PEAKING AND TAPERING IN ENDURANCE ATHLETES: A REVIEW

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THE POST [|] VOL. 1 ISSUE 1

LAKEHEAD UNIVERSITY'S INTERDISCIPLINARY UNDERGRADUATE RESEARCH JOURNAL

Abstract: In an effort to create optimal performance, annual periodization is a part of an elite athlete's training plan. More specifically, a "peak" or "taper" period prior to competition is often utilized in an effort to produce optimal performance. Despite its use and popularity, there is no common consensus on the optimal design or duration of a taper in endurance athletes. Thus, this paper examines the literature surrounding peaking and tapering in endurance athletes. Sixteen studies involving trained and elite endurance athletes were reviewed. These studies examined tapering using both short and long-term protocols, low- and high-volume, low- and high-intensity, and low- and high-frequency protocols. Despite the difference in study designs, the majority of studies reviewed showed a measurable benefit (2-8%) to peaking before competition for endurance athletes. In general, it appears that maintenance of training intensity while gradually reducing volume is a good base for developing a taper; however, it is not the only method of tapering that improves performance. Therefore, it appears that peaking and tapering should be prescribed and designed based on the specific athlete and situation.

The achievement of peak-level performance in competition is the ultimate goal of any athlete. This becomes increasingly important in sports where fractions of a second make the difference between finishing on the podium and failing to qualify for an event. As such, a performance that is not optimal can significantly affect an athlete's placing, qualifications, and records. In an effort to create an optimal performance at the appropriate time, annual periodization of training is implemented in high level and elite athletes (Hellard et al., 2013). As such, the best periodization protocol has been investigated in recent years; specifically, optimal peaking and tapering protocols for athletes during their competition season.

The principle of periodization states that training variables must be altered and cycled throughout the year in order to maintain optimal performance. Tapering is a key part of the periodization concept (Mujika, 2000). According to Mujika & Padilla (2000), a taper is "a progressive, non-linear reduction of the training load during a variable period of time, in an attempt to reduce the physiological and psychological stress of daily training and optimize sports performance" (Mujika & Padilla, p. 582). This definition provides some guidance in terms of how a taper should be designed, though it is still relatively vague. This is because the research on "optimal" peaking and tapering protocols is far from conclusive. However, tapering protocols based on this definition of a taper have been shown to elicit a 2-8% improvement in athletic performance (Luden et al., 2010).

The reasons underlying why tapering is effective are speculative at best (Mujika et al., 2000). Both physiological and psychological benefits have been cited in endurance athletes whose training takes tapering into account, including increased muscle power, improved running economy, peak force, and mood profile (Houmard et al., 1994; Hooper et al., 1998). However, cardiovascular and aerobic systems do not appear to show the same benefits with a taper (Luden et al., 2010). As such, research in the last 20 years has taken many angles to determine why tapering works and what conditions create the optimal taper and peak performance. Main topics of study have included volume, intensity, and duration of a taper and the resulting effects on performance measures.

A problem with trying to study optimal tapering methods is that there are several factors and situations that need to be accounted for. Training variables such as volume, intensity, duration, frequency, and type of training differ based on the sport and athlete (Bulbulian et al., 1996). In addition to training variables, one must consider the effect of non-training variables on athletic performance such as stress, nutrition, sleep, and other elements. As such, it is difficult to account for all of these factors in one single study. Tapering has been shown to consistently improve athletic performance (Luden et al., 2010); however, a specific recipe for tapering has not been consistently identified, with the majority of studies differing in design but not results. Therefore, the purpose of this review is to examine the literature surrounding peaking and endurance athletes in an attempt to produce a protocol for an optimal peak and taper.

Methods

Data Sources

Databases were searched using the keywords "peaking", "tapering", and "endurance". Databases used included (1) Pubmed, (2) Wolters Klewer, and (3) PLoS ONE. No restrictions were placed on publication dates, as there is not a substantial amount of literature on the subject.

Study Selection

Studies were reviewed if (1) they involved trained, or elite, or endurance athletes, (2) examined a training reduction of at least 30% of pre-taper values, (3) were at least 6 days in duration, (4) they involved a performance based dependant variable and (5) were published in a peer-reviewed journal. Sixteen studies that met these criteria were examined in this review. Of these studies, two were case studies, and two were mathematical models. The remaining studies reviewed were of an experimental or quasi-experimental design.

Table 1.

Short duration taper results (7 ≤ days)

Reference	Subjects	Taper Length	IV	DV	Results	Limitations
Mujika et al., 2000	8 well trained male middle distance runners (age 19.9 +/- 1.8 yrs)	6 days	-Low Volume Taper (75% reduction in volume) -Moderate Volume taper (50% reduction in Volume)	800 m race performance blood lactate, creatine kinase, red blood cell count, Hb, mean corpuscular volume	-No change in performance / some decreased performance -Some blood markers decreased	-Small sample -Only male subjects -Subjects pre-study training was individualized not standardized.

