Monitoring the training effect in different periods in elite athletes

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Abstract

Performance of elite athletes depends on their technical, physiological and psychological abilities. Different sports require various levels of aerobic, anaerobic, speed, power, agility, and strength capacities. Elite athletes and athletes who aim to become elite usually train year-round with carefully designed training programs. The close monitoring of physical capacities during the entire training period is essential for elite athletes to investigate the effect of the training program and determine if the recovery is sufficient. This study summarized the changes in aerobic and anaerobic capacity in different training periods in athletes of various sports. In addition to fitness tests, testosterone-to-cortisol ratio may be a useful indicator for the balance between anabolic and catabolic states. Testosterone-to-cortisol ratio may be measured in different training periods to estimate the degree of recovery.

Key words: training, taper, detraining, testosterone, cortisol

Introduction

Performance of elite athletes depends on their technical, physiological and psychological abilities. Different sports require various levels of aerobic, anaerobic, speed, power, agility, and strength capacities. Elite athletes and athletes who aim to become elite usually train year-round with carefully designed training programs. Competition naturally provides the best test for athletes. However, it is difficult to isolate various components of performance during competitions. In addition, the modification of training program may be required prior to the competitions according to athletes' current physical status in order to reach the best performance in the upcoming competition. Furthermore, the long-term high-intensity training may result in insufficient recovery, which may lead to chronic fatigue, staleness of performance, and even overtraining. Therefore, the close monitoring of physical capacities during the entire training period is essential for elite athletes for the following reasons [1]:

1. To study the effect of a training program.
2. To motivate the athletes to train more.
3. To give an athlete objective feedback.
4. To make an athlete more aware of the aims of the training.
5. To evaluate whether an athlete is ready to compete.
6. To determine the performance level of an athletes during a rehabilitation period.
7. To plan short-and long-term training programs.
8. To identify the weakness of an athlete.
9. To determine if the recovery is sufficient.

To obtain useful information from a test, it is essential that the test is relevant and resembles the conditions of the sport.

Changes in aerobic fitness in different training periods

It has been well-documented that in untrained or recreationally-trained subjects, aerobic training programs with sufficient intensity, duration, and length will increase VO2max by approximately 10-20% [2-5].

However, athletes with adequately developed aerobic capacities generally showed no change in VO2max after training programs or competitive seasons. Research in athletes in 'technical' sports in which performance is principally determined by skill, have suggested either reduced or unchanged aerobic fitness following training and competition seasons. VO2max was significantly lower after the competitive season in international-level male alpine skiers [6] and epee fencers [7]. Collegiate male ice hockey players showed no change in VO2max before and after the season which involved 2 games and 2 practice per week [8]. Similarly, collegiate female volleyball players did not show significant change in VO2max after a 21-week competitive season [9]. Elite players of the ball-game bandy showed no change in VO2max after a competitive season [10]. Elite junior female and male speed skaters also showed similar VO2max levels before, during, and

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after a competitive season [11]. These athletes had undergone intensive training for a long period of time and developed relative high levels of aerobic fitness that are suitable for their respective sports. It is possible that these athletes may have already reached their genetic potential in aerobic fitness. In addition, these athletes in 'technical' sports may spend considerable training time and effort on specialized techniques, thus reduce the amount of training on cardiovascular capacity. Therefore, they may maintain rather than change their aerobic fitness over year-round training and competition.

On the other hand, elite athletes participating in physically demanding sports have demonstrated different trends with unchanged or increased levels of VO2max have been reported during and after competitive seasons. Relative VO2max in International-level male middle and long distance runners showed progressive increase during the season and a reduction during the off-season [12]. Approximately 20% increase in VO2max was reported in Olympic oarsmen during in-season compared to off-season [13]. Elite road cyclists showed significant increase in VO2max after 3 months of pre-Olympic training [14]. VO2max was also significantly increased after a 5-month competitive season in elite varsity wrestlers [15]. On the contrary, elite professional cyclists showed no change in VO2max after 5 months of intensive training with more than 15000 km of training and competition despite significant increase in muscle oxidative enzyme activities [16]. These elite athletes had relatively high levels of aerobic capacity before entering their specialized training program. Therefore, it is possible that properly designed training program can still improve aerobic capacity even in elite endurance athletes.

