A Scientific Application of Tapering to Maximize Performance for the Elite Athlete Part I

Researched and Composed by Jacob Wilson, BSc. (Hons), MSc. CSCS and Gabriel "Venom" Wilson (Hons), CSCS

Abstract

Adaptation can be viewed as a constant flux of growth and decay and further growth of the combination of two intervening factors on performance. Banister et al. (1975) denotes these variables as fitness and fatigue, while performance is seen as the difference between the two. The fitness and fatigue theory of human performance is the current dominant theory of how organisms adapt to various training stimuli. In this context, a comprehensive examination of the theory, and its application to performance will be reviewed. Special emphasis will be placed on the taper. The taper is a concept in which an individual reduces total training load in order to maximize performance.

Introduction

In the now infamous documentary on the 1975 Mr. Olympia contest, the champion Arnold Schwarzenegger turned to Lou Ferrigno and expressed that he did not get his timing right. Ferrigno was defeated by those words both mentally, and finally physically only hours latter. Schwarzenegger encapsulated the 'temporal' or timing element of bodybuilding. This aspect is not only a part of this sport, but of all sports. The athlete strives continually, day after day to achieve peak performance. When viewed from an annual standpoint, Fitz-Clarke, Morton, and Banister (1991) explain that the athlete can only peak once a year. Zatsiorsky (1995) describes the performance of a team of athletes as the 'Efficacy coefficient.' The Efficacy coefficient is determined by the following equation.

> Number of athletes who achieved their best performances during most important competition of the season / Total number of athletes on the team

In order to reach peak performance athletes typically go through realization, regeneration, peak, or transformation cycles (Zatsiorsky, 1995, Pedmonte, 1982, Haff, 1994, Gambetta, 1992). A realization cycle is a period of time in which training load is reduced to increase performance (Banister, 1999, Gilbala, 1994, Houmard, 1994, Johns, 1992). This process is known as tapering. The taper itself has its roots in Hull's (1943) mathematical equation of human performance (See Wilson, 2005 for a review). Wilson (2005) provided the following overview of Hull's contribution:

> Hull was the first to examine the effect of massed practice on performance. Massed practice can be defined as practice in which work is longer than rest periods (Schmidt, 1999). In weight training this would entail 1 minute sets, with only 30 seconds of rest between sets. Several reviews on the subject (Lee and Genovese, 1988, McGeoch and Irion, and Bilodeau and Bilodeau, 1961) provide support for what is known as Hull's 8th postulate. Hergenhahn and Olson (2004) summarize the 8th postulate as follows:
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> 'Responding Causes Fatigue, which operates against the elicitation of a conditioned response.' This is known as reactive inhibition. Reactive inhibition entails the organism reacting to inhibit the action which caused fatigue. Bourne and Archer (1956) had 5 groups perform a tracking task with 0, 15, 30, 45, and 60 seconds of rest. It was found that as rest decreased, performance decreased. Of particular interest is that performance was severely depressed in the zero second condition; however, after a day of rest, performance had risen drastically from the end of the last trial.
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> The effect of improving in the absence of practice is known as reminiscence (Hergenhahn and Olson, 2004). This effect denoted by Hull provides the current basis for tapering. According to Hull (1943) reactive inhibition was masking the positive effects of practice, and a period of rest was needed to dissipate this effect. Today, the taper is defined as a period of rest, or lowered training load prior to competition meant to enhance performance.

Building on the work of Hull (1943), Banister et al. (1975) provided a two factor mathematical theory on human performance. This theory views the human as a reactive system which integrates a single input termed training impulse (TRIMP) and from this produces a single output known as performance (Busso et al., 1997). The model proposed that the system contained two controls or filters known as first order transfer functions. These two filters were denoted fitness and fatigue (Banister et al., 1975, Banister et al., 1985, Banister, 1991, Busso et al., 1991, Morton et al., 1990). The fitness represented the positive benefits induced by the training impulse, while the fatigue represented the negative effects of training. Performance was suggested to be a second order transfer function, and could be calculated by the difference between Fitness and Fatigue:

Performance = Fitness – Fatigue

The fitness fatigue model is based on the principle of parsimony. The principle of parsimony states that given two models with equal predictive value, the more simplistic of the two should be utilized. Banister (1991) explains: " To be effective the conjecture must be simple yet elegant. The criterion used in modeling behavior of even complex systems in engineering is to invoke as few elements (black box unknowns) as possible. These elements interact, enabling one to explain the dynamic working behavior of the system. Parsimony is achieved in the process of modeling and predicting the results by allowing only two elements to contribute to performance, each element being precisely specific and derived from a single quantitative measurement of training contained in the training impulse score."

