Physiological Changes Associated with the Pre-Event Taper in Athletes

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Abstract

Some of the physiological changes associated with the taper and their relationship with athletic performance are now known. Since the 1980s a number of studies have examined various physiological responses associated with the cardiorespiratory, metabolic, hormonal, neuromuscular and immunological systems during the pre-event taper across a number of sports. Changes in the cardiorespiratory system may include an increase in maximal oxygen uptake, but this is not a necessary prerequisite for taper-induced gains in performance. Oxygen uptake at a given submaximal exercise intensity can decrease during the taper, but this response is more likely to occur in less-skilled athletes. Resting, maximal and submaximal heart rates do not change, unless athletes show clear signs of overreaching before the taper. Blood pressure, cardiac dimensions and ventilatory function are generally stable, but submaximal ventilation may decrease. Possible haematological changes include increased blood and red cell volume, haemoglobin, haematocrit, reticulocytes and haptoglobin, and decreased red cell distribution width. These changes in the taper suggest a positive balance between haemolysis and erythropoiesis, likely to contribute to performance gains.

Metabolic changes during the taper include: a reduced daily energy expenditure; slightly reduced or stable respiratory exchange ratio; increased peak blood lactate concentration; and decreased or unchanged blood lactate at submaximal intensities. Blood ammonia concentrations show inconsistent trends, muscle glycogen concentration increases progressively and calcium retention mechanisms seem to be triggered during the taper. Reduced blood creatine kinase concentrations suggest recovery from training stress and muscle damage, but
other biochemical markers of training stress and performance capacity are largely unaffected by the taper. Hormonal markers such as testosterone, cortisol, testosterone : cortisol ratio, 24-hour urinary cortisol : cortisone ratio, plasma and urinary catecholamines, growth hormone and insulin-like growth factor-1 are sometimes affected and changes can correlate with changes in an athlete’s performance capacity.

From a neuromuscular perspective, the taper usually results in markedly increased muscular strength and power, often associated with performance gains at the muscular and whole body level. Oxidative enzyme activities can increase, along with positive changes in single muscle fibre size, metabolic properties and contractile properties. Limited research on the influence of the taper on athletes’ immune status indicates that small changes in immune cells, immunoglobulins and cytokines are unlikely to compromise overall immunological protection.

The pre-event taper may also be characterised by psychological changes in the athlete, including a reduction in total mood disturbance and somatic complaints, improved somatic relaxation and self-assessed physical conditioning scores, reduced perception of effort and improved quality of sleep. These changes are often associated with improved post-taper performances. Mathematical models indicate that the physiological changes associated with the taper are the result of a restoration of previously impaired physiological capacities (fatigue and adaptation model), and the capacity to tolerate training and respond effectively to training undertaken during the taper (variable dose-response model). Finally, it is important to note that some or all of the described physiological and psychological changes associated with the taper occur simultaneously, which underpins the integrative nature of relationships between these changes and performance enhancement.

The taper is a training phase before competition during which the training load is progressively reduced for a variable period of time to allow for physiological and psychological recovery from accumulated training stress, with the aim of maximising competition performance. Coaches and sports scientists involved in the preparation of elite athletes for major competitions are well aware of the performance-enhancing potential of a well designed taper. This awareness is based on both anecdotal reports from successful competitions and peer-reviewed publications describing the beneficial performance consequences of a taper following a period of intensive training.\(^{1-17}\)

The relationship between the reduced training load during the taper and performance benefits is well established, allowing investigators to make training recommendations to optimise pre-event tapering strategies.\(^{18-22}\) However, the physiological mechanisms underlying the observed performance changes are less well understood. With the exception of a report by Mujika\(^{20}\) existing reviews dealing with the physiological changes associated with the taper in athletes date back to the late 1980s and early 1990s.\(^{18,19,22}\) Nevertheless, considerable efforts by various sports science groups in the past few years are continuing to shed light on the physiological changes associated with the taper and mecha-
Table I. Effects of the taper on maximal oxygen uptake (VO2max)

<table>
<thead>
<tr>
<th>Study (year)</th>
<th>Athletes</th>
<th>Taper duration (days)</th>
<th>VO2max</th>
<th>Performance measure</th>
<th>Performance outcome (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Houmard et al.[32] (1990)</td>
<td>Runners</td>
<td>21</td>
<td>↔</td>
<td>5km indoor race</td>
<td>↔</td>
</tr>
<tr>
<td>D’Acquisto et al.[31] (1992)</td>
<td>Swimmers</td>
<td>14–28</td>
<td>↔</td>
<td>100m, 400m time trial</td>
<td>4.0–8.0 impr</td>
</tr>
<tr>
<td>Jeukendrup et al.[33] (1992)</td>
<td>Cyclists</td>
<td>14</td>
<td>↑</td>
<td>8.5km outdoor time trial</td>
<td>7.2 impr</td>
</tr>
<tr>
<td>Shepley et al.[34] (1992)</td>
<td>Cyclists</td>
<td>7</td>
<td>↔</td>
<td>Treadmill time to exhaustion</td>
<td>6–22 impr</td>
</tr>
<tr>
<td>McConell et al.[35] (1993)</td>
<td>Runners</td>
<td>28</td>
<td>↔</td>
<td>5km indoor race</td>
<td>1.2 decl</td>
</tr>
<tr>
<td>Houmard et al.[36] (1994)</td>
<td>Runners</td>
<td>7</td>
<td>↔</td>
<td>5km treadmill time trial</td>
<td>2.8 impr</td>
</tr>
<tr>
<td>Zarkadas et al.[37] (1995)</td>
<td>Triathletes</td>
<td>14</td>
<td>↑</td>
<td>5km field time trial run</td>
<td>1.2–6.3 impr</td>
</tr>
<tr>
<td>Banister et al.[38] (1999)</td>
<td></td>
<td></td>
<td></td>
<td>Incremental maximal test</td>
<td>1.5–7.9 impr</td>
</tr>
<tr>
<td>Dressendorfer et al.[40] (2002)</td>
<td>Cyclists</td>
<td>10</td>
<td>↑ slightly</td>
<td>20km simulated time trial</td>
<td>1.2 impr</td>
</tr>
<tr>
<td>Margaritis et al.[41] (2003)</td>
<td>Triathletes</td>
<td>14</td>
<td>↑</td>
<td>30km outdoor duathlon</td>
<td>1.6–3.6 impr</td>
</tr>
<tr>
<td>Neary et al.[23] (2003)</td>
<td>Cyclists</td>
<td>7</td>
<td>↑</td>
<td>20km simulated time trial</td>
<td>5.4 impr</td>
</tr>
</tbody>
</table>

decl = decline; impr = improvement; NR = not reported; ↑ indicates increased; ↔ indicates unchanged.

The mechanisms responsible for the observed improvements in performance. The aim of this review is to compile and synthesise the present knowledge on tapering-induced physiological changes in athletes and assess the possible relationships between these changes and performance benefits of the taper.

1. Cardiorespiratory Changes

Given the fundamental role that the cardiovascular and respiratory systems play during exercise training, they should respond to tapered training with considerable structural and functional changes, despite the relatively short duration of the taper typically performed by well trained athletes. These changes, as well as their potential effects on sports performance, are described in sections 1.1 to 1.5.

1.1 Maximal Oxygen Uptake

Maximal oxygen uptake (VO2max) can increase or remain unchanged during periods of taper before competition in highly trained athletes (table 1). This is a relevant finding, given that a decrease in VO2max during the taper would most likely be indicative of a poorly planned tapering strategy in endurance athletes. Recent investigations have reported VO2max enhancements of 6.0% in cyclists reducing their weekly training volume by 50% during 7 days. This change was concomitant with a 5.4% improvement in a simulated 20km time trial. On the other hand, neither an increase in VO2max nor a simulated performance gain was observed in cyclists reducing training volume by 30% or 80% during a 7-day taper.[23] The same group also reported an increase in VO2max (2.5%) and simulated performance (4.3%) in cyclists who maintained training intensity but reduced training volume. In contrast, cyclists maintaining training volume but reducing intensity only showed statistically non-significant improvements in VO2max (1.1%) and simulated performance (2.2%).[24] These results are in agreement with previous reports indicating that training intensity is a key factor for the maintenance or enhancement of training-induced adaptations and optimisation of sports performance.[3,4,19-22,25-30]

In line with these results, Jeukendrup et al.[33] reported a 4.5% increase in cyclists’ VO2max at the end of 2 weeks of reduced training (i.e. step taper, consisting of a non-progressive standardised reduction in the training load), accompanied by a 10%
higher peak power output and 7.2% faster 8.5km outdoor time trial. Well trained triathletes can increase \( \dot{V}O_2_{\text{max}} \) by 9.1% and criterion laboratory running (1.2–6.3%) and cycling (1.5–7.9%) performances after 2 weeks of taper.\(^{36,37}\) Margaritis et al.\(^{41}\) recently observed 3% gains in both \( \dot{V}O_2_{\text{max}} \) and simulated duathlon performance during a 14-day taper in long-distance triathletes.

Several investigators have observed unchanged \( \dot{V}O_2_{\text{max}} \) values as a result of a taper, but this did not preclude athletes from improving their performance (table I). In a study with high-school swimmers tapering for either 2 or 4 weeks, both groups improved their swimming time trial performance by 4–8% but \( \dot{V}O_2_{\text{max}} \) was unchanged.\(^{5}\) Shepley et al.\(^{10}\) reported similar findings of unchanged \( \dot{V}O_2_{\text{max}} \) values but enhanced treadmill performance in male cross-country and middle-distance runners, as did Houmard et al.,\(^{35}\) who observed a stable \( \dot{V}O_2_{\text{max}} \) but a 2.8% gain in a 5km treadmill time trial run and a 4.8% longer time to exhaustion in a progressive run on the treadmill in tapered distance runners. In a study of male cyclists who tapered by reducing their training frequency by 50% for 10 days, Dressendorfer et al.\(^{39,40}\) observed small improvements in \( \dot{V}O_2_{\text{max}} \) (2.5%) and a simulated 20km time trial (1.2%). Van Handel et al.\(^{31}\) also reported stable \( \dot{V}O_2_{\text{max}} \) values (65.4 pre-taper vs 66.6 mL/kg/min, post-taper) in college-aged swimmers (including Olympic medal winners) tapering for 20 days leading up to the US National Championships. Unfortunately, performance outcomes were not reported in this investigation. Similarly, there were no improvements in \( \dot{V}O_2_{\text{max}} \) or peak power output in a study in which trained cyclists underwent a step taper consisting of either continuous training or intermittent training,\(^{38}\) nor in runners during a 3-week\(^{32,42}\) or 4-week step taper.\(^{34}\)

Collectively, these studies generally show improved or stable \( \dot{V}O_2_{\text{max}} \) and performance gains after a taper, particularly where training intensity has been maintained. Although often non-significant from a statistical point of view, taper-induced improvements in performance could be worthwhile in practical terms relative to competition results.\(^{13,43}\) Improvements of approximately one-half of the typical within-subject variation in competition performance are considered to be worthwhile in terms of substantially increasing a top athlete’s chance of winning a medal. The magnitude of such practical improvements ranges from 0.9% in track sprinters,\(^{43}\) 1.4% for highly trained swimmers,\(^{44}\) 1.5% for cross-country runners and up to 3% for marathon runners.\(^{45}\) Another important consideration is that laboratory or field-based performance tests are much less reliable measures of performance than competition itself and enhancements in these tests may not necessarily translate into similar performance gains in competition.\(^{43}\)

### 1.2 Economy of Movement

The economy of movement is defined as the oxygen cost of exercise at a given submaximal exercise intensity. Economy has been assessed before and after taper in runners, swimmers and cyclists. Results of economy studies have been disparate, with the discrepancies probably related to factors such as differences in the training and tapering programmes and the calibre of the athletes. Houmard et al.\(^{35}\) assessed the submaximal energy expenditure in a group of 18 male and six female distance runners performing a progressive 7-day run or cycle taper where total training volume was reduced by 85%. The authors reported a 7% (0.9 kcal/min) decrease in calculated submaximal energy expenditure when running at 80% peak oxygen uptake (\( \dot{V}O_2_{\text{peak}} \)) on a treadmill. This magnitude of improvement in running economy was evident in seven of the eight subjects performing the run taper, but not in those performing the cycle taper. The investigators suggested that an elevation in the muscle’s mitochondrial capacity, along with neural, structural
and biomechanical factors could explain improvements in economy with the taper.\textsuperscript{[35]} These observations confirmed an earlier investigation by the same group that also described a lower oxygen cost of running after a 3-week period of reduced training.\textsuperscript{[32]}

Improvements in economy of movement have also been reported in swimming, but these gains appear to be inversely related to the calibre of the athletes. High-school level male and female swimmers tapering for 2 or 4 weeks showed downward shifts in their oxygen uptake (\(\dot{V}O_2\))-velocity curves (i.e. economy) between 4.9 and 15.6\% and between 8.5 and 16.7\%, respectively, at a range of different swimming velocities.\textsuperscript{[5]} The investigators suggested that changes in economy were dependent on reductions in training volume, and like Houmard and colleagues\textsuperscript{[35]} they speculated that the taper had a beneficial effect on biomechanics, allowing the swimmers to develop better stroke mechanics.\textsuperscript{[5]} Johns et al.\textsuperscript{[7]} also reported declines of 5–8\% in the oxygen cost of swimming after 10 or 14 days of taper in intercollegiate swimmers. In contrast, Van Handel et al.\textsuperscript{[31]} did not observe any tapering-induced changes in the economy curves of swimmers of much higher calibre, who were described as considerably more economical than less skilled swimmers.