Reference	**Subjects**	**Taper Length**	**IV**	**DV**	**Results**	**Limitations**
Neary et al., 2003	11 trained male cyclists (age 19-34 yrs)	7 days	-Pre-study standardized 3 week training block -30% decrease in training volume -50% decrease in training volume -80% decrease in training volume	-VO2 Max, Time trial performance ride, HR, RPE, time, velocity	-50% reduction in training volume = best performance	-No post taper VO2 max data -No power measurement -Only compared male subjects
Houmard et al., 1993	18 male, 6 female distance runners (48 km week/2 years) -No age	7 days	-Control taper -Run taper (85% reduction in volume) -Cycle taper (85% reduction in volume)	5 km time trial, leg extension force, submaximal treadmill run (80% Vo2 Max, maximal treadmill run (volatile fatigue).	3% decrease in 5 km run time in run taper group. Decrease in O2 intake and energy output.	Non-random assignment -No comparison to another taper protocol -learning effect -Specificity -No age provided
Shepley et al., 1992	9 male middle distance runners (age 21-24 yrs)	6 days	-8 weeks consistent training -Crossover design -high intensity low volume (daily 500 m intervals), -low intensity moderate volume (60% VO2 max, 30 km weekly total), -Rest only taper.	Treadmill fatigue run, isometric quadriceps strength, muscle glycogen, -citrate synthase, total blood and RBC count	-increased strength after all 3 tapers -High intensity -low volume produced greatest increase	-High intensity training was more intense than athletes normal training -Treadmill measure; not track -No pre-study washout period.

Table 2.

Long duration taper results (≥ 8 days)

Reference	**Subjects**	**Taper Length**	**IV**	**DV**	**Results**	**Limitations**
Tonnessen et al., 2014	11 (4 male, 7 female) world class cross-country skiers and biathletes Age 28 +/- 1 yr.	Up to 2 weeks	-Case study of highly detailed training journal. 1 year of daily training logs leading to their career best performance were examined.	-Peak race performance	-3 of 11 athletes somewhat followed recommended tapering protocols; all athletes had career best or gold medal performance	-Case study -Self reported training journals.
Luden et al., 2010	7 male, university long distance runners. Age 21 +/- 1 yr	3 weeks	-Weekly running volume	8 km XC race performance gastrocnemius single muscle fibre size and function, baseline and exercise-induced gene expression, citrate synthase activity, max and submax CV physiology	Race performance improved 3%. Improvements were also seen in peak force and power development	-No Control -Only males studied -Used cross-country course – inconsistent.
Neufer et al., 1987	24 trained male swimmers Age 20 +/- 1 yr.	4 weeks	-3 day per week taper -1 day per week taper -Rest-only training	Muscular strength, power, swim power, swim bench, stroke rate, stroke distance, blood lactate	In 3 day per week group aerobic performance did not decrease, strength maintained, swim power reduced.	-No VO2 measurement of the control group -Blood lactate taken 5 min post exercise.

Reference	Subjects	Taper Length	IV	DV	Results	Limitations
Mujika et al., 1996	18 elite (8 female, 10 male) swimmers Age 20.3 +/- 2.8 yrs.	3,4,6 weeks	-Negative impact of training -Positive impact of training -3 week taper -4 week taper -6 week taper	-Race performance	Mathematical model using fatigue and training as a predictor of performance displayed a strong fit	-Does not take into account individualized variables. -Dryland quantified the same way as water practice -Strictly physiological
Hooper et al., 1998	27 (12 male, 15 female) competitive swimmers Age 13-21.	2 weeks	-Auto-regulated taper based on daily journal -Reduced volume taper, -Reduced volume and intensity taper	-Mood state, tethered swimming force, time trial.	All 3 groups improved their mood state after week 1 (levels of depression, anxiety, etc.). Peak tethered swimming force improved after week 2 in all groups	-Subjective intensity measurements
Thomas et al., 2008	8 elite (4 male, 4 female) swimmers Age 19.8 +/- 2.5 yrs.	Varying	-Step taper -Progressive taper -Pre-taper overload	-Seasonal performance	Overload training before peaking resulted in better performance; however requires a longer duration taper	-Information for mathematical model came from non-athletes -Cannot predict for individual variations
Farhang-imaleki et al.,2009	24 elite endurance cyclists. Age 26.1+/- 3.6 yrs in taper, 24.8 +/1 2.9 yrs in control	3 weeks	Control group -Taper group who reduced training volume by 50%.	Time trial time, IL-1β , IL-6 and TNFα concentrations	Taper improved time trial results at week 1 and 3, inflammation markers only reduced after week 3	-Blood taken at inconsistent intervals. -Psychology / physiological effects of having blood withdrawn

Reference	Subjects	Taper Length	IV	DV	Results	Limitations
Hickson et al., 1981	21 female and male recreationally active individuals. Age 19-33 yrs	15 weeks	1/3rd- Training frequency -2/3rd reduction in training frequency	VO2 max running, VO2 max bike	1/3rd and 2/3rd training reduction group maintained VO2 max	Limitations; -No control Few exclusion criteria -Athletes sustained injuries
Hellard et al., 2013	32 (15 male, 17 female) elite swimmers. Age 18 +/- 2 yrs	3 week taper	-High training load with fast linear decay -Medium training with slow decay -Medium training load with slow decay, -Low training load followed by increase in load	best annual performance	Medium training load with slow decay of training volume linked to higher performance; however, design effectiveness changed based on stage of career. Higher training load with sharp decay better later on.	-Design changed over time; 9 year study
Rietjens et al., 2001	12 male cyclists. Age 25.3 +/- 7.3 yrs	3 weeks	Continuous endurance exercise Intermittent endurance exercise program	Maximal workload, VO2 max	Functional capacity maintained during 21 day volume reduction	Large SD in age Only compared male athletes