Training Impulse (w(t))

The main goal of the two factor theory is to predict human performance in a dose dependent fashion. While 30 years of modeling modifications have been made (Mujika, 2002) the gross equation for training impulse (TRIMP) is as follows

TRIMP = Training Intensity * Duration

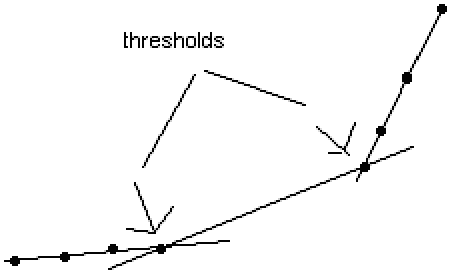
Banister et al. (1975) proposed that heart rate was the most stable reflection of intensity, as a participant training at the same rate along the same route has a remarkably consistent heart rate (Banister, 1991). The amplitude or intensity was then multiplied by the duration in minutes that the activity occurred. The exact equation is as follows

TRIMP = Duration * (Heart Rate exercise – heart rate rest) / (Heart rate maximum – heart rate rest)

Note that the equation only includes beats above that which occur during rest. Therefore, it takes into account only the extra beats needed to perform exercise, not the beats needed to maintain a resting energy output. Heart Rate exercise – Heart Rate Rest is known as 'Span Heart Rate' while Heart rate maximum (found by subtracting the participants age from 220) – Heart rate rest is known as Delta Heart Rate(Banister, 1991). In abbreviated terms the equation can be written as follows

w(t) = Tim(min) * Delta Heart Rate Ratio

Another factor to take into account is that the intensity of an exercise bout does not produce linear changes in the human body. Linear simply means that as intensity increases the body is stressed in a uniform manner. That is, for every point that intensity increases, the stress placed on the body increases by one point. This does not occur. To show this, Mortin et al. (1990) used work done on the lactate response curve by Green et al. (1983) to weight intensity. The work done by Green et al.(1983) found that lactate rises with two break points or sharp rises in which lactic acid accumulates in an exponential fashion to intensity. These breakpoints are known as lactate threshold 1 and 2.



In this context, it would be misleading to treat intensity increases as affecting the system in a uniform manner. Instead, a weighting factor was calculated which increased according to the lactic acid curve. This way, higher intensities would yield larger than linear increases in the training dose. The same effect of intensity on lactic acid can be found in numerous hormonal increases during exercise (King, 2003, Wilson, 2004, Wilson and Wilson, 2005, a, b, c, d)

Other training doses have also been calculated. For example Mujika et al. (1996a) used lactic acid build up to denote intensity. They formulated five different intensities based on lactic acid concentration in the body. And each intensity was weighted higher than the previous intensity.

The training dose is calculated for each variation within a training session, and then summed to yield the total dose for that session (Banister, 1991). For example, if a participant is interval training on the treadmill they may begin with a 10 minute warm up at 120 beats per minute, followed by 10 minutes at 140 beats, followed by 10 at 160 beats. The TRIMP would be calculated for each interval and then added together. Likewise consecutive training days could be added in this fashion.

Utilizing The Training Dose To Predict Performance

Once the training impulse, denoted w(t) has been calculated, the fitness impulse denoted p(t) and the fatigue impulse denoted f(t) can be calculated. On the basis of numerous studies the model predicts that the amplitude is approximately twice as high for the fatigue impulse than the fitness impulse (Banister, 1991, Fitz-Clarke, 1991, Mujika, 1996, Zatsiorsky, 1995). Therefore calculations are as follows:

$p(t) = K1w(t)$ and $f(t) = K2w(t)$

The equation states that the effect of the fitness impulse p(t) is found by multiplying the training dose w(t) by a weighting factor denoted K1, where K1 is equal to 1. Therefore if the training dose is 1 unit then p(t) would also equal 1. However, fatigue is multiplied or weighted by K2, which is equal to 2, suggesting that the fatigue impulse is twice the fitness impulse. This would explain why after a training session that performance drops off to such a notable extent, as the fatigue produced by the training dose is at a much higher amplitude then the fitness produced.

Before continuing, recall Hull’s (1943) work on reactive inhibition. He noted participants performance decreased during massed practice. However, after a period of rest, in the absence of practice their performance had increased (reminiscence). He postulated that the rest allowed the participant to dissipate the reactive inhibition, while maintaining positive gains. From this it can be deduced that fitness, though at a lower amplitude then fatigue, has a more stable decay constant. Banister (1991) and Fitz-Clarke et al. (1991) from numerous studies, including fitness fatigue models on strength athletes (Busso et al., 1990) have calculated the average decay constant for fitness to be 45 days, while the fatigue decay constant on average was 15 days. The decay constant denotes the time it takes for a value to decrease by 37 %. Therefore, it is predicted that a period of rest (taper) takes advantage of a rapidly decaying fatigue impulse to unmask the underlying fitness component. In this context, adaptation is said to be viewed as a constant flux of growth and decay and further growth of the combination of two intervening factors on performance.