In cyclists, Dressendorfer et al.\textsuperscript{[39]} did not observe a marked improvement in economy at a power output of 200W in male cyclists tapering for 10 days, when values were compared with the previous two training phases characterised by high volume and high intensity, respectively. Nevertheless, the oxygen cost of cycling at that power output remained lower after the taper (2.82 L/min) than at baseline (2.95 L/min). Houmard et al.\textsuperscript{[46]} reported unchanged submaximal \(\dot{V}O_2\)max after a 10-day taper in runners. Rietjens et al.\textsuperscript{[38]} did not observe any changes in either the oxygen cost of cycling at 165 or 270W in cyclists before and after a 3-week step taper, nor did McConnell et al.\textsuperscript{[34]} after a 4-week step taper in runners at 65\%, 85\% or 95\% \(\dot{V}O_2\)max.

### 1.3 Cardiac Function and Dimensions

#### 1.3.1 Resting Heart Rate

Few reports are available on the effects of tapering on athletes’ resting heart rate (HR), with the general consensus of investigators that resting HR does not appear to change during this phase of training (table II). Haykowsky et al.\textsuperscript{[47]} reported unchanged mean resting HR values of 57 and 59 beats/min before and after tapering for 2 weeks at an altitude of 1848m, respectively, and 59 and 56 beats/min at 1050m. Unchanged resting HR values were also observed by Flynn et al.\textsuperscript{[48]} before and after 3 weeks of taper in collegiate cross country runners (51 vs 52 beats/min) and collegiate swimmers (54 vs 55 beats/min). In line with these results, stable resting HR values were observed in a group of international-level swimmers tapering for 2 weeks,\textsuperscript{[49]} in elite weightlifters tapering for either 1 or 4 weeks\textsuperscript{[15]} and runners undergoing a 4-week step taper.\textsuperscript{[34]} In contrast with these reports, Jeukendrup et al.\textsuperscript{[33]} described a decrease from 54 to 51 beats/min in the sleeping HR of their group of cyclists after 2 weeks of reduced training. However, these subjects were purposely overreached before the taper, a condition that may have elicited abnormally high resting HR.\textsuperscript{[50]}

#### 1.3.2 Maximal Heart Rate

Results from investigations addressing the effects of taper on maximal HR are not consistent and values have variously been shown to decrease, remain constant or increase after a taper (table II). For instance, D’Acquisto et al.\textsuperscript{[5]} reported lower maximal HR in swimmers after tapers lasting 2 (187 vs 192 beats/min) or 4 (185 vs 194 beats/min) weeks. Maximal HR did not change during taper in runners performing a progressive treadmill run to exhaustion,\textsuperscript{[35,46]} nor in a group of cyclists performing an
### Table II. Effects of the taper on heart rate (HR)

<table>
<thead>
<tr>
<th>Study (year)</th>
<th>Athletes</th>
<th>Taper duration (days)</th>
<th>Resting HR</th>
<th>Maximal HR</th>
<th>Submaximal HR</th>
<th>Performance measure</th>
<th>Performance outcome (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Costill et al. [3] (1985)</td>
<td>Swimmers</td>
<td>14</td>
<td>NR</td>
<td>NR</td>
<td>↔</td>
<td>46–1509m competition</td>
<td>2.2–4.6 impr</td>
</tr>
<tr>
<td>Houmard et al. [46] (1989)</td>
<td>Runners</td>
<td>10</td>
<td>NR</td>
<td>↔</td>
<td>↔</td>
<td>Incremental maximal test</td>
<td>↔</td>
</tr>
<tr>
<td>Houmard et al. [32] (1990)</td>
<td>Runners</td>
<td>21</td>
<td>NR</td>
<td>↑ slightly</td>
<td>↔</td>
<td>5km indoor race</td>
<td>↔</td>
</tr>
<tr>
<td>D’Acquisto et al. [3] (1992)</td>
<td>Swimmers</td>
<td>14–28</td>
<td>NR</td>
<td>↓</td>
<td>↔</td>
<td>100m, 400m time trial</td>
<td>4.0–8.0 impr</td>
</tr>
<tr>
<td>Jeukendrup et al. [33] (1992)</td>
<td>Cyclists</td>
<td>14</td>
<td>↓</td>
<td>↑</td>
<td>↑</td>
<td>8.5km outdoor time trial</td>
<td>7.2 impr</td>
</tr>
<tr>
<td>McConell et al. [34] (1993)</td>
<td>Runners</td>
<td>28</td>
<td>↔↑↑</td>
<td>↑ slightly</td>
<td>↔</td>
<td>5km indoor race</td>
<td>1.2 decl</td>
</tr>
<tr>
<td>Flynn et al. [48] (1994)</td>
<td>Runners</td>
<td>21</td>
<td>↔</td>
<td>NR</td>
<td>↔</td>
<td>Treadmill time to exhaustion</td>
<td>↔</td>
</tr>
<tr>
<td>Jeukendrup et al. [33] (1992)</td>
<td>Swimmers</td>
<td>14</td>
<td>↔</td>
<td>NR</td>
<td>NR</td>
<td>23m, 366m time trial</td>
<td>↓-3 impr</td>
</tr>
<tr>
<td>Houmard et al. [35] (1994)</td>
<td>Runners</td>
<td>7</td>
<td>NR</td>
<td>↔</td>
<td>↑ slightly</td>
<td>5km treadmill time trial</td>
<td>2.8 impr</td>
</tr>
<tr>
<td>Haykowsky et al. [47] (1998)</td>
<td>Swimmers</td>
<td>14</td>
<td>↔</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
</tr>
<tr>
<td>Hooper et al. [48] (1999)</td>
<td>Swimmers</td>
<td>14</td>
<td>↔</td>
<td>↑ slightly</td>
<td>NR</td>
<td>100m time trial</td>
<td>↔</td>
</tr>
<tr>
<td>Rietjens et al. [38] (2001)</td>
<td>Cyclists</td>
<td>21</td>
<td>NR</td>
<td>↔</td>
<td>↔</td>
<td>Incremental maximal test</td>
<td>↔</td>
</tr>
<tr>
<td>Dressendorfer et al. [23] (2002)</td>
<td>Cyclists</td>
<td>10</td>
<td>NR</td>
<td>NR</td>
<td>↔</td>
<td>20km simulated time trial</td>
<td>1.2 impr</td>
</tr>
<tr>
<td>Neary et al. [23] (2003)</td>
<td>Cyclists</td>
<td>7</td>
<td>NR</td>
<td>NR</td>
<td>↔</td>
<td>20km simulated time trial</td>
<td>5.4 impr</td>
</tr>
</tbody>
</table>

**decl** = decline; **impr** = improvement; **NR** = not reported; ↓ indicates decreased; ↑ indicates increased; ↔ indicates unchanged.
incremental cycling test to exhaustion.\textsuperscript{[38]} In contrast, maximal HR was slightly increased after 1 week of taper in cyclists,\textsuperscript{[51]} 2 weeks of taper in swimmers,\textsuperscript{[49]} and 3\textsuperscript{[32]} and 4\textsuperscript{[34]} weeks of reduced training in runners. In an overreaching-recovery protocol, maximal HR increased from 178 to 183 beats/min, but this post-taper value was similar to that measured before undertaking the intensified training.\textsuperscript{[33]} Reduced maximal HR after intensified training is related with catecholamine depletion and indicative of the neuroendocrine nature of an athlete’s overreached/overtrained status.\textsuperscript{[52,53]} A possible explanation for the inconsistent findings could relate to opposite effects on maximal HR of blood volume expansion and the level of catecholamine depletion that may have been incurred during the preceding phase of intense training.

1.3.3 Submaximal Heart Rate

Most of the available literature on the effects of taper on submaximal exercise HR indicates few changes across a range of different athletic activities (table II). No change in HR was observed by D’Acquisto et al.,\textsuperscript{[5]} when swimmers were required to swim at submaximal velocities ranging between 1.0 and 1.3 m/sec before and after 2 or 4 weeks of taper. Costill et al.\textsuperscript{[3]} reported unchanged post-exercise HR after an evenly paced 183m (200 yard) swim at a speed representing 90% of individual season’s best performance after 1 and 2 weeks of taper. A 10-day taper did not elicit a change in HR when running at 265 or 298 m/min.\textsuperscript{[40]} Similarly, a 3-week taper did not affect HR while running at 75% VO\textsubscript{2max} in collegiate runners (161 beats/min before taper vs 163 beats/min after taper),\textsuperscript{[48]} nor did a 3-week step taper at 65% and 85% VO\textsubscript{2max}\textsuperscript{[32]} or a 4-week step taper at 65%, 85% or 95% VO\textsubscript{2max}.\textsuperscript{[34]} Submaximal HR while cycling at a power output of 200W was unchanged after a 10-day taper in male cyclists when compared with the preceding high-intensity interval training phase, even though HR was lower than at baseline (137 vs 152 beats/min, respectively), indicative of a positive training adaptation.\textsuperscript{[39]} Similarly, no changes in HR at power outputs of 165 and 270W were reported before and after 3-week continuous or intermittent training step tapers.\textsuperscript{[38]} In line with these results, Martín and Andersen\textsuperscript{[51]} observed identical HR-power output slopes before and after a 1-week taper in male collegiate cyclists, but these slopes were markedly shifted to the right when compared with baseline values. Neary et al.\textsuperscript{[23]} reported that HR during a simulated 20km time trial was identical before and after taper in a group of male cyclists, but the oxygen pulse increased from 23.1 to 24.8mL O\textsubscript{2}/beat in those subjects reducing weekly training volume by 50% during the 7-day taper, who also improved their simulated performance by 5.4%. Submaximal exercise HR values were also unaffected by 1 or 4 weeks of taper in weightlifters.\textsuperscript{[15]}

In contrast, HR was elevated during an all-out 5km treadmill run after performing both a running taper and a cycling taper. HRs were also 4–6 beats/min higher during a submaximal run at VO\textsubscript{2peak}, but this change did not attain statistical significance.\textsuperscript{[35]} The overreaching-recovery protocol of Jeukendrup et al.\textsuperscript{[33]} induced a clear increase in submaximal HR measured during an 8.5km outdoor cycling time trial after the taper. These changes were thought to be related with the level of neuroendocrine fatigue in the pre-taper condition.

1.3.4 Blood Pressure

Only three published reports are available on the effects of taper on resting blood pressure (BP), and none of them showed any substantial effect of tapering on BP. Flynn et al.\textsuperscript{[48]} reported pre- and post-taper systolic BP values of 112 and 114mm Hg in eight male runners, respectively, and 118 and 116mm Hg in five male swimmers. Diastolic pressures were 73 and 74mm Hg for the runners, and 76 and 78mm Hg for the swimmers. In swimmers, Hooper et al.\textsuperscript{[49]} reported modest declines of 3.4% and 2.2% in systolic and diastolic pressures during
taper, with standard deviation values of 12.5% and 12.2%, respectively. In terms of a power sport, the results of Stone et al.\[15\] indicated no tapering-induced changes in the resting BP of elite weightlifters.