Year= Yr, hemoglobin= Hb, Cardiovascular= CV

Discussion

The majority of studies reviewed showed a measurable benefit to tapering before competition for endurance athletes. This is based on performance measures such as force, time to exhaustion, and time trials. However, evidence for how long a peak should be to achieve these improvements is conflicting. Based on the design of the studies examined, it is necessary to examine the peak and taper from several angles. These include: length of a taper, volume of a taper, taper intensity, training frequency, and the resulting performance implications, as these are the independent variables in the majority of studies. Length of taper is important to examine, as a taper can last anywhere from 6- 28 days. As aerobic performance is thought to decrease quite rapidly after reduced training, it is imperative that we determine the optimal amount of time for a taper (Farhangimaleki et al., 2009). Furthermore, the distribution of volume over the time period of the taper can be examined, as some studies "front load" the volume; whereas others may gradually reduce volume throughout the taper. Psychological and physiological effects should also be examined to determine the effects of a taper beyond performance measures, as the psychological and physiological (fatigue, hemoglobin levels, and mitochondrial enzymes) state of an athlete can have major implications on performance (Foster, 1998; Hooper et al., 1995).

Volume

Volume refers to the total amount of work being performed by an individual. For example, running 50 km per week would be the volume of training for one week (Mujika et al., 2000). Because volume is easy to manipulate, the total volume of a taper has been the focus of much research specifically comparing low-, moderate-, or high-volume training to determine the volume in a taper that produces the best performance (Neary, Bhambhani, & McKenzie, 2003; Mujika et al., 2000; Hellard et al., 2013; Houmard et al., 1993). Neary et al., and Hellard et al. concluded that reducing the training volume by one-half during a taper would be most likely to enhance performance, this in comparison with tapers between 25% and 75% reduction of baseline training volume. However, Houmard et al. (1993) determined that up to an 85% reduction in training volume resulted in a 3% increase in 5 km run performance. However, Hellard et al. (2013) also found that the amount of volume that resulted in best performance times changed over an athlete's career, and that higher volume may be beneficial later in an athlete's career. Therefore, moderate and large reduction in training volume may both be effective depending on the athlete.

While moderate- and low-volume tapers are supported in studies by Neary, Bhambhani, & McKenzie (2003); Hellard et al. (2013); and Houmard et al., (1993), not all studies have come to the same conclusions. In a study of middle distance runners Mujika et al. (2000) examined the results of reducing training volume by 50% and 75%, respectively. In this study, 8 male middle distance runners performed 1 of 2 tapers; either a moderate-volume taper or a low-volume taper. Volume was established based on the previous 3 weeks of training and reduced in a stepwise fashion over 6 days. Before and after the 6 day taper, subjects performed an 800 m race to measure race performance. After the taper, 5 runners recorded an improved time, while 3 runners performed worse than the pre-test race. However, these differences were not statistically significant.

One reason for this may be that the pre-study training programs were not subject to experimental or study design, as each runner's training program was individually set, though by the same coach. In studies that support the use of a moderate- to low-volume taper, subjects were either placed on a study-designed program prior to the taper, or into created groups where there was no statistical difference between training distance and performance (Neary et al., 2003; Houmard et al., 1993). While each training program was individualized, this can create problems with the study design, as volume and intensity were not based on a specific measurement or variable for each runner. For example, total season volume was 669.6 km +/- 235.9 km, a difference of 35%, whereas subject's height, age, weight, and percentage of body fat differed significantly less than this. Therefore, it appears that each runner's training volume and intensity before the taper was not based on an objective measurement. Rather it is logical to assume that the coach either based training volume and intensity on measures other than height, age, weight, and body fat. It also seems the coach based athletic programming on subjective measures of performance, or was not implementing periodization principles. While taper volume was based on each participant's mean training volume from the previous 3 weeks of training, VO2 max or anaerobic threshold was not measured, creating the possibility that training status may have varied between each subject.

Another potential problem with Mujika et al. (2000) is its pre-test and post-test instruction. Subjects competed in heats comprised of 3 runners; however, the heats were composed of runners of with varying performance levels in an effort to minimize competition between participants. This represents a flaw in study design as the practice of tapering is used leading up to a **competition**. Competition presents a vastly different psychological environment compared to practice (Shepley et al., 1992). In competition, performance anxiety, racing strategy, and intensity may all be different when compared to practice. For example, a runner may run at a pace approaching their anaerobic threshold when running by themselves; however, in a race they may push this level higher, either successfully or unsuccessfully improving their performance time.

Support for moderate- to low-volume tapers is shown in studies by Neary, Bhambhani, & McKenzie (2003); Hellard et al. (2013); and Houmard et al. (1993). In a 2003 study by Neary et al., 11 male cyclists took part in one of three 7-day tapers; either an 80%, 50%, or 30% reduction in training volume. The authors found a 3% increase in 20 km time-trial performance in the moderate-volume group, whereas the high- and low-volume groups displayed no improvement. It is important to note that in an effort standardize training volume across groups; all participants completed a 3-week high-intensity training program prior to beginning the taper. Based on previous base training volume, this 3 week pre-taper period was equivalent to an overreaching phase for the subjects. Hellard et al. also employed this overreaching design prior to their taper period and found that medium, progressing to low-volume load resulted in a better performance than higher training volumes. Based on these studies, it appears that moderate- to low-volume tapers produce consistent performance improvements.