Changes in anaerobic fitness in different training periods

Elite female rowers showed a gradual increase in maximal power measured by a 2-min all-out rowing test over a 9-month pre-Olympic training [17]. Elite male high jumpers also showed the highest vertical jump height during the competitive seasons compared to other period of the year [18]. In addition, male elite sprint cyclists showed increased anaerobic index and acceleratory power in repeated interval sprints [19].

On the other hand, it has been shown that anaerobic power and capacity, measured by a 30 sec jumping test and maximal vertical jumping heights were decreased during a competitive season in female volleyball players, even with 4-5 weekly sessions for playing drill and competitions and 2-3 weekly sessions for conditioning [9]. The results of 30-sec Wingate test did not change at the before, during, and after a competition season in male elite skiers [6] and fencers [7]. Lack of seasonal variations in anaerobic power measured by vertical jumping and power output on a cycloergometer was also reported in male elite road-race cyclists [14]. In-season testing also demonstrated significantly lower peak torques for both dominant and non-dominant knee extensors compared with off-season assessments at all velocities [7]. Furthermore, concentric and eccentric quadriceps and hamstring torques were decreased after the season in male ice hockey players [8].

Influence of taper on the performance in elite athletes

Taper is defined as 'a progressive nonlinear 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' [20]. To reach the optimal sport performance at the right time, such as major competitions, requires the development of a closely controlled training program. Intensive training elicits adaptation responses that lead to improvement in performance. However, intensive training also results in fatigue that may limit the performance capacity. The purpose of taper is to maintain the physiological gains during the intensive training period while completely recover from the negative effects of the training [21]. The taper is crucial to athletic performance and the results of competitions. The improvements in muscular force and power, hormonal levels, neuromuscular functions, and psychological status could range from 0.5 to 6.0% after a successful taper in well-trained athletes [22]. A 2.2% improvement in swimming performance during the final 3 week of training leading to the Sydney 2000 Olympics was observed in all events by athletes from different countries and performance levels [23].

The marked reduction in training load during the tapering period should not be detrimental to training-induced adaptations. An insufficient training load during taper could result in detraining and therefore the loss of training effect. Thus, it is crucial to determine the training intensity, volume, and frequency during the tapering period to reduce fatigue and maintain training effect for optimal performance. It has been shown that high-intensity low-volume taper resulted in favorable changes in muscle glycogen, metabolic enzymes, hormones, muscle strength, and running time to fatigue in highly trained athletes [24-26]. Reductions in training volume by 50-90% during the taper have been shown to improve or maintain performance in well-trained athletes in swimming [27-29], cycling [30], triathlon [31, 32], endurance running [33, 34], and strength training [35]. It has been revealed that a reduction in training frequency by 50% during 2-4 weeks of taper could maintain or improve performance in well-trained cyclists [30, 36], swimmers [27], and endurance runners [37]. However, although training-induced adaptations could be maintained during taper at 50% reduction in training frequency, the more'technique-dependent' sports such as swimming may require less than 20% reduction in training frequency to prevent possible 'loss of feel' [23]. The duration of taper varied significantly among literatures, ranging from 4-14 days in cyclists and triathletes, a week in competitive runners, 10 days in strength athletes, and 10-35 days in swimmers [22, 38]. It appears that training volume and frequency can be reduced to a higher extent than training intensity, if detraining is to be avoided. It has also been suggested that a fast exponential decay of training volume (low-volume) may be the most appropriate method in taper [22, 31, 32].

Despite plenty of studies on various sports, the optimal taper program has not been clearly established, especially in team and strength sports. It is very likely that intensity, volume, and frequency of successful taper programs would be specific to sports, previous training programs, and initial fitness and performance levels of the athletes. Therefore, close monitoring of entire training period is essential to establish the optimal taper strategy for specific athletes in specific sports.