1.3.5 Cardiac Dimensions

The only study on the effects of a taper on cardiac dimensions assessed the effects of a 2-week swimming taper at moderate altitudes of 1050m and 1848m.\[47\] The taper consisted of a progressive 73% reduction in training volume, coupled with a slight increase in the percentage of high-intensity training. These investigators observed no marked change in diastolic or systolic cavity dimensions, ventricular septal wall thickness, estimated absolute or relative left ventricular mass, stroke volume, cardiac output, cardiac index or fractional shortening. The investigators concluded that 3 weeks of altitude training or control training followed by 2 weeks of taper training was not associated with alterations in structural and functional aspects of cardiovascular dynamics.\[47\]

1.4 Ventilatory Function

Few investigators have addressed tapering effects on athletes’ ventilatory function. Peak ventilatory volume during a simulated 20km cycling time trial was unchanged as a result of a 7-day taper, but the ventilatory equivalent for oxygen declined from 25.5 to 24.0 L/LO₂ in those cyclists tapering by reducing training volume by 50%.\[23\] Unchanged maximal ventilation was also observed in runners after a 4-week step taper.\[34\] Submaximal ventilation during a 10-minute treadmill run declined by 5.4% after a 7-day taper in distance runners.\[35\] Similarly, power output at the ventilatory threshold increased by 12% (28W) in cyclists during a high-intensity/low-volume taper eliciting a 4.3% performance improvement over a simulated 40km cycling time trial, and by 8% (19W) in a low-intensity/high-volume taper that induced a 2.2% simulated performance gain.\[24\] The same group observed a 12% (27W) improvement in the ventilatory threshold after tapers lasting either 4 or 8 days.\[54\] A smaller improvement of 2.9% was reported by Dressendorfer et al.\[90\] coupled with a performance gain over a simulated 20km time trial of only 1.2%.

1.5 Haematology

1.5.1 Balance Between Haemolysis and Erythropoiesis

The taper is a specialised training strategy that can be accompanied by a positive balance between exercise-induced haemolysis and recovery-facilitated erythropoiesis. Intensive athletic training can result in decreased red blood cells, haemoglobin concentration and haematocrit.\[55-62\] These changes have variously been attributed to a haemodilution caused by training-induced expanded plasma volume, an imbalance between haematopoiesis and intravascular haemolysis, or iron deficiency.\[58,63,64\]

On the other hand, taper-induced increases in blood and red cell volume have been reported in highly trained distance runners. Shepley et al.\[30\] observed a 15% increase in total blood volume after a 7-day high-intensity/low-volume taper in runners. This training-induced hypervolaemia is possibly associated with an elevation of plasma renin activity and vasopressin concentration during exercise and a chronic increase in the water-binding capacity of the blood.\[30,65-67\] Shepley et al.\[30\] also observed a 14% increase in red cell volume and a slight 2.6% increase in haematocrit, possibly the result of an increased haematopoiesis concomitant to a decreased intravascular haemolysis.

Consistent with the above results, haemoglobin concentration and haematocrit increased during the taper in competitive swimmers\[55,60,62\] and triathletes.\[41,68\] These results have also been attributed to a decreased haemolysis and a net increase in erythrocytes, presumably facilitated by the reduced training load that characterises periods of
taper.\textsuperscript{[18,19,22,30,69]} This suggestion seems to be confirmed by the findings of Mujika et al.\textsuperscript{[26]} showing a 40\% increase in the post-taper reticulocyte count in a group of middle-distance runners tapering for 1 week. This change was indicative of an enhanced red cell production resulting in the release of immature erythrocytes, with a smaller haemoglobin content and reduced mean corpuscular haemoglobin values.\textsuperscript{[70-72]}

Two additional indices of a positive red cell balance during taper are increased serum haptoglobin and decreased red cell distribution width. Serum haptoglobin is a glycoprotein that binds free haemoglobin released into the circulation to conserve body iron. Lower than normal haptoglobin levels have been found in middle- and long-distance runners and swimmers.\textsuperscript{[56,59,73,74]} These observations have been attributed to a rapid removal of the haptoglobin-haemoglobin complex from the blood by the liver and suggest a chronic haemolytic condition. In contrast, serum haptoglobin can increase with a 6-day taper in middle-distance runners.\textsuperscript{[12]} This finding was in parallel with a trend towards increased reticulocyte counts, suggesting that the reduced training load undertaken by the athletes during the taper facilitated a positive balance between haemolysis and erythropoiesis.

The red cell distribution width decreased slightly during 12 weeks of intensive training and 4 weeks of taper in highly trained swimmers to attain significantly lower values at the end of the taper.\textsuperscript{[69]} Slight reductions during taper have also been reported in runners and swimmers.\textsuperscript{[59]} Decrement in red cell distribution width are considered a positive adaptation to training, given that a high red cell distribution width has been associated with decreased deformability, decreased osmotic resistance and increased mechanical fragmentation of erythrocytes.\textsuperscript{[63,75]}

With respect to the possible influence of the observed haematological changes on performance, Shepley et al.\textsuperscript{[30]} attributed part of the reported 22\% improvement in a treadmill run to fatigue after taper to the increase in blood and red cell volume. Mujika et al.\textsuperscript{[69]} observed a 2.3\% mean competition performance improvement in tapered swimmers and a positive correlation was found between post-taper red cell count and the percentage improvement in performance attained by the swimmers during taper \((r = 0.83)\). Red cell count, haemoglobin and haematocrit increased by 3.5, 1.8 and 3.3\% in the swimmers for which the taper was most effective, whereas decreases of 2.2, 4.3 and 2.1\% occurred in those athletes improving less with the taper. The investigators suggested that the net increase in erythrocyte values observed in the successful swimmers during taper could have been in part responsible for the higher performance improvement attained, given that small percentage increases in the haemoglobin or haematocrit values can result in worthwhile improvements in VO\textsubscript{2max} and/or exercise capacity.\textsuperscript{[76,77]}

\subsection{1.5.2 Iron Status}

Enhanced erythropoietic activity in the bone marrow associated with the taper could jeopardise the iron status of athletes. An iron profile indicative of a prelatent-latent iron deficiency, with normal red cell count and haemoglobin, but lowered ferritin, serum iron and transferrin saturation and increased transferrin values\textsuperscript{[78,79]} has been reported in middle-distance runners at the end of 6-day tapers. This, however, did not seem to negatively affect the athletes’ competition performance.\textsuperscript{[12,26]} Lowered post-taper ferritin values have also been reported in male cross-country runners after a 3-week taper\textsuperscript{[59]} and in triathletes tapering for 2 weeks,\textsuperscript{[68]} but not in swimmers.\textsuperscript{[69]}

\section{2. Metabolic Changes}

Energy metabolism underpinning exercise performance can be altered during a pre-event taper. Decreases in training load in favour of rest and recovery lower an athlete’s daily energy expendi-
ture, potentially impacting on energy balance and body composition. Substrate availability and utilisation, blood lactate kinetics and muscle glycogen content may also be altered during the taper.

2.1 Energy Expenditure/Energy Balance

Margaritis et al.\textsuperscript{[41]} recently reported the daily energy intake, energy expenditure, body mass and body fat of 20 male long-distance triathletes during 4 weeks of overloaded training followed by 2 weeks of tapered training. Energy intake did not change between both training phases (13.8–15.0 vs 13.2–15.0 MJ/day), whereas energy expenditure decreased from 16.8–17.0 to 12.1–12.7 MJ/day. Total body mass did not change during the taper, but the percentage body fat increased slightly from 11.4–11.5\% to 11.8–12.1\%\textsuperscript{[41].} Similar changes were observed in a 4-week reduced training study on ten well trained male distance runners, whose body fat increased from 10.4\% to 11.8\%.\textsuperscript{[34]} These results indicate that a certain level of muscle mass loss may have taken place during the taper and suggest that athletes tapering for competition should pay careful attention to matching energy intake in accordance with the reduced energy expenditure that characterises this training period.

D’Acquisto et al.\textsuperscript{[5]} reported the body mass and percentage body fat of female swimmers before and after 2- and 4-week tapers and observed that neither variable changed significantly. There are additional studies indicating stability in body mass in well trained distance runners during a 3-week step taper\textsuperscript{[32,42]} and in collegiate cross-country runners and swimmers after a 3-week taper consisting of a 20–33\% weekly reduction in training volume.\textsuperscript{[48]} Similarly, nine male cyclists maintained their body mass during 10 days of taper consisting of resting every other day,\textsuperscript{[39]} as did collegiate swimmers preparing for the final meet of the season.\textsuperscript{[31]} These studies, however, did not report the possible changes in fat mass and muscle mass of the athletes.

2.2 Substrate Availability and Utilisation

There are few reports on the effects of tapering on the respiratory exchange ratio (RER), used as an index of substrate utilisation during exercise. During submaximal-intensity exercise, RER has been shown to decline or not to change after a taper. A group of club-level cyclists showed a post-taper shift in RER from 0.99 to 0.96 while cycling at a power output of 175W, suggesting a higher contribution from fat to energy production at moderate exercise intensity.\textsuperscript{[54]} Houmard and colleagues,\textsuperscript{[35]} on the other hand, reported unchanged RER values during a 10-minute continuous run at 80\% \(\dot{V}O_{2}\text{peak}\) and during submaximal running at 265 and 298 m/min.\textsuperscript{[46]} Rietjens et al.\textsuperscript{[38]} also showed unchanged rates of fat oxidation during a 90-minute steady-state cycle after 7, 14 and 21 days of a step-taper.

Three and 4-week step tapers elicited slight but statistically significant increases in runners’ RER at 65\%, 85\% and 95\% \(\dot{V}O_{2}\text{peak}\).\textsuperscript{[32,34]}

During maximal exercise, such as a simulated 20km cycling time trial, RER values have been shown to remain unchanged after tapering.\textsuperscript{[23]} Similarly, unchanged maximal RER values were reported during treadmill running after either a running or a cycling 7-day taper.\textsuperscript{[35]} These results suggest that the substrate contribution to power production during maximal-intensity exercise is not modified by a taper. This lack of change may be related to stable aerobic-anaerobic work production and oxygen deficit during the taper.\textsuperscript{[80]} Another explanation could relate to increased muscle glycogen concentration during the taper, which theoretically induces a higher carbohydrate utilisation during both maximal and submaximal exercise. Six days of taper coupled with a high carbohydrate diet increased carbohydrate oxidation and RER values during cycling at 80\% \(\dot{V}O_{2}\text{max}\).\textsuperscript{[81]}

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2.3 Blood Lactate Kinetics

2.3.1 Maximal Exercise

Peak blood lactate concentration after maximal exercise can increase as a result of tapering (table III). This change, which could be related to an increased post-taper muscle glycogen concentration by a mass-action effect, might underpin enhanced maximal performance capabilities. In a study on middle-distance runners, percentage 800m competitive performance change during the taper positively correlated with changes in peak post-race blood lactate concentration \( r = 0.87 \). In a subsequent study by the same group, post-race peak blood lactate increased by 7.6%, with peak lactate correlating highly with running performance. Statistically significant relationships between increases in peak post-race blood lactate levels and competition performance enhancement \( r = 0.63 \) were seen in international calibre swimmers during two consecutive seasons. Male cyclists’ peak blood lactate concentration increased by 78% after 14 days of a step taper, concomitant with a 7.2% improvement in an 8.5km outdoor time trial and a 10.3% increase in peak power output. Competitive high-school female swimmers increased their peak blood lactate concentration by 20% after taper programmes that induced time trial performance gains of 4–8%. Shepley et al. reported modest peak blood lactate increases after high (7.2%) and low (9.8%) intensity tapers, while a laboratory-based performance measure (time to exhaustion at 1500m run pace) improved by 22% and 6%, respectively. Van Handel et al. also showed modest changes in peak lactate concentrations in collegiate swimmers preparing for national championships (6.9 to 7.5 mmol/L). A similar trend (peak blood lactate concentration increased from 14.4 to 15.8 mmol/L) was observed in elite junior rowers after a 1-week taper. In contrast, no change in peak blood lactate values or performance were observed in a study in which rowers performed maximal 500m indoor rowing tests before and after a 1-week taper subsequent to 3 weeks of overload training. The investigator of the study concluded that the 25% decrease in training volume during the taper was insufficient, or the length too short a time for positive regenerative adaptations and improved performance to occur. Taken as a whole, these findings and other similar results support the contention that post-competition peak blood lactate values may be a useful index of anaerobic capacity and a sensitive marker of tapering-induced physiological changes.

