic Games. Team-sport tapers include variants for "regular season" peaking and "major tournaments" (Mujika, 2007b). The physical preparation of players prescribed in these settings has evolved through trial and error rather than experimental research.

Sports scientists should take advantage of the wide range of experimental designs available to explore the physiological and performance bases of the taper. Broadly speaking, the sequence of experimental designs in order of scientific rigour and robustness of evidence they provide for causality is: case study, cross-sectional study, retrospective and prospective observational studies, action research, and randomized controlled (intervention) trials. Sports scientists working closely with elite performers and their coaching staff should emphasize: (a) the existing gaps in the present knowledge regarding the optimal tapering strategies for different sports and competition formats, and the physiological and non-physiological mechanisms associated with tapering-induced performance changes; (b) the potential performance benefits of these investigations. This type of approach should benefit both the scientific community and athletes seeking a performance edge in Vancouver in 2010 and London in 2012.

Traditional approaches and experimental manipulations of training variables

Most available studies on taper-related issues on highly trained competitive athletes are purely observational in nature. Although this approach has provided a useful body of knowledge about tapering strategies in sport, athletes' adaptations and impact on performance, it relies heavily on coaches' *savoir faire* and leaves little room for experimenting with new tapering methodologies and models. Some investigators have experimentally manipulated the taper programme of a group of athletes, most often to compare the physiological adaptations to different tapering patterns and/or varying duration, training volume, intensity and frequency, and the magnitude of performance enhancement. Although insight gained from experimental manipulation of training variables and taper characteristics is helping coaches and athletes, more intervention studies are needed to quantify the effects of all different combinations of the key elements of tapering.

A recent line of investigation relies on the use of mathematical models. Modelling can describe the consequences of tapering strategies used by highly trained athletes and simulate the performance outcomes of training manipulations, or the necessary training input for a desired performance output (Busso & Thomas, 2006; Thomas & Busso, 2005; Thomas et al., 2008). The simulations are based on model parameters obtained from real training and performance data. Although this approach shows promise and could be a useful preliminary step to assess the theoretical consequences of a tapering intervention, real-life experimental manipulations will always be needed to accept or reject the predictions made through mathematical modelling.

Performing across time zones: Travel, peaking, and chronobiology

Olympic athletes are frequently required to travel across continental boundaries for purposes of training or competing. Long-haul flights lead to travel fatigue, a relatively transient malaise that is quickly overcome with rest and sleep. Crossing multiple meridians causes desynchronization of human circadian rhythms and leads to the syndrome known as jet-lag. This condition can persist for some days, depending on the number of time zones crossed, the direction of flight, the times of departure and arrival, and individual factors (Waterhouse, Reilly, Atkinson, & Edwards, 2007b). Concomitant with the experience of jet-lag, there is impairment in a range of performance measures until the endogenous "body clock", located in the hypothalamus, is retuned to the new local time. Decrements have been reported for muscle strength, reaction times, and subjective states indicative of arousal (Reilly, Atkinson, & Budgett, 2001). Among the recommendations to help cope with jet-lag during the period of desynchronization is a lowering of the training load (Reilly et al., 2007a). This reduction would compensate for the temporary decrease in physical capabilities associated with jet-lag and avoids exposure to risk of injury in training (especially if complex practices are attempted) when symptoms are experienced. In effect, there is a temporary taper imposed by the need to cope with the malaise of jet-lag until readjustment has occurred, the duration of which depends mainly on the direction of flight and the number of time-zone transitions. Clearly, there are major implications for athletes undertaking long-haul travel to Canada for the Vancouver 2010 Winter Olympic Games and to the United Kingdom for the London 2012 Summer Olympic Games. The jet-lag-imposed modifications to the training load should be considered in context of the overall training programme and the taper leading to competition.

The time-scale for adjustment of the body clock can be incorporated into the taper when competition requires travel across multiple meridians. It is logical that sufficient time is allowed for the athlete to adjust completely to the new time zone before competing (Waterhouse et al., 2007b). The period of readjustment might constitute a part of the lowered training volume integral to the taper. Allowance should be made for the timing of training over the first few days, since training in the morning is not advocated after travelling eastwards so that a phase delay rather than the desired phase advance is not erroneously promoted (Reilly, Waterhouse, & Edwards, 2005). There also seems little point in training hard at home prior to embarkation, since arriving tired at the airport of departure may slow up adjustment later (Waterhouse, Nevill, Edwards, Godfrey, & Reilly, 2003). Similarly, attempting to shift the phase of the body clock in the required direction for some days prior to departure is counterproductive, since performance (and hence training quality) may be disrupted by this strategy (Reilly & Maskell, 1989).

Tapering should proceed as planned in the company of jet-lag even if the interactions between body clock disturbances and the recovery processes associated with tapering have not been fully delineated. While quality of sleep is an essential component of recovery processes, napping at an inappropriate time of day when adjusting to a new time zone may slow up re-synchronization (Minors & Waterhouse, 1981), but in certain circumstances a short nap of about 30 min can be restorative (Waterhouse, Atkinson, Edwards, & Reilly, 2007a). Suppression of immune responses is more likely to be linked with sleep disruption than with jet-lag *per se* (Reilly & Edwards, 2007). The circadian rhythm in digestion is largely exogenous and jet-lag is associated mainly with a displacement of appetite rather than reduced energy intake (Reilly, Waterhouse, Burke, & Alonso, 2007b). Therefore, readjustment of the body clock should be harmonized with the moderations of training during the taper. Athletes, coaches, managers, and support staff should implement strategies to minimize the effects of travel stress prior to departure, during long-haul international travel, and upon arrival at the destination.