Detraining effect

Detraining, a period of insufficient or terminated stimulus, can lead to significant loss of adaptations obtained from previous training. Reactive hyperemic blood flow, a substantial increase in blood flow in response to relief of ischemia or an exercise stimulus, in arm and leg artery decreased after several weeks of bed rest and limb immobilization [39, 40]. Reactive hyperemic blood flow is a marker for the vasodilator capacity of the resistance vascular bed and can be used to evaluate structural changes in the circulation [41]. Nitric oxide (NO) is a crucial factor of endothelium function and responsible for flow-mediated vasodilation during exercise. Surprisingly, flow-mediated dilation was enhanced after several weeks of inactivity. It is possible that the chronically increased levels of basal shear stress in deconditioned vessels may lead to an upregulation of endothelial nitric oxide synthase (eNOS) expression and activity [42]. Thus, NO production and responsiveness to a stimulus was increased. Three months of endurance training could increase femoral artery diameter by approximately 10%, while endurance athletes showed approximately 30% increase, compared to sedentary controls. On the other hand, 1 week of immobilization resulted in approximately 10% decrease, while 52 days of complete bed rest resulted in approximately 20% decrease in femoral artery diameter, compared to sedentary controls [41]. In sedentary healthy subjects, inactivity within 3-8 weeks could result in a significant loss of vascular dimension and increase in flow-mediated vasodilation [41].

In well-trained athletes, short term detraining of less than 4 weeks could result in a rapid decline in VO2max and blood volume. Stroke volume and maximal cardiac output were also reduced while the increased heart rate at the same work load could not compensate for the losses. The loss ranging between 4-14% in VO2max has been reported in highly trained athletes with excellent aerobic power [43-45]. In recently-trained subjects, a reduction of 3.6-6% in VO2max has been shown after 2-4 weeks of cessation of training [46, 47]. The loss in blood volume was the most important factor responsible for the decline in VO2max after short term detraining. Total blood and plasma volume have been shown to reduce by 5-12% in endurance athletes after 1-4 weeks of detraining [43, 48]. Decline in plasma volume in the first 2 days of inactivity was also reported [49]. Approximately 5-10% increase in exercise heart rate at submaximal and maximal intensities has been revealed after short term detraining [43, 48, 50]. Reductions of 10-17% in stroke volume and 8% in cardiac output have been reported after short term training cessation [44, 51]. These losses in cardiovascular functions caused detrimental effects on endurance performance in highly trained athletes. Reductions of 4-25% of time to exhaustion in endurance athletes have also been revealed [43, 48, 52].

An increased respiratory exchange ratio at submaximal [50, 51] and maximal [43] exercise intensities have been shown after short term detraining, indicating a shift towards higher reliance on carbohydrate as energy source during exercise. Detraining resulted in a decrease in insulin-mediated glucose uptake, possibly due to a reduction of 17-33% in muscle GLUT-4 protein level [53, 54]. Muscle glycogen content decreased by approximately 20% even after 1week of detraining [54], partially resulted from 42% decrease in glycogen synthase activity [55]. Oxidative enzyme activities and oxidative capacity were decreased [50, 56], while glycolytic enzyme activities were increased [56] in skeletal muscle after short term detraining.

Loss in muscular force and power in strength-trained athletes was less significant. Muscular strength measured by free weight did not change, while EMG activity and isokinetic eccentric knee extension force were decreased in power athletes after 2 weeks of training cessation [57]. Trained swimmers maintained muscular strength but showed a 13.6% decrease in swim power after 4 weeks of detraining [58].

Cortisol and growth hormone level did not change after 5 days of detraining in endurance athletes [59]. However, strength athletes showed an anabolic trend of hormonal change as growth hormone, testosterone, and testosterone/cortisol ratio were increased after 14 days of detraining [57].