2.3.2 Submaximal Exercise

Blood lactate concentration at submaximal exercise intensity shows variable responses after the pre-event taper (table III). Kenitzer described a decrease in blood lactate concentration at 80% of maximal HR during the first 2 weeks of a taper in female swimmers, but a subsequent increase during weeks 3 and 4, leading to the tentative conclusion that 2 weeks was the optimum taper duration. In contrast, D’Acquisto et al. observed reduced blood lactate values during submaximal swimming in high-school females tapering for either 2 weeks (15–26% decline) or 4 weeks (26–33% decline). These results are consistent with those of Costill et al., who described a 13% reduction in submaximal lactate, in parallel with a mean 3.1% swimming performance improvement in competition after a 2-week taper. Similarly, an 8.0% higher post-taper power output at a blood lactate concentration of 4 mmol/L has been reported in rowers. In contrast to reports on higher blood lactates, Flynn et al. did not observe any change in blood lactate concentration in collegiate athletes running at 75% VO\(_{2}\)max or swimming at 90% VO\(_{2}\)max. Unchanged submaximal blood lactate concentrations were also observed in runners performing either a run or a cycle taper for 7 days in collegiate swimmers tapering for either 10 or 14 days before a

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### Table III. Effects of the taper on blood lactate concentration ([H\text{La}])

<table>
<thead>
<tr>
<th>Study (year)</th>
<th>Athletes</th>
<th>Taper duration (days)</th>
<th>Peak [H\text{La}]</th>
<th>Submaximal H\text{La} (%)</th>
<th>Performance measure</th>
<th>Performance outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Costill et al.\cite{3} (1985)</td>
<td>Swimmers</td>
<td>14</td>
<td>NR</td>
<td>↓</td>
<td>46–1509m competition</td>
<td>2.2–4.6 impr</td>
</tr>
<tr>
<td>Van Handel et al.\cite{31} (1988)</td>
<td>Swimmers</td>
<td>20</td>
<td>↑ slightly</td>
<td>↑ slightly</td>
<td>NR</td>
<td>NR</td>
</tr>
<tr>
<td>D’Acquisto et al.\cite{5} (1992)</td>
<td>Swimmers</td>
<td>14–28</td>
<td>↑</td>
<td>↓</td>
<td>100m, 400m time trial</td>
<td>4.0–8.0 impr</td>
</tr>
<tr>
<td>Jeukendrup et al.\cite{33} (1992)</td>
<td>Cyclists</td>
<td>14</td>
<td>↑</td>
<td>NR</td>
<td>8.5km outdoor time trial</td>
<td>7.2 impr</td>
</tr>
<tr>
<td>Johns et al.\cite{7} (1992)</td>
<td>Swimmers</td>
<td>10–14</td>
<td>NR</td>
<td>↔</td>
<td>46–366m competition</td>
<td>2.0–3.7 impr</td>
</tr>
<tr>
<td>Shepley et al.\cite{30} (1992)</td>
<td>Runners</td>
<td>7</td>
<td>↑ slightly</td>
<td>NR</td>
<td>Treadmill time to exhaustion</td>
<td>6–22 impr</td>
</tr>
<tr>
<td>McConell et al.\cite{34} (1993)</td>
<td>Runners</td>
<td>28</td>
<td>NR</td>
<td>↑</td>
<td>5km indoor race</td>
<td>1.2 decl</td>
</tr>
<tr>
<td>Flynn et al.\cite{48} (1994)</td>
<td>Runners</td>
<td>21</td>
<td>NR</td>
<td>↔</td>
<td>23m, 366m time trial</td>
<td>↔</td>
</tr>
<tr>
<td></td>
<td>Swimmers</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Houmard et al.\cite{35} (1994)</td>
<td>Runners</td>
<td>7</td>
<td>NR</td>
<td>↔</td>
<td>5km treadmill time trial</td>
<td>2.8 impr</td>
</tr>
<tr>
<td>Stone et al.\cite{84} (1996)</td>
<td>Weightlifters</td>
<td>7–28</td>
<td>NR</td>
<td>↔</td>
<td>Competition</td>
<td>8.0–17.5kg impr</td>
</tr>
<tr>
<td>Kenitzer\cite{82} (1998)</td>
<td>Swimmers</td>
<td>14–28</td>
<td>NR</td>
<td>↓ 14 days, ↑ 21–28 days</td>
<td>4 × 91m submaximal set</td>
<td>↔ 4 impr</td>
</tr>
<tr>
<td>Bonifazi et al.\cite{1} (2000)</td>
<td>Swimmers</td>
<td>14–21</td>
<td>↑</td>
<td>NR</td>
<td>100–400m competition</td>
<td>1.5–2.1 impr</td>
</tr>
<tr>
<td>Mujika et al.\cite{26} (2000)</td>
<td>Runners</td>
<td>6</td>
<td>↑ slightly</td>
<td>NR</td>
<td>800m competition</td>
<td>↔</td>
</tr>
<tr>
<td>Smith\cite{12} (2000)</td>
<td>Rowers</td>
<td>7</td>
<td>↔</td>
<td>NR</td>
<td>500m simulated time trial</td>
<td>↔</td>
</tr>
<tr>
<td>Steinacker et al.\cite{38} (2000)</td>
<td>Rowers</td>
<td>7</td>
<td>↑ slightly</td>
<td>NR</td>
<td>2000m time trial-competition</td>
<td>6.3 impr</td>
</tr>
<tr>
<td>Rieijens et al.\cite{15} (2001)</td>
<td>Cyclists</td>
<td>21</td>
<td>NR</td>
<td>↔</td>
<td>Incremental maximal test</td>
<td>↔</td>
</tr>
<tr>
<td>Mujika et al.\cite{12} (2002)</td>
<td>Runners</td>
<td>6</td>
<td>↑</td>
<td>NR</td>
<td>800m competition</td>
<td>0.4–1.9 impr</td>
</tr>
</tbody>
</table>

\textit{decl} = decline; \textit{impr} = improvement; \textit{NR} = not reported; \textit{↓} indicates decreased; \textit{↑} indicates increased; \textit{↔} indicates unchanged.
major competition,[11] in cyclists performing a step taper for 21 days[38] and in elite weightlifters tapering for 1 or 4 weeks.[15] Van Handel et al.[31] reported a subtle shift of the blood lactate-swimming velocity curve back to the left after taper, whereas lactate recovery curves were unaffected. McConell et al.[34] on the other hand, reported a higher blood lactate at 95% VO_{2max} in runners after a 4-week step taper. Inconsistent findings may be related to the duration and the type of training performed during the taper.

2.4 Blood Ammonia

When the rate of muscular adenosine triphosphate (ATP) hydrolysis exceeds the rate of adenosine diphosphate (ADP) rephosphorylation through either oxidative or non-oxidative processes, ATP is resynthesised via the myokinase reaction. This process results in the formation of adenosine monophosphate (AMP), which is then deaminated leading to the production of inosine monophosphate and ammonia.[88-90] Post-exercise blood ammonia levels are used as a marker of exercise-induced adenine nucleotide degradation and to monitor training stress and overtraining.[91] Mujika et al.[11] observed stable resting ammonia concentrations during a 4-week taper, but mean post-taper values (34.1 µmol/L) returned to baseline (32.8 µmol/L) after they had been elevated by 12 weeks of intensive training (65.6 µmol/L). Plasma ammonia values, however, did not reflect changes in competition performance. Elite weightlifters’ resting and post-exercise blood ammonia concentrations were not changed by 1 or 4 weeks of taper, during which performance in competition increased by 8 and 17.5kg, respectively.[15] Similarly, blood ammonia was not affected by 1 week of taper in elite rowers performing a maximal 500m rowing ergometer time trial.[83] Given the potential influence of the taper on exercise metabolism and pre-exercise energy substrate availability, further research on blood ammonia changes associated with different tapering strategies is warranted, especially in high-intensity/short-duration sporting events.

2.5 Muscle Glycogen

Muscle glycogen concentration has been shown to increase progressively during periods of taper. Neary and colleagues[24] showed an increase in muscle glycogen concentration of 17% after a 4-day taper and 25% in an 8-day taper. The same group of investigators compared the change in muscle glycogen concentration after two different 7-day tapers in male cyclists: one in which training intensity was maintained at around 85–90% of maximal HR and training duration progressively reduced from 60 to 20 minutes; and the second where the duration remained constant at 60 minutes but intensity declined progressively from 85% to 55% of maximal HR. Muscle glycogen concentration increased by 34% and simulated 40km time trial performance by 4.3% during the shorter more intense taper, whereas muscle glycogen concentration increased by 29% and performance by 2.2% in the longer less intense taper.[30] A similar high-intensity/low-duration tapering brought about a 15% increase in muscle glycogen and 22% in running performance on a treadmill, whereas no change in glycogen and a moderate 6% performance gain were observed with the low-intensity/moderate-duration taper.[30]

Six days of tapering during the luteal phase of eumenorrheic athletes’ menstrual cycle resulted in a 13% higher muscle glycogen level when a high carbohydrate diet (78% carbohydrate) was consumed during the final 3–4 days of the taper period compared with a moderate carbohydrate diet (48% carbohydrate). The women were able to supercompensate glycogen during the taper, but not to the same magnitude as generally reported in men. Concomitantly, cycling time to exhaustion at 80–82% VO_{2max} increased by 8%.[81]
Table IV. Effects of the taper on blood creatine kinase (CK) concentration

<table>
<thead>
<tr>
<th>Study (year)</th>
<th>Athletes</th>
<th>Taper duration (days)</th>
<th>Blood CK concentration</th>
<th>Performance measure</th>
<th>Performance outcome (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Burke et al. [93] (1982)</td>
<td>Swimmers</td>
<td>28</td>
<td>↓</td>
<td>NR</td>
<td>NR</td>
</tr>
<tr>
<td>Millard et al. [92] (1985)</td>
<td>Swimmers</td>
<td>28</td>
<td>↓</td>
<td>NR</td>
<td>NR</td>
</tr>
<tr>
<td>Houmard et al. [40] (1990)</td>
<td>Runners</td>
<td>21</td>
<td>↓</td>
<td>5km indoor race</td>
<td>↔</td>
</tr>
<tr>
<td>Costill et al. [46] (1991)</td>
<td>Swimmers</td>
<td>14–21</td>
<td>↓</td>
<td>Competition</td>
<td>≈3.2 impr</td>
</tr>
<tr>
<td>Flynn et al. [48] (1994)</td>
<td>Runners</td>
<td>21</td>
<td>↔</td>
<td>Treadmill time to exhaustion</td>
<td>↔</td>
</tr>
<tr>
<td>Mujika et al. [11] (1996)</td>
<td>Swimmers</td>
<td>28</td>
<td>↓</td>
<td>100–200m competition</td>
<td>0.4–4.9 impr</td>
</tr>
<tr>
<td>Hooper et al. [49] (1999)</td>
<td>Swimmers</td>
<td>14</td>
<td>↑ slightly</td>
<td>100m time trial</td>
<td>↔</td>
</tr>
<tr>
<td>Mujika et al. [12] (2000)</td>
<td>Runners</td>
<td>6</td>
<td>↔</td>
<td>800m competition</td>
<td>↔</td>
</tr>
<tr>
<td>Mujika et al. [12] (2002)</td>
<td>Runners</td>
<td>6</td>
<td>↔</td>
<td>800m competition</td>
<td>0.4–1.9 impr</td>
</tr>
</tbody>
</table>

impr = improvement; NR = not reported; ↓ indicates decreased; ↑ indicates increased; ↔ indicates unchanged.

2.6 Mineral Metabolism

Mineral metabolism (basal plasma and 24-hour urinary calcium, magnesium, iron, zinc and copper) was studied in nine male cyclists during 6 weeks of volume training, 18 days of high-intensity interval training and 10 days of a reduced frequency taper. Urinary calcium decreased by 11.4%, plasma calcium concentration increased by 5.1% with the taper, but the metabolism of all other studied minerals remained unchanged. The apparent rebound in renal calcium might have resulted from either decreased urinary calcium filtration associated with lower ionised plasma calcium or increased plasma parathyroid hormone levels. Irrespective of the regulating mechanism, reducing the frequency of interval training during the taper appeared to trigger compensatory calcium retention.

3. Biochemical Changes

3.1 Creatine Kinase

Blood levels of creatine kinase (CK) have been used as an index of training-induced physiological stress. Creatine kinase is a muscle enzyme occasionally increased in the blood following strenuous or eccentric exercise, most probably as a result of altered permeability of tissue cell membranes. Factors that influence the degree of CK efflux into the blood include exercise duration and intensity, exercise mode and fitness level of the individual. Various studies have shown decreases in CK levels during the taper (Table IV). Studying ten male and ten female collegiate swimmers before and after a 4-week taper, Millard et al. [92] noted a 70% lower post-training and a 30% lower resting serum CK after the taper in the males, and 28% and 7% lower values in the females. Absolute post-taper CK values were not different between sexes, and fell to their lowest levels of the season during the taper. These results suggested that CK levels appear to reflect training volume rather than intensity. Yamamoto et al. [62] also observed decreased CK levels after swimming tapers correlating with the daily workout volume during the taper.