Distribution of Volume

While total volume may be important to achieving a peak performance post-taper, distribution of the total volume may play a significant role. Depending on study design, tapers may be designed in a step-wise fashion, where volume is gradually reduced through the taper, while maintaining total weekly volume (Neufer et al., 1987; Houmard et al., 1993; Neary et al., 2003, Mujika et al., 2000; Shepley et al. (1992), or they may be an abrupt reduction of volume, as seen in a study by Rietjens, Keizer, Kuipers, & Saris, (2001) where volume remains consistent throughout the week. This is important to note as "undulating periodization" (in which volume is cycled daily) has been shown to elicit greater performance when compared to linear programing of volume (Rhea et al., 2002). As such, it is important to investigate the variation and distribution of volume over a taper.

In studies that gradually reduce the volume through the taper we see mixed results. Mujika et al. (2000) found no performance improvements when volume was dropped 10-15% per day over 6 days, whereas Houmard et al. (1993) found a 3% increase in 5 km performance times. This study is also in line with findings by Mujika, Padilla, & Pyne (2002), Mujika et al. (1996), and Luden et al. (2010) that show a 3% improvement in performance following a taper, all of which used a gradual reduction of volume in study design. In the study by Houmard et al., subjects performing a run taper reduced volume to 15% of previous distance, and of that 15%, 20% was performed on day 1; 15% on day 2; 12% on day 4; 10% day on 5: 8% on day 6; and 5% on day 7. This distribution of volume is better representative of the undulating method of volume distribution than Mujika's step-reduction of 20% of volume per day. Undulating distribution of volume is also seen in Mujika's 1996 study, where the effect of a taper on performance was measured in competitive swimmers. This study observed volume reductions in different intensity zones 1-5 (5 being high-intensity, 1 being very low) during the first taper on the season; whereas in subsequent tapers during the season, volume of training performed at different intensities was varied and manipulated. This study also displayed the 3% improvement in performance seen in other literature (Mujika et al., 1996).

The reason that we may see this increase in performance when training at different intensity levels is varied throughout the taper is likely because of undulating periodization. General linear, or block periodization often involves focusing on training one variable for a given period of time (Rhea et al., 2002)., whereas undulating periodization will involve daily to weekly variations in training variables, such as volume and intensity. (Poliquin, 1988). For example, during a specific preparatory period, an athlete may only focus on high-intensity and sport specific exercise for a given period of time if following a block model of periodization; if they were following an undulating model of periodization, they might focus on endurance, strength, speed, work capacity, or other areas simultaneously. A traditional periodization design may remove speed training altogether during certain parts of the year.

The proposed benefit of undulating periodization is that it prevents detraining of exercise variables, as it has been established that endurance and aerobic fitness decrease quickly after cessation of training (Poliquin et al., 1988). As such, it would make sense to try to maintain aerobic capacity even when reducing volume in a taper, creating the need for different intensity zones in an effort to reduce the effects of detraining. It is important to note that no studies were found on undulating periodization in endurance athletes. The research is promising in strength athletes (Rhea et al., 2002).

A concern of many coaches and athletes with tapering is that a reduction in training volume may result in detraining effects that will negatively affect annual training. In a study of competitive swimmers, Neufer et al. (1987) examined the effects of reduced training frequency on strength and endurance in an effort to determine how long it takes before the effects of detraining are present. The authors compared the effects of reducing training frequency to 1 and 3 days per weeks for 4 weeks compared to complete rest for 4 weeks. The authors found that strength and power were maintained in all 3 groups in the swim bench and power test; however, when strength and power were measured using a tethered swim, swim power and strength decreased almost 6 watts from week 0. Additionally, stroke rate and stroke distance declined in the group that only trained 1 day per week, whereas stroke rate and distance were maintained in the group that trained 3 days per week. Thus, the conclusion of this study was that training adaptation could be maintained on a 3 day per week training program for 4 weeks; however, detraining would occur on a 1 day per week, or 0 days per week training program.

The notion that training can be maintained for an extended period of time with a reduced training load is known as the principle of maintenance (Jekauc et al., 2015). That is, if an athlete is training 6 times per week to increase their anaerobic threshold, they should be able to maintain their current fitness level by training less than 6 days per week. As noted by Neufer et al. (1987), swimmers who tapered while only training 3 days per week with a 30% reduction of volume from the pre-taper period maintained swim power, force and strength over a 4 week period. A study by Hickson & Rosenkoetter (1981) also supports these findings; however, the authors of this study found that training as little as 2 days per week is enough to maintain anaerobic threshold as long as 15 weeks. It is important to note that subjects in this study performed high-intensity (approaching the subject's VO2 max) as well as low-intensity/long duration exercise; one day of high-intensity cycle ergometer intervals, and 1 day of continuous running. Additionally, these subjects were not elite athletes; and undertook a 6 day per week, 10 week program to improve their VO2 max, before reducing training volume for 15 weeks.