Exercise-induced changes in hormones

Testosterone has been viewed as anabolic indicator as it can stimulate glycogen storage and muscular protein synthesis. On the other hand, cotisol has been used as an indicator of catabolic state for its role in gluconeogenesis via the proteolytic pathway [60-62]. An equilibrium between anabolic and catabolic states in athletes is often represented by the ratio of these two hormones, the testosterone-to-cortisol ratio (T/C) [63-66]. T/C has been suggested as a potential marker for insufficient recovery and overtraining syndrome in athletes as it was decreased after intensive endurance exercise [67, 68] and chronic high volumes of endurance training [65, 69-71]. Our previous study has also shown that T/C ratio was decreased after a triathlon [72]. Most studies showed 1.5- to 5-fold of increase in cortisol after intensive endurance exercise, resulting in significantly lower T/C [73-76]. It appeared that T/C ratio decreased only after relatively intensive endurance exercise, as 2 hours of rowing at approximately 75% of anaerobic threshold did not result in significant change in serum T/C ratio [62]. The mechanisms of the decreased testosterone levels may include decreased gonadotropin-releasing hormone secretion by hypothalamus [77], enhanced prolactin and inhibited luteinizing hormone (LH) releases by pituitary [78], and/or direct inhibition by cortisol [79]. Recently, it has been suggested that dehydroepiandrosterone (DHEA)-to-cortisol ratio (DHEA/C) may also serve as a marker for the anabolism and catabolism balance [80, 81].

Previous researches have been inconsistent with the acute response of testosterone after intensive endurance exercise. It has been shown that testosterone increased after a marathon [73, 75], possibly due to the increased gonadotropin-independent testicular production [82] or reduced rate of clearance from plasma [83]. Other investigators have reported no change [74, 84] or decrease [76, 85] immediately after intensive endurance exercise.

Similar to testosterone, a single bout of endurance exercise resulted an increase in DHEA and DHEAS in both men and women. Surprisingly, DHEAS levels could remain elevated for hours or even days after an intensive bout of endurance exercise [86, 87]. Therefore, some investigators suggested that DHEAS concentrations could be an indicator of stress level, similar to cortisol [80].

Acute resistance exercise with sufficient intensity and volume has been shown to produce substantial elevations in testosterone levels [88]. The magnitude of increase depends on the exercise intensity and numbers of sets and repetitions [89-92].

Changes in resting testosterone concentrations during long-term resistance training have been inconsistent or non-existent in men and women [88]. Some studies have reported increases in resting testosterone concentrations during or after long-term resistance training [93, 94], while others have shown no change [95, 96] or even decrease [97]. It appears that the resting testosterone levels are influenced by the current state of training. Substantial changes in training volume and intensity may elicit transient changes in resting testosterone levels. These values may return to baseline when the individuals return to their normal training [88].

Most studies showed 1.5- to 5-fold of increase in cortisol after intensive endurance exercise [73-76]. It has also been revealed that cortisol levels increased substantially after an acute bout of resistance exercise [93, 97, 98]. Significant positive correlations between blood lactate and cortisol levels have been reported after resistance exercise [99, 100]. The protocols high in volume with moderate to high intensity with short rest periods have elicited the greatest acute lactate and cortisol response [101, 102].

Resting cortisol levels generally reflect a long-term training stress. Results on resting cortisol levels during chronic resistance training have been equivocal, as no change [97, 103], reductions [96, 104], and elevations [105] have been reported.

It has been demonstrated that salivary testosterone and cortisol was a better measure of the biologically active fractions of these hormones than those obtained from serum [106]. In addition, salivary testosterone revealed the decline in testicular function associated with aging [107, 108]. Only the free fraction of these hormones in plasma can move across cell membranes and elicit biological responses. More than 95% of the testosterone in plasma is bound to sex-hormone binding globulin and albumin [109], while approximately 80% of the plasma cortisol is bound to corticosteroid binding globulin and albumin [110]. Furthermore, saliva collection is fast, noninvasive, and may reduce the stress response of cortisol during the sampling process. Thus, monitoring changes in saliva has been successfully used in investigating the responses of testosterone and cortisol during various competition and training periods [60, 73, 111, 112].

Conclusion

The suitable physiological and biochemical tests of various training periods are necessary to ensure the progress of the training plan for elite athletes. It is essential to establish the personal profile of the test results for each athlete as large individual variation is expected. In addition to the fitness tests that most coaches are familiar with, the hormone analyses, especially testosterone and cortisol, in different training periods can provide valuable information on the physiological response and stress in the athletes.

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