Flynn et al. [48] described a CK reduction of 38% during 3 weeks of taper. Mujika et al. [11] also reported a 43% decline in plasma CK during a 4-week taper, but this did not correlate with swimming performance improvements, which ranged between 0.4% and 4.9%. Costill et al. [4] measured 28% lower CK values after 2–3 weeks of taper, which resulted in an average performance improvement of 3.2%. Burke et al. [93] also observed a decline in CK levels.
after the taper in swimmers, but their values remained in the high-normal range.

In a group of male distance runners performing simulated half-marathons before and after either a 7-day taper or normal training, lower serum CK values were measured after the second half-marathon in the tapered athletes. This attenuated release of CK into the bloodstream was unlikely to be a consequence of lower muscle force generation, reduced oxidative stress or increased extracellular antioxidant protection. It was speculated that the taper may have facilitated muscle recovery, such that CK returned to resting values prior to the second half-marathon and resistance to exercise-induced injury was similar to that observed before the taper. Despite evidence that the taper reduced muscle damage, half-marathon performance did not improve.

A 3-week step taper also resulted in decreased serum CK in well trained runners.

In contrast to studies showing lower CK values after the taper, Hooper et al. measured a statistically non-significant 17% increase in plasma CK during a 2-week taper, with very large inter-individual variation among swimmers. These investigators argued that plasma CK is not a reliable marker of training stress and reflects an acute response to a single exercise session rather than an athlete’s homeostatic status. They also suggested that the large inter-individual variation could indicate large differences in the athletes’ physiological response to the taper. Very large inter-individual variations with unchanged means were also observed in middle-distance runners after 6-day tapers. Nevertheless, plasma CK levels increased with increasing low-intensity continuous training distance during the taper, which led the authors to suggest that middle-distance runners could limit the exercise-induced skeletal muscle damage before competition by reducing continuous running volume during the taper.

Taken as a whole, the published literature appears to suggest that plasma CK values could be of some interest to assess recovery from acute training stress and muscle damage during the taper, but the validity of this parameter as a marker of an individual athlete’s performance capabilities seems limited.

### 3.2 Other Biochemical Parameters

Few biochemical parameters have been shown to exhibit marked changes during the pre-event taper, limiting their utility as markers of physiological recovery and increased performance capacity. Yamamoto et al. measured serum glutamic oxalacetic transaminase and glutamic pyruvic transaminase (GPT) during two separate tapers in male swimmers, with declines in GPT in the initial 4–9 days of each of the tapers. The authors speculated that this decrease may reflect an increased post-taper ATP availability, maintaining the integrity of the cellular membrane and reducing the efflux of enzymes into the bloodstream. Banister et al. reported marked declines in the pattern of an elevation of serum enzyme activity (including CK, lactate dehydrogenase and aspartate aminotransferase) during 32 days of taper subsequent to 28 days of normal training in two subjects.

Other purported biochemical markers of training stress and performance capability, including blood urea, uric acid and creatinine were unchanged during 6-day tapers in middle-distance runners. Serum uric acid did not change in distance runners during a 7-day taper. Costill et al. did not detect any taper-induced changes in their swimmers’ blood pH, partial pressures of carbon dioxide and oxygen, HCO₃ and base excess after a 183m (200-yard) submaximal swim at 90% of the season’s best performance.
4. Hormonal Changes

4.1 Testosterone, Cortisol and the Testosterone : Cortisol Ratio

The plasma levels of testosterone (T) and cortisol (C) could represent anabolic and catabolic tissue activities, respectively. Although the T : C ratio has been suggested as a marker of training stress,[96,97] the available data in the literature concerning androgen and C responses to tapering in athletes are inconclusive (table V). In a study on collegiate runners and swimmers, Flynn et al.[48] observed no change in the runners’ total testosterone (TT), free testosterone (FT) and TT : C or FT : C ratios during 3 weeks of taper. Within the same study, on the other hand, a group of swimmers’ TT and FT returned towards baseline during the taper, after showing blunted values throughout the intensive training phases of the season. No changes were noticed in the TT : C and FT : C ratios. Interestingly, changes in TT and FT during training and taper, but not in TT : C or FT : C ratios paralleled changes in performance during criterion swims.[48] Male cyclists’ serum T increased by 5.3%, and 24-hour urinary C decreased marginally by 4.6% during 10 days of reduced training, in the face of a 1.2% improvement in performance. In addition, the serum T : urinary C ratio was unaltered by the taper.[39] No changes were seen in resting blood levels of T, C and TT : C in runners performing a 3-week step taper,[42] nor in these variables and sex-hormone binding globulin (SHBG) in elite weightlifters after either 1 or 4 weeks of taper, during which competition performance improved by 8.0 and 17.5kg, respectively.[15]

Mujika and colleagues[11,12,26] have also assessed the effects of tapering on selected hormones in swimmers and middle-distance runners. In a study on swimmers, plasma TT, non-SHBG-bound-testosterone (NSBT), which is the sum of FT and albumin-bound T representing the biologically active
fraction of T, C, TT : C and NSBT : C remained stable during a 4-week taper subsequent to 8 weeks of intensive training, despite large variations in training volume. Nevertheless, the 4 weeks of taper resulted in a 2.3% improvement in competition performance and percentage variations in swimming performance during the taper correlated with changes in the TT : C (r = 0.81) and NSBT : C (r = 0.76) ratios, and with changes in NSBT concentration (r = 0.71).

In an initial 6-day taper study on 800m runners, TT, FT, C, TT : C and FT : C remained stable as a result of the taper and individual changes in these markers did not parallel changes in performance during the taper. However, TT correlated inversely with low-intensity continuous training distance during the taper and positively with high-intensity interval training distance. A subsequent study on 800m runners who also tapered for 6 days showed increased TT values after the taper, attributed to the elimination of low-intensity continuous training from the main part of the training sessions during the taper. The mechanism for increased TT post-taper is thought to relate to enhanced pituitary response to the preceding period of intense training, bringing about a positive influence on androgenic-anabolic activity during the subsequent taper, characterised by reduced levels of physiological stress.

In view of the relationship between LH and T, regulated by the hypothalamic-pituitary-testicular axis, and given that the C secretion is in part controlled by a common regulatory pathway (i.e. the hypothalamic-pituitary-adrenocortical axis), future investigations should assess possible changes in the adrenocorticotropic hormone (ACTH) concentration during the taper.

Changes in resting C concentration during the taper have been proposed as a means of monitoring performance capacity in athletes (table V). Collegiate swimmers’ resting C values declined by 23–30%, T concentration increased by 22% during the first taper, and the athletes’ competition performance improved by an average of 3.2% in two different 2- to 3-week tapers within a season. On the other hand, no changes in TT, C or the TT : C ratio were observed during 6 weeks of progressive increase and 2 weeks of gradual decrease in training volume in well trained swimmers. A follow-up investigation on elite swimmers over a two-season period showed that the 1.5–2.1% performance improvements during the tapers before the major competitions of each season were positively related with the corresponding 22–49% increases in post-competition peak lactate concentrations, but negatively related (r = –0.66) with the 19–29% change in resting pre-competition plasma C concentration. The conclusion of this study was that a low C concentration formed a prerequisite for improved performance in events that rely largely on the contribution of anaerobic metabolism to total energy supply. In keeping with this conclusion, Mujika et al. observed strong correlations between changes in peak blood lactate concentration after an 800m running race during a 6-day taper and changes in serum C (r = –0.75) and the TT : C and FT : C ratios (r = 0.82). Collectively these findings indicate that a hormonal milieu propitious to anabolic processes is necessary for optimum function of the glycolytic power system and performance in middle-distance events.

Elite junior rowers showing clear signs of over-reaching and hypothalamic downregulation during a high-load training phase reportedly recovered during a subsequent week of taper. Time trial (2000m) performance improved by 6.3%, while peripheral and central steroid hormone concentrations increased by about 10%. These changes were accompanied by positive changes in the Recovery-Stress-Questionnaire for Athletes, which led the authors to suggest that the hypothalamus plays an important role in integrating different kinds of stress influences, and responds by means of the endocrine
Female collegiate swimmers’ salivary C levels have been reported to decrease back to baseline values after 4 weeks of taper, consisting of a progressive 63% reduction in training volume. A similar finding was reported in male swimmers, whose salivary C decreased marginally by 4.8% during the taper, to attain the lowest values of the entire training season. Several investigations, however, have reported unchanged or slightly increased C concentrations as a result of a taper in swimmers, cyclists, and rowers. Plasma C concentrations are subject to different kinds of physiological and psychological stressors, which could explain conflicting findings. The physical stress produced by the pre-taper intensive training could be replaced in the post-taper condition by the psychological stress associated with the oncoming major competition.

A recent investigation by Atlouisi et al. speculates that explanations for discrepancies among studies include: (i) C binding with corticosteroid binding globulin; (ii) varying densities of receptors in target tissues; and (iii) pre-receptor metabolism of C by tissue-specific enzymes 11β-hydroxysteroid dehydrogenase (11β-HSD). Two isoenzymes of 11β-HSD interconvert active C and inactive cortisone (Cn) within target cells, modulating C action at an autocrine level in peripheral tissues. Given that the 24-hour urinary C : Cn ratio is a valid index of renal 11β-HSD activity, it was suggested that the C : Cn ratio could provide insight into the adaptations of the hypothalamic-pituitary-adrenal axis to training and tapering. The study of Atlouisi et al. showed a decline of the C : Cn ratio during 3 weeks of taper subsequent to 4 weeks of intensive training.

4.3 Growth Hormone and Insulin-Like Growth Factor-1

Human growth hormone levels increased 10% from baseline following 3 weeks of intensive training in rowers, but decreased by 30% during the following 2-week taper phase. Insulin-like growth factor-1 (IGF-1), a 7.5 kDa polypeptide that
plays an important role in the regulation of somatic growth, metabolism, and cellular proliferation, differentiation and survival, has also been measured before and after taper in athletes.\cite{114} Nine male collegiate swimmers’ total serum IGF-1 increased progressively by 76% above baseline during 4 months of intensive training and these elevated values were maintained during 4 weeks of tapering. The levels of free IGF-1 increased by 77–102% at all training measurements, including the taper. The levels of immunoreactive IGF binding protein-3 (IGFBP-3) were 30% higher after intensive training, and remained elevated during tapering. In contrast, IGF binding protein-1 declined to baseline values during tapering. Performance measures were not reported, but the authors of the study suggested that the increased total and free IGF-1 and total IGFBP-3 could have played a role in the observed reductions in skinfold measurements during the season.\cite{114} Two weeks of reduced training characterised by less intense training, no weight training and shorter interval training in junior team handball players resulted in a 7.7% increase in IGF-1, which returned to baseline after being depressed during a period of intensive training. This change during the taper was concomitant with gains in repeated sprint (2.1%) and vertical jump (3.2%) performance.\cite{115}

4.4 Other Hormones

Other hormones have been suggested as markers of training stress and overtraining\cite{102,116,117} during periods of taper. To date, the relevant studies have yielded inconclusive results about the usefulness of hormonal monitoring. Thyroid-stimulating hormone, triiodothyronine and thyroxine concentrations, for instance, were not altered by a 4-week taper in male national and international level swimmers.\cite{111} Steinacker et al.\cite{114} reported increased resting insulin and C-peptide levels during a 1-week taper in rowers, suggesting a higher post-taper carbohydrate turnover capacity. This suggestion, however, was not reflected by the exercise lactate levels, which remained unchanged and there was no indication of glycogen depletion among the participating subjects.

5. Neuromuscular Changes

The extraordinary plasticity of skeletal muscle tissue allows it to adapt to variable levels of functional demands, neuromuscular activity and hormonal signals, and reversibly change its functional characteristics and structural composition.\cite{118,121} A pre-competition taper presumably reduces the demands placed on the neuromuscular system compared with previous phases of a training programme.

5.1 Strength and Power

Increased strength and power as a result of a taper have been a common observation in different athletic activities (table VI). In 1985, Costill et al.\cite{3} were among the first researchers to describe such gains in swimmers. These investigators described an 18% improvement in swim bench power and a 25% gain in actual swim power in a group of 17 collegiate swimmers undergoing a 2-week taper. Swim power improvement correlated with a 3.1% competition performance gain ($r = 0.68$). The reduced training may have allowed for an increase in maximal tension development through changes in the contractile mechanisms and/or neural controls on fibre recruitment.\cite{3} In keeping with these results, Johns et al.\cite{7} observed a 5% increase in tethered swimming power and a 2.8% improved performance in competition after 10 and 14 days of taper. National and international level swimmers’ isolated mean arm and leg power has also been shown to increase during a 4-week taper, especially during the initial 5–24 seconds of exercise.\cite{2} Competition performance increased by an average of 2.6% during the taper.