Such a process also explains a phenomenon known as delayed transformation of gains (Hartmann, 1989, Plisk et al., 2003, Verkhoshansky, 1986, 1988, Zatsiorsky, 1995). In this context, an athlete may reach a plateau and increase work load, which leads to a further increase in gains. Once a plateau is hit, workload is increased again, but gains do not follow. The athlete then decreases workload, to take advantage of the decay of fatigue to reveal the gains that were masked (delayed transformation of gains).

Models Prediction on Duration of the Taper

The taper is based on two further functions predicted by the model. The first is defined as tn, which is the critical time before a competition in which training can contribute positively to performance at a specific date (Mujika et al., 1996, Fitz-Clark et al., 1991). Given the decay constants of 15 and 45 days for fatigue and fitness, Fitz-Clarke (1991) calculated tn or the threshold for training benefits to be 16 +/-6 days. The second function is denoted tg and is defined as ‘the time before competition necessary to reach a maximal benefit from training (Mujika et al., 1996).’ Given the same constants, FItz-Clarke et al. (1991) calculated tg to be 40 +/- 8 days. In this context, the taper should occur between the time when training results in maximal performance (tg) and the time when training contributes negatively to performance tn. Fitz-Clark et al. found this to be between 16 +/- 6 and 40 +/-8 days.

The Models Predictive Value and Optimal Duration for Tapering

Ultimately the numbers for decay constants, and amplitudes of first order functions have been derived from numerous studies (Banister, 1991, Fitz-Clark, 1991). However, authors of the models also explain that their predictive value must take into account each athlete individually (Banister, 1991, Mujika et al., 1996). For this to occur, each athletes’ training impulse and predicted performance values are typically plotted against actual performance (Banister, 1991, Mujika et al., 1996). When done this way, decay constants can be adjusted to the actual individual. Mujika et al. (1996) investigated a predictive model on swim performance in elite swimmers based on a modified version of the Banister (1975) model and found that predicted values could account for up to 85 % of performance. When plotting actual values, they found that the mean or average decay constant for fitness was 40 days, which is very close to the predicted 45 day value, and that the fatigue decay constant was 12 days on average, again close to the 15 day predicted value in the Fitz-Clark (1991) and Banister (1991) studies. Further these investigators found tn and tg, to be between 12 ± 6 and 32 ± 12 d for the group of swimmers. Again this is close to the predicted values in the Fitz-Clarke (1991) study, as well others (Johns et al., 1992, Banister et al., 1985, Calvert et al., 1976, Morton et al., 1990) .

The investigators also examined the effects of three tapers utilized by the swimmers during the season. The first lasted for 14 days, the second for 21 days, and the third for 41 days. The athletes increased performance by 3 percent in both the 14 and 21 day tapers, but did not get significant increases in the 41 day taper. In another study, Martin et al. (1994) had participants perform 6 weeks of high intensity aerobic training, followed by a 14 day taper. It was found that cycling performance increased by 8% and QUAD strength increased by 8-9%. In another study, Zarkadas et al. (1995) investigated the effect of a 10 day and 13 day taper interspersed between 3 months of intense training in triathletes. In the 10 day taper, a 4% improvement was found in their 5 km criterion run and a 6 % increase In the 13 day taper. The greater results in the 13 day taper may reflect a longer time period to dissipate the fatiguing impulse. Mujika et al. (1996b) investigated the effect of a 28 day taper following 12 weeks of intense training in elite swimmers. It was found that performance decreased slightly during the most intense aspect of the 12 weeks by .5 %, but increased by nearly 2.5 % during the taper. Trappe et al. (2000) and Trappe et al. (2001) found that 21 day tapers in elite swimmers elicited an increase in power, swim performance, and muscular size. In another study, participants were placed on an elbow flexor strength training program for three weeks followed by a 10 day taper. It was found that maximum voluntary contraction increased significantly in all participants (Gibala, 1994).

From the above data, it can be seen that significant increases in performance ranged from 10 – 28 day tapers. However, the range has extended even further with increases seen from 10-35 days in swimmers (Mujika et al., 2003) and as low as six to seven in runners (Mujika et al., 2000, MUjaka et al., 2002, Shepley et al., 1992). These data roughly fall within the ranges found in the Mujika (1996) study in which the optimal taper ranged from 12-32 days, as well as the estimates by Fitz-Clark (1991) who found the optimal tapers to be between 16 +/- 6 and 40 +/- 8 days.

