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Functional Overreaching: The Key to Peak Performance during the Taper?

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ABSTRACT

AUBRY, A., C. HAUSSWIRTH, J. LOUIS, A. J. COUTTS, and Y. LE MEUR. Functional Overreaching: The Key to Peak Performance during the Taper? *Med. Sci. Sports Exerc.*, Vol. 46, No. 9, pp. 1769 – 1777, 2014. **Purpose:** The purpose of this study is to examine whether performance supercompensation during taper is maximized in endurance athletes after experiencing overreaching during an overload training (OT) period. **Methods:** Thirty-three trained male triathletes were assigned to either OT ($n = 23$) or normal training groups ($n = 10$, CTL) during 8 wk. Cycling performance and maximal oxygen uptake ($\dot{V}O_{2max}$) were measured after 1 wk of moderate training, a 3-wk period of OT, and then each week during 4-wk taper. **Results:** Eleven of the 23 subjects from the OT group were diagnosed as functionally overreached (F-OR) after the overload period (decreased performance with concomitant high perceived fatigue), whereas the 12 other subjects were only acutely fatigued (AF) (no decrease in performance). According to qualitative statistical analysis, the AF group demonstrated a *small to large* greater peak performance supercompensation than the F-OR group (2.6% T 1.1%) and the CTL group (2.6% T 1.6%). $\dot{V}O_{2max}$ increased significantly from baseline at peak performance only in the CTL and AF groups. Of the peak performances, 60%, 83%, and 73% occurred within the two first weeks of taper in CTL, AF, and OR, respectively. Ten cases of infection were reported during the study with higher prevalence in F-OR (70%) than that in AF (20%) and CTL (10%). **Conclusion:** This study showed that 1) greater gains in performance and $\dot{V}O_{2max}$ can be achieved when higher training load is prescribed before the taper but not in the presence of F-OR; 2) peak performance is not delayed during taper when heavy training loads are completed immediately prior; and 3) F-OR provides higher risk for training maladaptation, including increased infection risks. **Key Words:** TRAINING LOAD, FATIGUE, OVERTRAINING, ENDURANCE TRAINING, PERFORMANCE SUPERCOMPENSATION

The primary goal for coaches of high-performance athletes is to deliver a well-controlled training program to ensure that the maximal performance is achieved at major competitions. The best competition performances in endurance sports are often achieved after a taper phase, which is typically completed after periods of heavy training. The taper has been defined as a progressive, nonlinear reduction of the training load in the period before competition (19). The main purpose of the taper is to reduce physiological and psychological stressors of previous training and to remove residual fatigue so that sport performance can be optimized.

Appropriate tapering is considered to be critical for maximizing athletic performance. However, at present, there is relatively little scientific information that can be used to guide coaches in prescribing appropriate tapering strategies for

individual athletes, and as a result, many adopt a trial-and-error approach. Indeed, only recently has good empirical evidence been provided to allow us to understand the relations between the characteristics of endurance training during a taper and the associated endurance performance changes (2,16). For example, Bosquet et al. (3) used a meta-analytic analysis to describe the effects of alterations in the training characteristics during the taper on performance in competitive athletes. The results showed that the most efficient taper strategy for maximizing endurance performance gains was to perform a 2-wk taper with an exponential reduction in training volume by 41% – 60% without any modification of either training intensity or frequency.

Using mathematical modeling simulations, Thomas and Busso (21) demonstrated that the training leading into the taper may also influence the performance responses during taper (21). These stimulations predicted that a 20% increase in training beyond normal training load during 28 d before a taper would elicit larger performance gains compared with when habitual training load was maintained. This hypothesis was recently supported by Le Meur et al. (16), who compared performance supercompensation after a 1-wk taper in trained triathletes after 3 wk of training, which consisted of either overload or habitual training. At the end of the overload training (OT) period, a 9% decline in performance