Raglin et al.\cite{14} also reported gains during a 4- to 5-week taper in swimming peak power (16%) and mean power (20%). In addition, they observed a
23% gain in neuromuscular function, as determined with the soleus Hoffmann reflex, an indicator of the general excitability of the α-motor neuron pool. These changes correlated with changes in power and were accompanied by a 2.0% improvement in competition velocity. The investigators concluded that neurological adaptations may have a role in the performance gains that often follow the taper. More recently, Trappe et al. noted a 7–20% increase in swim bench muscle power, a 13% increase in swim power and a 4% enhancement in competition performance as a result of a 3-week taper in six male collegiate swimmers. However, Prins et al. and Hooper et al. reported unchanged muscular force as a result of a taper, concluding that pre-taper force levels were not compromised by the training load undertaken by swimmers. Differences with studies reporting gains in force after a taper may relate to variations in the calibre of the swimmers, and the training and tapering programmes undertaken.

In cross-country and middle-distance runners, Shepley et al. observed an increase in maximal voluntary isometric strength of the knee extensors after both a high-intensity/low-volume and a low-intensity/moderate-volume taper, despite unchanged percentage motor unit activation. Percutaneously nerve-stimulated evoked contractile properties of the right knee extensors also improved during both tapers, with peak twitch torque gains amounting to 13% and 19%, respectively. Similar positive changes were also observed when the athletes performed no training at all for a week, a strategy that resulted in a 3% performance decline. This and other similar findings, such as a 12% gain in peak tethered swimming force, which was not accompanied by statistically significant improvements in competition performance during a taper in male and female swimmers, or a 2.8% treadmill running performance gain despite a lack of change in leg peak isometric or concentric force, suggest that the involvement of muscular force is influenced by a multiplicity of physiological and environmental factors.

In contrast with these findings, the evoked contractile properties (peak twitch torque, time to peak twitch, half relaxation time and maximum rate of torque development) were unchanged after 4 and 10 days of taper in strength trained athletes. The taper, however, induced an increase in the isometric peak torque of the elbow flexors (7.5% at day 6, and 6.8% at day 10 of the taper), despite unchanged

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Table VI. Effects of the taper on muscular strength and power

<table>
<thead>
<tr>
<th>Study (year)</th>
<th>Athletes</th>
<th>Taper duration (days)</th>
<th>Strength and/or power</th>
<th>Performance measure</th>
<th>Performance outcome (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Costill et al. (1985)</td>
<td>Swimmers</td>
<td>14</td>
<td>↑</td>
<td>46–1509m competition</td>
<td>2.2–4.6 impr</td>
</tr>
<tr>
<td>Cavanaugh and Musch (1989)</td>
<td>Swimmers</td>
<td>28</td>
<td>↑</td>
<td>46–1509m competition</td>
<td>2.0–3.8 impr</td>
</tr>
<tr>
<td>Prins et al. (1991)</td>
<td>Swimmers</td>
<td>28</td>
<td>↔</td>
<td>NR</td>
<td>NR</td>
</tr>
<tr>
<td>Johns et al. (1992)</td>
<td>Swimmers</td>
<td>10–14</td>
<td>↑</td>
<td>46–366m competition</td>
<td>2.0–3.7 impr</td>
</tr>
<tr>
<td>Shepley et al. (1992)</td>
<td>Runners</td>
<td>7</td>
<td>↑</td>
<td>Treadmill time to exhaustion</td>
<td>6–22 impr</td>
</tr>
<tr>
<td>Gibala et al. (1994)</td>
<td>Strength trained</td>
<td>10</td>
<td>↑</td>
<td>Voluntary elbow flexor strength</td>
<td>7 impr</td>
</tr>
<tr>
<td>Houmard et al. (1994)</td>
<td>Runners</td>
<td>7</td>
<td>↔</td>
<td>5km treadmill time trial</td>
<td>2.8 impr</td>
</tr>
<tr>
<td>Martin et al. (1994)</td>
<td>Cyclists</td>
<td>14</td>
<td>↑</td>
<td>Incremental maximal test</td>
<td>8.0 impr</td>
</tr>
<tr>
<td>Raglin et al. (1996)</td>
<td>Swimmers</td>
<td>28–35</td>
<td>↑</td>
<td>Competition</td>
<td>2.0 impr</td>
</tr>
<tr>
<td>Hooper et al. (1998)</td>
<td>Swimmers</td>
<td>14</td>
<td>↑</td>
<td>100m, 400m time trial</td>
<td>↔</td>
</tr>
<tr>
<td>Hooper et al. (1999)</td>
<td>Swimmers</td>
<td>14</td>
<td>↔</td>
<td>100m time trial</td>
<td>↔</td>
</tr>
<tr>
<td>Trappe et al. (2000)</td>
<td>Swimmers</td>
<td>21</td>
<td>↑</td>
<td>Competition</td>
<td>3.0–4.7 impr</td>
</tr>
</tbody>
</table>

impr = improvement; NR = not reported; ↑ indicates increased; ↔ indicates unchanged.
motor unit activation and increased concentric peak torque at low velocity (7.7% at day 4, and 2.8% at day 10). These results were attributed to enhanced contractile performance and/or an increase in neural activation.\textsuperscript{[123]} Collegiate cyclists showed improvements in their isokinetic quadriceps strength at 30° and 120° per second after a 2-week step taper, but strength gains were not correlated with improvements in laboratory cycling performance.\textsuperscript{[124]}

The above studies suggest that muscular strength and power production is usually suppressed by chronic intensive training, but most likely recover during the taper, when the training load is markedly reduced. The mechanisms responsible for the taper-induced improvements in muscular strength and power may be related to local changes in enzymatic activities, and single muscle fibre characteristics positively affecting neuromuscular, biomechanical and metabolic efficiency.

5.3 Muscle Fibre Characteristics

5.3.1 Muscle Fibre Size

In male collegiate swimmers, no changes in type I fibre diameter and cross-sectional area were observed after a 3-week taper. On the other hand, type IIA fibre diameter increased by 11%, and cross-sectional area by 24%.\textsuperscript{[17]} In male cyclists, a 7-day high-intensity (85–90% of maximal HR)/low-volume (progressive reduction from 60- to 20-minute sessions) taper brought about a moderate 6.9% increase in type I fibres’ cross-sectional area and a much larger 14% increase in type II fibres. When the taper was high-volume (60-minute sessions)/low-intensity (progressive reduction from 85% to 55% of maximal HR), the observed 7.0 and 11% increases in type I and type II fibres were not statistically significant.\textsuperscript{[24]}

5.3.2 Metabolic Properties

Only one investigation is available that analysed the effects of the taper on the metabolic properties of different fibre types. Neary \textit{et al.}\textsuperscript{[54]} did not observe changes in mitochondrial enzymes carnitine palmitoyltransferase, citrate synthase, \(\beta\)-hydroxyacyl CoA dehydrogenase and cytochrome oxidase, and the cytoplasmic enzyme lactate dehydrogenase after 4 or 8 days of taper. The lack of change could have been related to the small group sizes and/or a mixture of males and females within each group.\textsuperscript{[54]} Shepley \textit{et al.}\textsuperscript{[30]} observed an 18% increase in citrate synthase activity after a 7-day high-intensity/low-volume taper in a group of nine male runners. In light of this finding, they attributed part of the laboratory performance gain to an increased capacity to maintain a high rate of oxidative energy production, despite the potentially inhibitory effects of increasing intracellular temperature, hydrogen ion and lactate concentration, and superoxide free radicals.\textsuperscript{[30]}

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The single fibre level, are more pronounced when a high-intensity taper is performed and contribute to performance changes observed in whole body muscle function. Type II fibres seemed to be more responsive to the taper, possibly due to their specific contractile properties and a greater potential to increase their oxidative enzyme capacity.[24]

5.3.3 Contractile Properties

Neuromuscular adaptations also occur at the single fibre level after tapering. After a 3-week taper, Trappe et al.[17] observed, in deltoid muscle samples of highly trained collegiate swimmers 30% higher peak isometric force, 67% faster shortening velocity and 250% higher absolute fibre power in type IIA muscle fibres. Type I fibres also increased their shortening velocity by 32%. These observations led the authors to suggest that changes in contractile properties may have been tightly related with the observed improvements in whole muscle strength and power measures after the taper.[17]

6. Immunological Changes

Many aspects of the immune system exhibit a range of responses to acute exercise and prolonged training in athletes preparing for competition: increased leucocyte cell counts particularly neutrophils and lymphocyte subsets,[105] decreased functional activity of the neutrophil respiratory burst and natural killer cytotoxicity,[125,126] decreased response to mitogen-induced T-lymphocyte proliferation,[127] decreased concentration of mucosal immune parameters, such as secretory immunoglobulin A,[128,129] impaired delayed-type hypersensitivity response (T-cell function),[130] unchanged or increased circulating concentration of cytokines, such as the interleukin family, tumour necrosis factor-α and interferon-γ.[131]

Despite the high level of clinical and research interest in the effects of exercise and training on immunity, there are only a limited number of studies that have directly examined immunological changes in athletes during the taper phase prior to competition. Most studies have focused on the acute effects of exercise on cellular and soluble immune responses immediately post-exercise and in the first few hours of recovery. Observations of a temporary suppression in the immune response after intensive exercise lead to the creation in early to mid 1990s of the ‘J-curve’[132] and ‘open window’[133] models. More recently, attention has focused on possible mechanisms of immunosuppression, with the T-helper lymphocyte subsets Th1 and Th2 thought to regulate immunological control.[134] It appears that the prevailing cytokine pattern elicited by exercise and training activates specific Th1-precursor cells leading to upregulation of either the Th1 (cell-mediated immunity) or Th2 (humoral immunity and antibody production) response.[134] Future studies are required to fully characterise the time-course of changes in these key immunological control mechanisms during training and the taper.

While exercise and training-induced perturbations in immune function of healthy athletes are relatively transient, it is thought that an inability to restore baseline levels after continual upward and downward fluctuations may, in some athletes after several years of training at the elite level, result in chronic immunosuppression and an increased risk of illness.[135,136] Although evidence of immunosuppression in athletes is indicated indirectly by between-subject comparison of trained subjects with sedentary individuals, a more direct indication is obtained by analysis of within-subject changes for a given athlete during a specified training period or taper prior to competition. The key questions for the athletes and coaches, clinicians and researchers are the magnitude and duration of immunological changes with training and whether any observed changes manifest into relevant clinical consequences and impact negatively on training and competitive performance.
6.1 Immune Cells

Studies of athletes in training across a range of sports have examined various immune cell counts and functional activities. In general, these studies show relative stability in immunological parameters with little evidence of clinical consequences. While there is substantial evidence in controlled studies that short periods of intensified training lower resting cell counts,\textsuperscript{137-140} observational studies of athletes in training have failed to demonstrate the same findings. One study which experimentally manipulated training volume and intensity in nine well trained cyclists before an 18-day taper showed improvements in cycling efficiency (6%) and simulated 20km time trial performance (6%) whereas resting immune status (lymphocyte subset counts and incidence of respiratory illness) was unchanged throughout a 10-week training programme.\textsuperscript{39} Stability in cell counts was also observed in 12 young male runners during 40 days of heavier and easier endurance training; transient reductions were observed in lymphocyte subsets (CD4+ and CD4/CD8 ratio), particularly during periods of increased training (high-intensity 1000m intervals) compared with increased volume (double normal training volume).\textsuperscript{141}

A small number of studies have directly examined immune cell changes during a taper. National and international level swimmers tapering for 4 weeks after 8 weeks of intense training had a decreased percentage of neutrophils after the taper, whereas lymphocytes tended to increase.\textsuperscript{10} The increase in lymphocytes correlated positively with the reduction in training volume during taper ($r = 0.86$). In contrast, a short 6-day taper (involving an 80% reduction in high-intensity interval training) in nine male middle-distance runners elicited a modest but statistically significant increase in neutrophils (13%) and granulocytes (11%). However, the magnitude of the observed changes was considered too small to be of immunological significance.\textsuperscript{10,12} A 3-week taper (50% reduction in training volume and intensity after 22 weeks of 18–20 h/week training) in 20 collegiate swimmers elicited an increase in total leucocytes but a decrease in B-cell lymphocyte count.\textsuperscript{142} However, total T-cells, neutrophils, and lymphocyte proliferative responses were unchanged over the same period suggesting that overall immunoprotection was largely unchanged. It also appears that antioxidant supplementation during the taper enhances plasma antioxidant protection,\textsuperscript{41} potentially maintaining the delicate balance between oxidant and antioxidant properties of immune cells.\textsuperscript{143} Sixteen male triathletes volunteered for a controlled-training double-blind antioxidant supplementation and taper programme. Two weeks of tapered training induced decreases in resting blood glutathione concentration, erythrocyte superoxide dismutase activity and plasma antioxidant status, but had no effect on lipoperoxidation or markers of muscle damage.\textsuperscript{41} In seven male distance runners, a 7-day taper did not enhance serum free radical scavenging capacity prior to, or during, exercise.\textsuperscript{104} Collectively these studies show small transient changes in the distribution of immune cells during the taper that are unlikely to have any substantial clinical consequences.