Current evidence suggests that the optimal taper duration be decided based on past training length and intensity (Kubukeli et al. 2002, Zatsiorsky, 1995). While the exact duration of taper which elicits a detraining effect is not precisely known (Mujaki, 2000), Kubukely et al. (2002) suggests that both intensity and duration of previous training effect the time needed to dissipate fatigue. These investigators suggest a minimum of a 2 week taper for extremely hard and long previous training, with lower periods (i.e. 6-10 days) for lower volume, and duration training phases. Similarly, Zatsiorsky (1995) suggests that tapers should last for 4 +/- 2 weeks, with training phases containing numerous shock cycles on the upper end, and lower volume moderate training phases on the lower end.

A Clearer Look at Fitness and Fatigue

In the Mujika (1996) study on elite swimmers, both the 14 and 21 day tapers produced a 3 % increase in performance. Fitness in this study was denoted PI and summated all factors contributing to increased performance, where as fatigue denoted NI was a summation of all factors contributing to decreased performance. Statistical analysis among first order functions found a significant decrease in NI during the first two tapers, with no significant increase or decrease in PI. This again supports the Hull (1943) reactive inhibition, and Banister (1975) two factor theory.

Fitness and fatigue in modeled studies are examined on various parameters, such as hormonal concentrations (Busso et al., 1990, Busso et al., 1992). One of the major determinants used is the testosterone to cortisol ratio (Adlercreutz et al., 1986, Stone et al., 1991). A decrease in the testosterone to cortisol ratio is associated with fatigue, while an increase is associated with fitness (Fry et al. 2000). Therefore, an increase in performance can occur with an increase in testosterone (fitness) or a decrease in cortisol (dissipation of fatigue) levels (Busso et al., 1992, Mujika et al., 1996, Mujika et al. 1996b). Briefly, testosterone is associated with anabolism, while cortisol is associated with catabolism (King 2002, Wilson and Wilson 2005). In this context, Busso et al. (1992) modeled the performance of elite weight lifters during a four week intense training phase, followed by a two week taper. During the four week intense training program testosterone levels decreased, and this was significantly correlated with fatigue. However, lutinzing hormone concentrations also increased and were significantly correlated with increases in fitness (r = .9, meaning that 81 % of the increase in lutinzing hormone was in common with predicted increases in fitness). During the two week taper, testosterone levels increased along with increased performance, and this was highly correlated (r = .97) with the increased lutinzing hormone concentration seen in the four week period. Again, this lends support to the two factor theory. King (2003) explains that lutinzing hormone stimulates an increase in testosterone levels. In another investigation Hakkinen et al. (1987) found significant increases in cortisol during a 4 week intensive training cycle with a concomitant decrease in the testosterone/cortisol ratio. However, after a two week taper cortisol levels decreased (fatigue was dissipated) which increased the testosterone / cortisol ratio. Similarly Mujika et al. (1996b) investigated the testosterone / cortisol ratio during 12 weeks of intense training and 4 weeks of tapering in elite swimmers. Performance slightly decreased during the 12 weeks and this was significantly correlated to a decrease in the testosterone / cortisol ratio, while performance increased during the taper, and was correlated with an increase in the testosterone / cortisol ratio.

Wilson (2003) in his investigation into precompetition carbohydrate depleting and replenishing strategies also provided support for the fitness and fatigue model. To summarize his research, 6 days before a contest bodybuilders deplete glycogen stores through high volume training and low carbohydrate diets. During this phase glycogen is depleted and this represents fatigue. However, simultaneously an enzyme known as glycogen synthase which is responsible for glycogen formation increases in activity. Following the 3 days of depletion, training is lowered and carbohydrates are increased. During this time glycogen is replenished rapidly to the point where it reached pre depletion stages. This represents a dissipation of fatigue; however, the fitness gain remains longer (its decay constant is slower) as glycogen synthase activity is still high, leading to 3-5 times the original levels of muscle glycogen saturation.

Summary

Banister et al. (1975) suggested that an organism should be viewed as a system which receives input in the form of training, and produces output in the form of performance. The model suggests that the duration and intensity of training, termed training impulse, effects the system by causing a fatiguing and fitness effect. In this context, performance is calculated by subtracting the negative fatiguing impulse from the positive fitness impulse.

Generally fatigue is thought to have a two fold higher initial amplitude or effect on the organism than fitness. However, the positive fitness adaptations obtained from the training impulse last three times longer than the fatigue. Tapering protocols are implemented to take advantage of the differences in these decay constants. Because fatigue dissipates faster than fitness, a relatively short period of lowered volume in training can remove the fatigue, while maintaining positive adaptations.

Jacob Wilson
President Abcbodybuilding / The Journal of HYPERplasia Research

jwilson@abcbodybuilding.com

Gabriel “Venom” Wilson
Executive of Bioenergetic Research
Venom@abcbodybuilding.com

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