While this study may provide evidence of maintenance of aerobic fitness in recreational athletes, it is difficult to tell if we would see the same results in elite athletes. Training adaptations are often quickest in those who do not have a lot of training experience (Neufer et al., 1987). As such, in the first 10 weeks of the program participants saw an increase of 25-30% in their VO2 max from baseline, and then were able to maintain this increase (Hickson & Rosenkoetter, 1981). VO2 max increased from an average of 40 ml/kg/m to around 50 ml/kg/min, which is much lower than one would expect to see in an elite endurance athlete (MSU, 1998). As such, reducing the training frequency and volume maintained VO2 max in this 50 ml/kg/min range; however, it is questionable if we would see the same results in athletes with much higher VO2 max scores (60 ml/kg/min), as these athletes often have years of base training experience contributing to their fitness (Tonnessen et al., 2014).

Another study that may lend support for long term reduced training and maintenance of fitness was conducted by Rietjens, Keizer, Kuipers, & Saris (2001). In this study, the authors found that a reduction in training volume of 50% of pre-taper values after a one week overload period with a reduction of training frequency to 3 days per week had no effect on maximal or submaximal aerobic performance in conjunction with the reduction in training intensity. This study involved highly trained cyclists who normally trained 5+ days per week and had a mean VO2 max close to 60 ml/kg/min. This study therefore lends support to the premise that detraining will not occur over a 3 week period with a reduced frequency of training, reinforcing the 3-4 week taper studies by Mujika et al. (1996), and Hellard et al. (2013), following a period of overreaching. Therefore, the length of an effective taper may depend on training leading up to the taper period.

Intensity

Training intensity is another variable that is altered frequently when programming a training plan. Intensity is the qualitative measurement of work that an athlete performs and is measured in work over time (Spencer et al., 2005). Therefore, the more work the athlete performs over a given time, the higher the intensity (Spencer et al.). This makes intensity a key training tool when we consider progressive overload; however, like volume, intensity must be varied appropriately. During an annual training plan, intensity increases as training becomes more sport and performance specific (Plisk & Stone, 2003). However, unless volume is reduced appropriately, problems can arise for the elite athlete. The principle of specificity states that training should be specific to the type of activities, muscle fibres, energy systems, and contractions involved (Coffey & Hawley, 2007). Based on the principle of specificity, training for a 10 km run will not contribute greatly to 100 m performance. We have already shown above that it is optimal for athletes to train at intensities close to levels seen in competition. Regrettably, statistically significant correlations have been found between acute injuries in men and chronic injuries in women with high training intensity, as well as increased levels of physical exhaustion (Vetter & Symonds, 2013). Even so, high-intensity interval training has been shown to improve aerobic performance equally, if not better than long duration, lower intensity exercise (Laursen & Jenkins, 2002). Therefore, intensity can be considered an important item in the toolbox of any athlete, even when peaking during training.

In studies by Houmard et al. (1993), Shepley et al. (1992), Tonnessen et al. (2014), high-intensity, low-volume tapers were compared with moderate- or low-intensity, and moderate- to low-volume tapers. The researchers found that for the most part, a high-intensity, low-volume taper resulted better performances than the low-intensity groups. This is a curious finding, as high-intensity exercise has been shown to accumulate more fatigue than low-intensity exercise (Bogdanis et al., 2007). If the goal of the taper is to increase recovery time, and elicit super-compensation, it would be logical to assume that high-intensity exercise would prevent this. However, this does not appear to be the case. The use of high-intensity exercise during a taper is examined in a study by Tonnessen et al. (2014). In this study, eleven world cup cross-country skiers recorded their training for one year prior to their best career performance. It was found that the majority of skiers averaged 3 high-intensity exercise sessions (above their lactate threshold) in the week preceding their competition. Furthermore, volume was not significantly reduced from the competition to peaking period. Despite this, these athletes all won their major competitions.

The study by Tonnessen et al. (2014) was an analysis of the training journals of elite cross-country skiers leading up to their most successful competition. As such, accuracy of the training journal may come into question; however, the authors note that the participants meticulously and thoroughly recorded their training from junior to senior year. Because of this it is reasonable to assume that these journals were fairly accurate, as the results of this study display similar findings as Houmard et al. (1993) and Shepley et al. (1992) in more controlled studies regarding intensity. However, it is important to note that the athletes in this study maintained the majority of their training volume (32% +/- 15%) during the peaking phase. Despite this high-volume and high-intensity taper, these athletes achieved a winning performance. This brings up the question of if this the optimal way to taper, or if could these athletes have done better if they had employed suggested tapering practices (Tonnessen et al., 2014). An answer to this may be found in a study by Mujika et al. (1996) of modelled physiological responses to tapering in swimmers.

In 1996, Mujika et al. endeavoured to create a mathematical model of predicting performance based on the taper intensity, volume, and duration. In addition, the authors attempted to determine at which time point during the season negative influences of training, such as fatigue have a greater impact on performance than positive effects of training, such as increasing VO2 max. This represents a different way of looking at the impact of a taper, by examining the principle of diminishing returns. The authors tested 3 taper periods consisting of 3, 4, and 6 weeks. What they found was that the mathematical model could accurately model performance in 17 swimmers. The authors also concluded that the negative impact of training (fatigue) was a key determinant of performance. The authors found that negative influences of training can affect performance up to 27 days before competition. Even so, training is most beneficial to performance from 0-56 days (Mujika et al.) before competition in some athletes Not only does this show the immense variation between people in regard to the effect of exercise on the body, but it suggests that training sessions up to 27 days before a competition may not be contributing to improving performance, but rather may hinder it. This study gives support to the notion that even in winning performances, it may be possible to improve performance even further, especially if no taper was utilized in the training leading up to the competition. This further supports the central premise that tapering in training helps to consistently achieve optimal performance.