Interaction with environmental factors: Heat and altitude

A taper is dependent on removal or minimization of the athlete's habitual stressors, permitting physiological systems to replenish their capabilities or even undergo "supercompensation". There is very little scientific information with respect to possible interactions with environmental variables on tapering processes in athletes, whether the stressor is heat, cold or altitude. Experimental work on the additive effects of altitude on climatic stress and travel fatigue or jet-lag is lacking (Armstrong, 2006). This gap in knowledge is largely due to the enormous difficulties in addressing these problems adequately in experimental designs, and the challenges that researchers in the field are faced with in controlling the many variables involved. Nevertheless, the likely effects of environmental factors must be considered in a systematic way when tapering is prescribed within the athlete's or team's annual plan.

Training camps, whether for altitude training or warm-weather training to secure heat acclimatization, pose a different set of problems to those presented by travel schedules. Both altitude and hot environments present hostile conditions for athletes where the primary objective of the visit is to subject themselves to the prevailing stressors. The principle is that physiological benefits derived from the adaptations to the new environment presumably transfer during the taper to enhance competitive performance. In both conditions, the absolute exercise intensity is lowered by necessity, even if the relative physiological stress is the same as that usually encountered. This uncoupling of physiological and biomechanical loading may have unknown consequences in terrestrial sports for the mechanisms associated with the tapering response, particularly when the exercise intensity is light to moderate during the first tentative exposures to heat or altitude.

Tapering in hot conditions before competition is compatible with the reduction in training volume advocated when encountering heat stress. The increased glycogen utilization associated with exercise in the heat should be compensated by the reduced training load – both intensity and duration (Armstrong, 2006). Athletes should be acclimatized to heat, otherwise performance in the forthcoming competition might be compromised. In winter-sport events there is no corresponding problem, since protection against climatic conditions and the initial diuresis that occurs is secured by behavioural measures, such as donning appropriate clothing, seeking shelter when necessary, and restoring hydration status.

At altitude, maximal oxygen uptake is reduced according to the prevailing ambient pressure. An immediate consequence is that the exercise intensity or power output at a given relative aerobic loading is decreased. In the first few days at altitude, a respiratory alkalosis occurs due to the increased ventilatory response to hypoxic conditions. This condition is normally self-limiting due to a gradual renal compensation. Winter Olympic athletes using training camps at altitude resorts recognize that a reduction in training load is imperative at altitude, prior to an increase as the initial phase of acclimatization occurs. The extra hydration requirements due to the dry ambient air and the initial diuresis, combined with plasma volume changes (Rusko, Tikkanen, & Peltonen, 2004), increased utilization of carbohydrate as substrate for exercise (Butterfield et al., 1992), and propensity to sleep apnoea (Pedlar et al., 2005), run counter to the benefits of tapering. In this instance, the reduced training load would not substitute for a taper. There is the added risk of illness due to decreased immunoreactivity associated with exposure to altitude (Rusko et al., 2004). Maximal cardiac output may also be reduced in the course of a typical 14- to 21-day sojourn to altitude as a result of the impairment in training quality.

Altitude training camps should therefore be lodged strategically in the annual plan to avoid unwanted, if unknown, interactions with environmental variables.

Altitude training is used in many sports at elite level for conditioning purposes. For example, it is accepted as good practice among elite swimmers and rowing squads preparing for Olympic competition despite an absence of compelling evidence of its effectiveness. There remains a question as to the timing of the return to sea level for best effects, an issue relatively neglected by researchers in the field, with a few exceptions (Ingjer & Myhre, 1992). A period of lowered training is espoused prior to competing after altitude training, which constitutes a form of tapering. The extent of the benefit, as well as the variation between individuals, has not been adequately explored.

Specific guidelines for coaches and athletes

On the basis of existing research, the practical experience of coaches, athletes, and support staff, and published recommendations (Bosquet et al., 2007; Mujika & Padilla, 2003), the general guidelines for a likely effective taper are: a 2- to 3-week period incorporating a 40–60% reduction in training volume following a progressive non-linear format, maintaining training intensity, and a modest, if any reduction ($\sim$20%) in training frequency. If managed successfully with the reduction in residual fatigue, an enhancement of power output, and other beneficial physiological and psychological changes, athletes should typically expect a 2–3% improvement in performance. In terms of long-term planning, coaches and athletes should evaluate the interaction between the 2- to 3-week taper and the preceding 4- to 8-week training phase(s). Integration of the taper with environmental and behavioural factors, and the preceding phase of training are important issues for athletes preparing for the Vancouver 2010 and London 2012 Olympic Games.

Conclusions

The physical preparation of athletes continues to evolve and sports science will play an important part in refining existing and developing tapering methodologies. Future developments should involve a combination of research and practical experience of coaches and athletes, experimental and observational research, and elegant mathematical models to refine our understanding of the physiological and performance elements of the taper. Successful evaluation and implementation of different combinations of the taper should contribute to improvements in sports performance at the Olympic level.

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