6.2 Immunoglobulins

In addition to cellular changes, there has been extensive examination of training-induced changes in soluble immunoproteins in athletes, particularly secretory immunoglobulin A (SIgA), which plays a major role in effective specific immunity,\textsuperscript{136} and the immunoregulatory cytokines which are a diverse family of intracellular cellular signalling molecules released by immune cells that exert important influences on inflammatory and immune responses.\textsuperscript{144} Some training studies showed that marked reductions in SIgA after acute exercise\textsuperscript{145} and in the latter stages of a prolonged season of training,\textsuperscript{128,146} are associated with an increased risk of upper respirato-
ry illness. Elite swimmers showed a 4% reduction in SIgA per month over a 7-month season and values <40 mg/L were associated with an increased risk of illness. In contrast, other studies of swimmers and rowers have not shown this association. The interpretation of these disparate findings requires consideration of the inherent biological variability in immune parameters and methodological differences in experimental design, sample collection and assay techniques. Clearly, further studies are required to resolve these conflicting findings of the soluble immune protein response to training and the taper prior to competition.

6.3 Cytokines

Similar to leucocytes and immunoglobulins, there are many studies of the acute effects of exercise on circulating cytokine concentration, but little is known about longitudinal changes in highly trained athletes during training and the taper. Cytokines have a role in both the acquired and innate arms of host defence and can be pro- or anti-inflammatory in nature. Most of the exercise studies have focused on just three cytokines, interleukin (IL)-1α, IL-6 and tumour necrosis factor-β. In general, the blood concentration of these cytokines is either unchanged or increased in response to acute exercise such as the marathon. There are also conflicting findings on the influence of exercise intensity and type on cytokine response. The pattern of post-exercise cytokine response (increases in IL-6 and IL-10) to eccentrically biased bench press and leg curl exercise in untrained males was less pronounced and occurred at a later timepoint (72–144 hours post-exercise) than after strenuous endurance exercise. Interpretation of the biological significance is also complicated by the notion that the immunological action of cytokines is regulated by the balance between concentration of the active molecules and their inhibitors, rather than their circulating concentration per se. Recent studies have pointed to cytokines such as IL-1 and IL-6 forming a communication link between systemic circulation, energy metabolism and skeletal muscle adaptation to exercise. Studies are required to characterise the time course of cytokine changes during training and the taper, in order to fully understand physiological mechanisms underpinning these processes in athletes.

Collectively, the interpretation of these studies suggests that athletes should be mindful of excessive loads during peak training periods, but can train with confidence during the taper prior to competition in the knowledge they are unlikely to compromise overall immunological protection. Given the variable findings of existing studies, one-off measures of cellular and soluble immune parameters are unlikely to be informative unless immunosuppression is severe. A multi-faceted approach involving systematic monitoring of underlying mucosal and cellular immunity, review of clinical, training and lifestyle factors and attention to practical strategies may provide a more effective means of managing the health of athletes during the taper period. This approach should be communicated to athletes, coaches and physicians to reassure the sporting community that maintaining good health during the taper is compatible with elite level training.

7. Psychological Changes

It is unlikely that the physiological changes completely explain the performance benefits associated with a successful taper. Competition performance is the result of a conscious effort and it would be a major oversight to obviate the paramount contribution of psychological and motivational factors to post-taper athletic performance. Optimisation of an athlete’s physiological status resulting from a well designed tapering strategy is presumably accompanied by beneficial psychological changes, including mood state, perception of effort and quality of sleep. Reports describing these changes are summarised in...
sections 7.1 to 7.3, but an in-depth analysis and discussion of the psychological parameters affected by a taper is beyond the scope of this review.

7.1 Mood State

Mood states are sensitive to variations in the training load undertaken by athletes and alterations should be expected as a result of a taper where the training load is markedly reduced. Numerous investigators have reported mood state changes associated with a pre-competition taper. Most, but not all, of these reports indicate that tapering induces positive changes in the athlete’s mood state, contributing to enhanced performance measures (table VII). Morgan et al. and Raglin et al. first described decreased global mood scores computed from the Profile of Mood States (POMS) questionnaire in college athletes tapering for 4 weeks. The decrease in global mood scores was associated with decreased levels of perceived fatigue, depression, anger and confusion accompanied by increased levels of vigour. These investigators also reported that decreases in mood disturbance were related to reductions in the training load with identical effects in both males and females. However, some individual athletes did not respond to the taper and no declines in tension scores were observed, with values being higher in female than male athletes. In fact, tension was the only mood variable that remained elevated above baseline following the taper. It has been speculated that elevated tension probably reflects anxiety provoked by the anticipation of the pending major championship.

In contrast, Taylor et al. reported sex differences in tapering-induced mood state alterations. Relatively small (1.3%) competition performance gains attained by female swimmers during taper were presumably related with a deterioration in mood state indicated by increases in tension-anxiety (56%), depression-dejection (218%) and confusion-bewildernment (86%), and a 20% decrease in vigour-activity ratings.

Flynn et al. reported a 17% reduction in the global mood state of a group of male swimmers after a 3-week taper. A similar 16% decline in total mood disturbance was also observed by Raglin et al. in 12 collegiate female swimmers tapering for 4–5 weeks. This decline correlated moderately with mean swimming power (r = 0.34), which increased by 20% with the taper. Swimming velocity in competition also improved by 2.0%. Hooper et al. observed reduced tension, depression and anger after 1 week of taper in state-level swimmers and a 10% lower total mood disturbance after 2 weeks, which resulted in marginal time trial performance gains of 0.2% in 100m and 0.7% in 400m events. However, in a subsequent investigation on international calibre swimmers, these authors did not detect any change in the total mood disturbance after a 2-week taper. In another study, young competitive swimmers showed an acute decrease in total mood disturbance after practices that were shorter in duration than usual during a pre-competition week of taper. These competitive swimmers reported short-term mood benefits including decreases in scores of depression, confusion and tension. However, these acute mood benefits during training prior to competition did not appear to be related to subsequent performance in competition.

Total mood disturbance has also been shown to decline by 21% in track cyclists tapering for 2 weeks after a period of overreaching. At the same time, simulated 4km pursuit performance improved by 2.0% and mean power output by 2.3%, but no substantial correlations were found between changes in psychological variables and performance changes. During the tapering period the total mood score of the POMS also decreased in nine male and five female world-class canoeists tapering for 3 weeks, so that 1 week before the Olympics this score was of the same magnitude as the basal off-
**Table VII.** Effects of the taper on mood state and perception of effort

<table>
<thead>
<tr>
<th>Study (year)</th>
<th>Athletes</th>
<th>Taper duration (days)</th>
<th>Mood state</th>
<th>Perception of effort</th>
<th>Performance measure</th>
<th>Performance outcome (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Morgan et al. (1987)</td>
<td>Swimmers</td>
<td>28</td>
<td>↑↑</td>
<td>↓</td>
<td>NR</td>
<td>NR</td>
</tr>
<tr>
<td>Raglin et al. (1991)</td>
<td>Swimmers</td>
<td>28</td>
<td>↑↑</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
</tr>
<tr>
<td>Snyder et al. (1993)</td>
<td>Cyclists</td>
<td>14</td>
<td>NR</td>
<td>↓</td>
<td>NR</td>
<td>NR</td>
</tr>
<tr>
<td>Berglund and Säärström (1994)</td>
<td>Canoeists</td>
<td>21</td>
<td>↑↑</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
</tr>
<tr>
<td>Flynn et al. (1994)</td>
<td>Runners</td>
<td>21</td>
<td>↔↔</td>
<td>↑↑</td>
<td>23m, 366m time trial ↑↑</td>
<td>↑↑</td>
</tr>
<tr>
<td>Houmard et al. (1994)</td>
<td>Runners</td>
<td>7</td>
<td>NR</td>
<td>↔↔</td>
<td>5km treadmill time trial ←3 ↑</td>
<td>↑↑</td>
</tr>
<tr>
<td>Raglin et al. (1996)</td>
<td>Swimmers</td>
<td>28–35</td>
<td>↑↑</td>
<td>NR</td>
<td>Competition</td>
<td>2.0 ↑</td>
</tr>
<tr>
<td>Berger et al. (1997)</td>
<td>Swimmers</td>
<td>7</td>
<td>↑↑</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
</tr>
<tr>
<td>Taylor et al. (1997)</td>
<td>Swimmers</td>
<td>NR</td>
<td>Deteriorated</td>
<td>NR</td>
<td>Competition</td>
<td>1.3 ↑</td>
</tr>
<tr>
<td>Hooper et al. (1998)</td>
<td>Swimmers</td>
<td>14</td>
<td>↑↑</td>
<td>NR</td>
<td>100m, 400m time trial ↔</td>
<td>↔</td>
</tr>
<tr>
<td>Berger et al. (1999)</td>
<td>Cyclists</td>
<td>14</td>
<td>↑↑</td>
<td>NR</td>
<td>4km simulated pursuit 2.0 ↑</td>
<td>↑↑</td>
</tr>
<tr>
<td>Hooper et al. (1999)</td>
<td>Swimmers</td>
<td>14</td>
<td>↔↔</td>
<td>NR</td>
<td>100m time trial ↑</td>
<td>↔</td>
</tr>
<tr>
<td>Martin and Andersen (2000)</td>
<td>Cyclists</td>
<td>7</td>
<td>NR</td>
<td>↓</td>
<td>Incremental maximal test ←6 ↑</td>
<td>↑↑</td>
</tr>
<tr>
<td>Martin et al. (2000)</td>
<td>Cyclists</td>
<td>7</td>
<td>↔↔</td>
<td>NR</td>
<td>Incremental maximal test ←6 ↑</td>
<td>↑↑</td>
</tr>
<tr>
<td>Steinacker et al. (2000)</td>
<td>Rowers</td>
<td>7</td>
<td>↑↑</td>
<td>NR</td>
<td>2000m time trial – competition 6.3 ↑</td>
<td>↑↑</td>
</tr>
<tr>
<td>Eliakim et al. (2002)</td>
<td>Handball players</td>
<td>14</td>
<td>↑↑</td>
<td>NR</td>
<td>4 × 20m sprint, vertical jump 2.1–3.2 ↑</td>
<td>↑↑</td>
</tr>
<tr>
<td>Margaritis et al. (2003)</td>
<td>Triathletes</td>
<td>14</td>
<td>↑↑</td>
<td>NR</td>
<td>30km outdoor duathlon 1.6–3.6 ↑</td>
<td>↑↑</td>
</tr>
<tr>
<td>Neary et al. (2003)</td>
<td>Cyclists</td>
<td>7</td>
<td>↔↔</td>
<td>NR</td>
<td>20km simulated time trial 5.4 ↑</td>
<td>↑↑</td>
</tr>
</tbody>
</table>

NR = not reported; ↓ indicates decreased; ↑ indicates improvement; ↔ indicates unchanged.
season total mood score of the POMS.\textsuperscript{157} Twenty long-distance triathletes’ POMS score also decreased by 10–12% after 14 days of tapering, during which total training load was progressively reduced by 32–46%.\textsuperscript{41} In contrast, Martin et al.\textsuperscript{99} did not observe any change in the total mood scores or the specific mood state scores (i.e. tension, depression, anger, vigour, fatigue and confusion) in a group of cyclists tapering for 1 week after 6 weeks of high-intensity interval cycling, despite major differences in the training load and performance assessments at the end of each of these training phases. These investigators also indicated that some athletes with relatively large mood disturbances responded well to the taper, whereas others responded poorly, suggesting a low predictability of the POMS for responses to the taper.\textsuperscript{99}

A 1-week step taper was enough for ten world-class male junior rowers showing clear signs of overreaching to recover after 18 days of intense training. Somatic complaints and somatic relaxation assessed with the Recovery-Stress-Questionnaire for Athletes returned to baseline values during the taper. Maximal power during an incremental rowing test increased by 2.7% and a 2000m time trial performance improved by 6.3%.\textsuperscript{84} Similarly, Eliakim et al.\textsuperscript{115} reported a return to baseline in the self-assessment physical conditioning score during 2 weeks of less intense training in a group of junior handball players, the values of which were reduced during the preceding intensive training period.