Mujika, Padilla, & Pyne (2002) further explored this notion in an observational study of Olympic swimmers leading up to the 2000 Sydney Olympics. What they found was, when compared with other competitions during the season, the 3 weeks prior to the Olympic Games resulted in up to a 2.57% improvement when compared with performances earlier in the season. This brings up the question of what the athletes did during these 3 weeks that was different from tapering for their other competitions. Does the length of the last taper play a role?

Duration

While it is generally accepted that a peaking period should be programmed into an annual training plan, there is much debate as to how long a taper should be. Studies have shown performance increases with tapers lasting as little as 6 to 7 days (Neary et al., 2003; Houmard et al., 1994; Shepley et al., 1992). Longer tapers, ranging from 2-4 weeks appear to be more common and the norm, especially when competitions are not close together. Studies by Hooper et al. (2013), Luden et al. (2010), Mujika et al. (2002), and Thomas et al. (2007) all examined longer duration tapers. These comparisons between short and longer duration tapers are important because of detraining concerns; one does not want to have detraining occur from peaking. However, if a taper period is too short, the athlete may not achieved the desired benefits (Hooper et al.). Therefore, it is crucial for an athlete to know the time-frame that is optimal for their taper.

In Mujika et al.'s 1996 study they found that a taper up to 28 days was required to maximally achieve associated benefits of a taper. These results are resonated in a similar study by Thomas et al. (2007). In a study of elite swimmers, Thomas et al. looked to determine the performance responses to taper using computer simulations. As with the study by Mujika et al. the researchers found a statistically significant fit from the predicted performance and the swimmers actual performance, further validating the development of a performance prediction model. However; what is most intriguing about this study is that it examined tapering with and without a prior overreaching period. The authors found that a longer duration taper was required (22.4 days) compared to those who did not perform an overreaching phase prior to tapering (16.4 days) (Thomas et al.). In similar fashion to Mujika et al. (1996) the authors based and defined performance as "the balance between positive and negative responses to training" (Thomas et al., p. 645). In other words, they used adaptation that occurred as a result of training, versus fatigue that occurred as a result of training when attempting to predict performances.

An overreaching phase is a microcycle of training that has high-volume and high-intensity (Hellard et al., 2013). As noted previously, volume and intensity are commonly manipulated variables when creating an annual training plan and taper; generally lower intensity exercise will be prescribed with higher volume in order to achieve the desired training stimulus, while higher intensity exercise will have lower total volume. This is because high-intensity exercise requires much more time to recover from (Laursen & Jenkins, 2002).

Mujika et al. (1996) determined that training has mostly negative effects on performance in the 27 days leading up to competition. This is an interesting approach, as the authors used an overload period of 28 days in their study design before tapering, theoretically producing more fatigue in athletes as they finish the period of overreaching. An overreaching approach before tapering appears to be effective: here, those who implemented an overreaching phase before tapering had a better performance than those who did not (Thomas et al., 2008). Based on these results, it appears that overreaching may be an important ingredient when setting an athlete up for a peak.

Hellard et al. (2013) also employed a model that included an overload period preceding the taper. In this study the authors examine 32 swimmers for up to 9 taper periods. The study was designed so that participants performed a 3 week period of overload training prior to a 3 week taper. Time to exhaustion (blood lactate) was measured after the overload period, and then after the taper. As with other studies, intensity was placed on a scale of 1-5, with 5 representing intensity above the anaerobic threshold. As such, based on training volume and intensity, we can also say that this study utilized an undulated model of volume and intensity distribution. What the authors found was that subjects who reached peak intensity and training volume 6 weeks prior to a competition (but maintained intensity during the overload, followed by a reduction of volume for 2 weeks) had a 1.7% improvement in time-to-exhaustion from the end of the overload period to the end of the taper (Hellard et al.).

In similar fashion to Mujika et al.'s 1996 study, Hellard et al. (2013) determined that an overload period prior to a taper resulted in improved performance. Specifically, reaching peak training load and intensity 6 weeks prior to competition, before beginning to reduce training volume and intensity resulted in the best improvements to performance. There are some important points to note about this study. Because this study took place over multiple seasons and tapers, the authors did not include a pre-test for blood lactate levels, and instead tested them after the overload period and taper period (Hellard et al., 2013). This is curious, as one of the goals of the study was to determine optimal training design during this overload period. As such, it would have been interesting to know the difference between blood lactate and time to exhaustion pre- and post-overload periods. If pre-overload training blood lactate had been measured, we could also measure the performance improvements from this point to the end of the peak, rather than from the end of the overload period to the end of the peak. Theoretically, we would expect to see a dip in performance after the overload phase, followed by an increase in performance from baseline if we apply the principles of periodization (Hellard et al., 2013). Nevertheless, an increase of 1.7% in time to exhaustion from post-overload to end of taper does display the power of super-compensation, one of the touted benefits of tapering.

Unlike the studies by Neary et al. (2003), Houmard et al., (1994), and Shepley (1992), Hellard et al. (2013) examined a 21 day peak, rather than a 7 day peak. While Mujika et al. (1996) and Hellard et al. (2013) note that a longer taper is required when using an overload period prior to tapering, the overall performance results are less than spectacular when compared to studies that examined shorter-term tapers that did not utilize an overload period. In a study by Shepley et al., the authors found an almost 22% improvement in time to exhaustion after only 7 days of tapering.

Shepley et al. (1992) looked to examine the performance and physiological effects of a 7 day high-intensity, low-volume taper; a low-intensity, moderate-volume taper; and a taper that consisted of only rest in long distance runners. This study was a crossover design, whereby each group of 3 completed a taper and then proceeded to training normally for 4 weeks, before completing the other 2 taper models. Therefore, this study did not involve an overload period per se; however, 9 subjects trained with normal training volume and intensity for 8 weeks prior to commencing the first taper and 4 weeks before subsequent tapers. The high-intensity taper group performed 500 m sprint intervals as the primary form of training, with a volume of 5 repeats on day 2, 4 repeats on day 3, and so on, with a rest day on day 6. The low-intensity taper had each athlete running for 10 km at 60% of their VO2 max on day 2, 8 km on day 2, and so on, with a rest day on day 6. The rest-only taper group did no training over the course of the taper. The authors found that while there were no statistically significant improvements in the low-intensity and rest-only taper groups, there was a 22% improvement in time to exhaustion in the high-intensity taper group. All participants' voluntary strength improved significantly when compared with pre-taper values.

This 22% improvement in time to exhaustion is a significant finding, when compared the consistent findings of 1-3% improvement in performance from a taper. This finding also questions the use of a specific overload period prior to the taper, which is common practice amongst swimmers (Hellard et al., 2003). Another consideration in regards to this study is the fact that it was a crossover design; all participants completed each taper protocol, with consistent results between taper protocols and subjects. The high-intensity, low-volume taper resulted in improved performance. The lower intensity taper did not produce any significant improvements (Shepley et al., 1992). What is also intriguing is that the rest-only taper group recorded a decrease of 3% in time to fatigue. Notably, this decrease is not statistically significant (Shepley et al.). This asks us to carefully how long training adaptation can be maintained in athletes. If complete rest for a week does not produce significant decreases in performance, how long can super-compensation during a taper last for?

Psychological Implications

While the physiological results of tapering are the focus of many coaches and athletes, the psychological benefits of a taper are often forgotten. Being a successful athlete requires more than skill, it also requires certain psychological characteristics. Stress levels, arousal, and mood state all play a part in athlete performance (Guttman et al., 1984). However, despite the fact that mood state could play a significant role in a taper, few studies of tapering have examined the psychological effects during and after a taper (Hooper et al., 1998).

One study that did consider athletes' mood states when designing a taper was conducted by Hooper et al. (1998). The authors of this study examined 3 different tapers; an auto-regulated training taper based on the athlete's daily mood state; a reduced training volume group; and a reduced training volume and intensity group. After 2 weeks of tapering, the researchers found no statistical significance in the differences between the 3 tapering techniques. All tapering groups saw an improvement in mood states, and peak tethered swimming force (Hooper et al.).

Before tapering, participants completed 4 weeks of similar training, in an effort to standardize previous training. Additionally, intensity and volume were undulated between workouts and were measured (on a 1-7 scale) during the taper and similar training periods. During the 2 week taper, the reduced training volume group and the reduced training volume and intensity group systematically reduced their daily training volume by 10%. Athletes in the auto-regulated taper group followed the same training protocol as the last week of the 4 weeks preceding the taper, for 2 weeks. Quality of sleep, muscle soreness, and stress were all recorded on a scale of 1-7 by each participant before the morning practice (1 being very good, 7 being very bad) (Hooper et al., 1998). If the participant rated above a 5 in week 1, the second workout of the day was not completed. If a participant rated above a 4 in week 2, again the second workout was not completed for the day. At the end of the study, all taper groups saw an increase in tethered swimming force after 2 weeks; however, after one week of tapering, no improvements in strength or performance were noted. Performance did not significantly change over the course of the 2 week taper; however, all groups saw an improvement in their psychological state (Hooper et al.).

While the performance results of this study are less than spectacular, we can most likely attribute this to taper design and to previous training. Mujika et al. (1996) and Thomas et al. (2007) both found that a taper of between 21-28 days was required to obtain an optimal performance. An implication of these studies is that it may have taken a longer taper duration for Hooper et al. (1998) to measure performance increases. If we compare these findings to the results of Neary et al. (2003), Houmard et al. (1994), and Shepley et al. (1992) found, we would expect to see an improvement in performance after a week when using a step-reduction in training volume, which Hooper et al. (1998) did do. One can speculate about reasons for this; however, the fact that there was only a 10% reduction in in volume per day may not have been enough to allow for the physiological adaptations of a peak, as studies of shorter peaking periods have used a 20% step-reduction.

Regardless of the lack of performance improvements seen in this study, the improvement in mood states across all groups is important. As noted by Guttman et al. (1984), athletes who are successful have lower incidence of mood disturbances (Hooper et al.). Furthermore, increased rates of depression are associated with athlete injury (Vetter & Symonds, 2010). Therefore, even if improved performance is not achieved with a taper, the psychological improvement created by a taper may be beneficial over the long term, as it could possibly reduce the instances of athlete burnout, depression, and overtraining, which could possibly lead to a dropout from sport altogether.