7.2 Perception of Effort

The perception of effort during exercise is influenced by a number of physiological and psychological variables,\textsuperscript{160-162} some of which are presumably affected by a taper. The most widely used measure of effort perception is Borg’s Rating of Perceived Exertion (RPE),\textsuperscript{163,164} which has been shown to change as a result of tapered training (table VII). The perception of effort was decreased in swimmers of both sexes after a 4-week taper in collegiate athletes.\textsuperscript{154} Flynn et al.\textsuperscript{48} reported that RPE while swimming at 90% of pre-season $\dot{VO}_{2\text{max}}$ decreased from an average value of 14 (somewhat hard/hard) after 2 weeks of hard training, to 9 (very light) at the end of the taper. On the other hand, these same investigators did not observe any taper-associated changes in the RPE of eight male cross-country runners during treadmill running at 75% of pre-season $\dot{VO}_{2\text{max}}$, despite major changes in training loads. The same was true in a study on distance runners performing on a treadmill at 80% $\dot{VO}_{2\text{peak}}$ before and after a 7-day taper.\textsuperscript{35} and on male cyclists performing a simulated 20km time trial before and after a taper of the same duration.\textsuperscript{23}

The HR-RPE relationship could be a more valid marker for monitoring an athlete’s response to the taper. Neary et al.\textsuperscript{23} observed a 4.5% decline in the HR : RPE ratio after a 7-day stepwise taper during which training volume was reduced by 50% and performance enhanced by 5.1%. Martin and Andersen\textsuperscript{51} reported a 3.2% decline in the HR : RPE ratio after a 1-week taper in collegiate cyclists, associated with a 6% improvement in a graded exercise to exhaustion. Changes in the HR-RPE relationship during 6 weeks of high-intensity interval training were a powerful predictor of performance responses to the taper. Subjects who demonstrated the greatest decrease in HR for a given RPE tended to have the greatest performance increases in response to the taper ($r = 0.72$), confirming the usefulness of the HR-RPE relationship.\textsuperscript{51} Using a similar approach, the submaximal blood lactate concentration (H[La]) : RPE ratio has been put forward as a valid physiological-psychological index of fatigue.\textsuperscript{156} During 2 weeks of recovery training, the values for the H[La] : RPE ratio, which were reduced as a result of two previous weeks of high-intensity interval training, returned to normal baseline levels.
7.3 Quality of Sleep

Given that tapering strategies are characterised by reduced training loads, it seems plausible that sleep quality could also be affected by the taper. Forcing habitual exercisers to spend a sedentary day modifies sleep patterns and body temperature. With reduced exercise load, slow-wave sleep pressure is reduced, resulting in lower levels of slow-wave sleep and increased rapid eye movement sleep.\[^{165}\]

The most in-depth investigation dealing with sleep patterns during tapering in athletes indicates that sleep onset latency, time awake after sleep onset, total sleep time and rapid eye movement sleep time were unchanged during the taper in female swimmers. On the other hand, slow-wave sleep, which represented 31% of total sleep time during the peak training period, was reduced to 16% following the taper, suggesting that the need for restorative slow-wave sleep is reduced with reduced physical demand.\[^{16}\] However, the number of movements during sleep was reduced by 37% after the taper, indicating less sleep disruption compared with previous periods of higher training loads.\[^{16}\] Hooper et al.\[^{49}\] reported a slightly improved quality of sleep in swimmers after 2 weeks of tapering for the Australian national championships.

8. Insights from Mathematical Modelling

In an attempt to go beyond descriptive experimental procedures to analyse the consequences of training, mathematical analysis of the relationship between performance and the amounts of training was initiated by Banister and coworkers.\[^{166-168}\] The development of such mathematical models could contribute to a better understanding of tapering effects.

8.1 Fatigue and Adaptation Model

Taper effects can be described in model studies by the difference in the time course of fatigue and adaptation induced by exercise bouts. Training and performance measurements were undertaken to establish a dose-response relationship based on the negative and positive influences of training.\[^{166}\] Model performance was considered to be the balance between these two antagonistic functions ascribed respectively to fatigue (negative) and adaptation (positive). A controlled experiment in which total work was reduced after 28 days of strenuous training showed that repeated training bouts could yield a fatigue accumulation greater in magnitude than adaptation.\[^{168}\] A greater increase in fatigue than adaptation provoked a transient decrease in performance during the intensified period of training. A subsequent reduction of training loads allowed fatigue (negative influence) to dissipate more quickly than adaptation (positive influence), yielding to criterion performance peaking.\[^{168}\]

Training responses were modelled in 18 elite swimmers over a full competitive season including three taper periods.\[^{8}\] This study showed that a progressive reduction of training over 3 or 4 weeks alleviated fatigue accrued with repeated training without compromising the adaptations. The enhancement of competition performance observed with taper was attributed to a reduction of the negative influence of training.\[^{8}\] This general scheme for the effects of taper should be applicable to a large range of sports, since the model adequacy has also been tested in long distance running,\[^{169}\] triathlon,\[^{37}\] weightlifting\[^{102,170}\] and hammer throwing.\[^{171}\] The goodness-of-fit indicators showed that the model structure allowed an acceptable description of the responses to training across these different sports.

Model simulations have been undertaken to determine the optimal design of a training programme including taper duration and pattern of training reduction.\[^{37,172,173}\] Theory and data derived from the model studies suggest that the biological responses to taper primarily involve a restoration of physiological capacities following alterations due to intensi-
fied training. The physiological basis of recovery with tapering would include variations in cardiopulmonary, metabolic and neuromuscular systems, which could have a direct influence on performance.

8.2 Variable Dose-Response Model

New developments in training modelling provide an alternative explanation of the effects of taper. Time-dependent alterations in responses were observed using a model with time-varying parameters. Training experiments in non-athletes showed an enhancement in the negative effect of a training bout when training was intensified and training frequency was increased. These observations yielded a variable dose-response model in which fatigue induced by a training dose varies with the accumulation of training. Responses of six subjects who trained on a cycle ergometer were more precisely described using this new model formulation than the initial model proposed by Banister et al. However, the revised model should be tested with other training designs and in athletes in a real training and competition situation. Nevertheless, to determine whether the new model provides a useful representation of an athlete’s responses to heavy training and tapering, experimental data in athletes were compared with model simulations with similar training variations. The high level of agreement between modelled and actual data gave further support for the underlying theory of the model including the fatigue factor increasing with training.

The variable dose-response model would explain performance peaking by accounting the positive influence of training done during the taper. Model computations show that transient decreases in performance with intensified training could be attributable to a change in the responses to the training dose. A designated work session well assimilated during periods of normal training could be more difficult to cope with when training is intensified. Conversely, a progressive reduction of training volumes or loads would allow the athlete to respond more effectively to this session. Peaking performance with taper would arise from both the recovery from past training and restoration of the tolerance to training. The intensification of training would firstly delay the positive influence of training. The reduction of training would facilitate enhanced performance because of the combination of delayed responses to past training and early reaction to training done during the taper. This observation highlights the importance of maintaining sufficient amounts of training during the taper. From a physiological point of view, the change in dose-response between exercise and performance could be related to neuroendocrine responses to training. Modulations of endocrine system and autonomic nervous system with heavy training could induce a negative change in the body’s adaptive capacity to exercise bouts. Changes in the neuroendocrine environment with reduced training could modify and amplify the recovery and adaptation process, permitting volumes of training during the taper phase to maintain or increase the body’s adaptation for enhanced performance.

9. Future Research

Despite undeniable advances in this area, many questions relating to the physiological consequences of tapering and their performance implications remain to be elucidated. From a physiological point of view, future research should focus on a more systematic assessment of the validity of potentially useful metabolic, biochemical and hormonal indices of adaptation to changing training loads (e.g. blood ammonia, ACTH and urinary catecholamines). Contrary to the static approach to the effects of the taper employed by the majority of studies available to date, investigations of a more dynamic nature are required to describe, and eventually predict the time course of physiological changes during the tapering...
phase. In addition, tapering-induced metabolic changes during actual competitive events need to be addressed. To this aim, the use of spectral analytical techniques such as Fourier-transform infrared spectroscopy shows promise.\(^{(180-190)}\) Notwithstanding the integrative nature of physiological changes associated with athletic training, the relationships between observed changes and performance enhancement should be assessed.

From the point of view of performance optimisation, more research is needed to ascertain the most suitable tapering strategies in strength and power sports (e.g. weightlifting, sprinting, jumping and throwing) on the one hand, and on endurance (e.g. marathon and Olympic distance triathlon) and ultra-endurance (e.g. road cycling and long-distance triathlon) events on the other hand. In addition, optimal tapering programmes for high-intensity intermittent team sports also require further investigation, particularly in the lead-up to multi-day tournaments and championship events.

**10. Conclusions**

Some of the physiological mechanisms underlying the performance gains associated with the taper are slowly being unveiled. Increases in \(\dot{V}O_{2\text{max}}\) during the taper may contribute to post-taper performance gains, but enhanced performances have also been observed without changes in \(\dot{V}O_{2\text{max}}\). A lower oxygen cost of exercise after the taper (i.e. a better economy of movement) can also contribute to improved performances, but this change is more likely to occur in athletes of a lower calibre. Cardiac function and dimensions, and ventilatory function are not generally affected by the taper, and any observed change seems to be a reflection of the athletes’ adaptation to preceding training rather than to the taper itself.

Haematological changes strongly suggest that the reduced training loads undertaken by athletes during the taper facilitate a positive balance between haemolysis and erythropoiesis, contributing to taper-induced performance improvements, but potentially compromising the iron status of the athletes. Reduced training loads will also have an impact on daily energy expenditure and athletes should pay special attention to their energy intake during the taper to avoid energy imbalance and undesirable changes in body composition. Substrate contribution to power production during exercise usually remains stable during the taper, but an elevated contribution from carbohydrates could take place due to increased muscle glycogen concentration. Higher peak blood lactate concentrations after a taper have been related with enhanced maximal performance capabilities in swimming, running, cycling and rowing. On the other hand, unchanged or reduced blood lactate concentrations at submaximal exercise intensities should be expected after an efficient taper. Blood ammonia concentrations have been measured to assess changes in adenine nucleotide degradation during the taper, but results have been inconclusive.

Blood levels of CK are usually reduced after a taper, indicating recovery from training stress and muscle damage. T, C and the T: C ratio can provide information on the physiological stress, recovery and performance capacity of an athlete during the taper, but performance gains also occur without concomitant changes in these parameters. The 24-hour urinary cortisol : cortisone ratio, plasma and urinary catecholamines, growth hormone and IGF-1 show promise as tools for monitoring training stress and tapering-induced adaptations, but further research is needed to make a solid statement about their validity. Muscular strength and power, usually suppressed by intensive training, increase during the taper, contributing to an athlete’s enhanced performance capabilities. Local increments in oxidative enzymatic activities, and positive changes in single muscle fibre size, metabolic and contractile properties are tightly related with whole muscle strength.
and power measures and performance changes observed in whole body muscle function. There is very limited research on the effects of the taper on athletes’ immune function, but small transient changes in immune cells, soluble immunoproteins and cytokines during the taper are unlikely in most individuals to have marked immunological or clinical significance.

Given that competition performance is the result of a conscious effort, positive psychological and motivational changes taking place during the taper, including an enhanced mood state, a reduced perception of effort and an improved quality of sleep can make a worthwhile contribution to athletic performance. Finally, mathematical models have brought some insight in the attempt to explain the biological responses to the taper. The fatigue and adaptation model indicates that a restoration of previously impaired function takes place during the taper. The enhancement of performance with the taper would be related with a recovery of physiological capacities that were impaired by past training. The more recently developed variable dose-response model suggests that taper-induced peak performance arises from both the recovery from past training and a restoration of the tolerance to training. Further adaptations during the taper would also contribute to performance gains. These changes in recovery and adaptation could be related to the neuroendocrine responses to training.

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