Physiological Implications

While performance metrics are usually considered when studying tapering, measuring changes at the cellular level is not as common. Luden et al. (2010), Farhangimaleki, Zehsaz, & Tiidus (2009), Hellard et al. (2013), Shepley et al. (1992), and Mujika et al. (2000) all measured physiological changes other than VO2 max, including but not limited to blood lactate concentration, red blood cell count, and muscle fibre type. Luden et al. looked to examine several of these factors, including muscle fibre remodelling and size, citrate synthase, and respiratory exchange ratio (RER), in addition to performance measurements. These are important physiological factors to consider, as the distribution of muscle fibre types, and resulting physiological effects can influence force production, athletic ability, and fatigue (Luden et al.). Additionally, RER values can indicate the primary fuel source that is being metabolized by the individual; a long distance endurance athlete would want to be able to oxidize fat, rather than carbohydrates thus making RER an important measurement when tapering (Reitjens et al., 2001). Muscle fibre adaptation, improved blood lactate levels, and increased red blood cell count have all been found to improve in these studies, possibly presenting a cause for the improvements that are observed during tapers.

In Luden et al.'s 2010 study, the authors looked at the effects of a 3 week taper on competitive runners, including physiological and performance changes. What they found was a 3% improvement in race performance after a 3 week taper that significantly reduced moderate-intensity training volume. Perhaps more interesting was the observation that Type IIa muscle fibre diameter in the gastrocnemius increased by 7%, along with peak force (11%) and absolute power (11%); however, RER and the aerobic enzyme citrate synthase did not increase (Luden et al.). Additionally, VO2 max levels were similar between pre- and post-taper (Luden et al.).

The results of this study are in line with previous studies that found a 3% improvement in performance following a taper (Houmard et al., 1994; Mujika et al., 1996). While these studies examined shorter term tapering periods, the study by

Luden et al. (2010) left the training up to the coaches using the authors' recommendations. This complicates any attempt to compare the design of the taper protocols in terms of performance improvements. A strong point of this study is that one of its performance measures was an actual cross-country competition, rather than a simulated track run, as most studies that have examined tapering in runners have used (Mujika et al., 2000; Houmard et al., 1994; Shepley et al., 1992). Thus, we can see application to real world competition. Additionally, this study supports the notion presented by Houmard et al. (1994) that the benefits of a taper are related to an increase in force and power, rather than an increase in aerobic fitness.

Support for physiological changes being behind the benefits of a taper can also be found in a study by Farhangimaleki et al. (2009), where systemic inflammation was measured after 1 and 3 weeks of tapering. The authors found that while performance did increase without reducing inflammation, after a one week taper, inflammation was reduced and performance improved after a 3 week taper. This supports the notion put forth by Mujika et al. (1996) that training too close to a competition produces more negative adaptations (such as fatigue accumulation that could affect performance. Exercise is a stress applied to the body and will result in short term inflammatory response as part of the recovery process and can affect training (Farhangimaleki et al.; Bruun et al., 2006). This should be a concern, especially in those athletes who train multiple times per day, as it may have an accumulation effect potentially creating chronic inflammation, fatigue, and poor performance. Because high level athletes will have a large training stress, it is logical to assume that this stress will produce inflammation that could negatively influence their performance, making reduction of inflammation a key component and benefit of the taper.

Conclusion

The idea that tapering can improve performance is found consistently throughout the literature; however, the extent to which it improves performance seems to vary. A 2-8% increase in performance appears to be the generally accepted range of performance improvement in endurance athletes. However, it is not surprising that there are large differences between studies that have come to this conclusion, with some showing no performance improvements, and others showing up to a 22% improvement in performance (Mujika et al., 2000; Shepley et al., 1992). This is due at least in part to to the extreme diversity of study designs and the number of variables that have to be accounted for. Some studies have found success with up to 3 weeks of tapering (Mujika et al., 1996); other studies have found similar success with only one week of training (Neary et al., 2003). Additionally, these studies have examined swimmers, cyclists, and runners. There may or may not be carry-over from sport to sport.

Study design varies considerably in tapering research due to the innumerable training variables that can be accounted for and so, it is difficult to compare results directly from one study to another. Future researchers should endeavour to more closely model past studies in an effort to confirm their results and real world applications.

Based on the studies examined, we can provide a very broad prescription for tapering; however, individualization and schedule of competitions may be the most important factors. Based on this review, it appears that maintenance of training intensity, while gradually reducing training volume in a step or undulated fashion will produce the desired effects of a taper; however, this approach is not the be all to end all, nor are these the only training factors that matter. Frequency of training, stress, base training, intensity, and volume will all have a role when designing a taper in an athlete's training. It also appears that an athlete can taper for up to 4 weeks and still see similar performance improvements without detraining. Sometimes a 4 week taper is not always a viable option due to competition scheduling, so taper length should then be based on the annual training plan. Even if a 4 week taper is not required to achieve peak performance, athletes should consider longer peaks for other factors, including psychological well-being and injury prevention.

At the end of the day, endurance athletes should utilize a method that they have found works for them; if a certain protocol does not work they should also be open to refining their methods and experimenting with different protocols when necessary. A taper that worked for one competition may not be appropriate for the next due to a change in training status, available time, or injury. As such, recording as many variables as possible in a training journal may help to determine what methods of tapering are most appropriate given each set of individual circumstances. Tapering should be approached as a growing and evolving phase of an athlete's training plan, and may not remain static throughout their career. Therefore, all taper designs may be strategic, so long as they fit into the basic framework of a reduction in volume, and a maintenance of (or slight reduction in) intensity.

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