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was observed in the OT group. After completion of a recovery week, all the subjects in the overload group improved performance (+7.9% of Pre value), with a 79% chance of greater performance supercompensation than the control group over the whole protocol. Unfortunately, only one performance test was performed during taper, making difficult the possibility to compare the amplitude of the performance rebound between groups. In a similar study, Coutts et al. (5) compared performance changes in well-trained triathletes after either 4 wk of OT and a 2-wk taper or 4 wk of normal training and a similar taper. Overreaching was diagnosed in the intensified training group after the 4 wk of OT, with a poorer (3.7%) 3-km running time-trial performance. In contrast, a gain in performance (+3.0%) was observed in the normal training group during the same period. During the taper, gains (+7.0%) in 3-km running time-trial performance were observed in the intensified training group. These findings suggested that a 2-wk taper was enough for the intensified training group to recover and experience a positive training adaptation. Nevertheless, there was no difference in performance improvement between both training groups, suggesting that the length of the taper for the intensified group may not have been sufficient to allow for full recovery. However, other than these examples, there is limited scientific literature supporting the use of deliberate overreaching for potentiating performance gains beyond normal training doses in trained athletes (18). Despite the limited scientific support, it is common for athletes to undertake OT before tapering, in an attempt to maximize performance gains.

The aim of the present study was to describe the relations between performance and training completed before and during a simulated taper. Specifically, we aimed to examine whether well-trained triathletes ($n = 28$) would demonstrate greater performance improvements than a control group ($n = 12$) during a simulated 4-wk taper after completing 3 wk of OT. In a previous study involving the same profile of triathletes (15), we reported that most of the participants become overreached after a 3-wk overload period, during which the habitual training load was increased by 40%. Through programming a 30% OT before the taper in a large population of triathletes of the same caliber, we hypothesized that some participants would demonstrate signs of overreaching (i.e., decreased performance), whereas others would not. This approach allowed us to determine whether larger performance supercompensation would be observed during taper in participants who experienced overreaching compared with those who did not. On the basis of previous work (16,21), we hypothesized that completing OT before the taper would allow bigger performance gains, particularly in the overreached athletes—but this would require a longer taper for performance compensation.

MATERIALS AND METHODS

Subjects

Forty well-trained male triathletes volunteered to participate in this study. Their performance level over the short

(Olympic) distance triathlon (i.e., 1.5-km swimming – 40-km cycling – 10-km running) ranged between 2 h and 2 h 20 min (mean performance: 131 T 5 min, regional to national level of competition). The experimental design of the study was approved by the Ethical Committee of Saint-Germain-en-Laye (acceptance no. 12048) and was conducted in accordance with the Declaration of Helsinki. Before participation, subjects underwent medical assessment by a cardiologist to ensure normal electrocardiograph patterns and obtain a general medical clearance. All subjects were free from chronic diseases and were not taking medication at the commencement of the study. After comprehensive verbal and written explanations of the study, all subjects gave their written informed consent to participate.

The subjects were assigned to either the control group ($n = 12$) or the OT group ($n = 28$) according to a matched group experimental design on the basis of performance level, habitual training volume, and past experience in endurance sports. All subjects had regularly competed in triathlons for at least 3 yr and were training a minimum of 10 h/wk¹.

Study Design

An overview of the study design is shown in Figure 1. The training of each triathlete was monitored for a period of 11 wk in total, which was divided into four distinct phases. The two first phases were similar for both OT and control groups. The first phase (I) consisted of 3 wk during which the subjects completed their own usual training regimen (i.e., classic training). The second phase (II) consisted of 1 wk of moderate training load during which the subjects were asked to reduce their habitual training volume by approximately 30% while maintaining the training intensity. These tapering strategies were selected according to the guidelines for optimal tapering in endurance sports (3). During the third period (III), the OT group completed 3 wk of training designed to deliberately overreach the subjects: the duration of each training session of the classic training period was increased by 30% (e.g., a 1-h run including 10 repetitions of 400 m at the maximal aerobic running speed was converted into an 80-min run including 13 repetitions of 400 m at the maximal aerobic running speed). The participants reproduced the same training program during each week of the overload period, so that both the content and the weekly distribution of the training sessions were kept consistent. The control group repeated its classic training program during this period. Next, all the participants completed a 4-wk taper, where their normal training load was decreased by 40% each week (e.g., a 1-h run including eight repetitions of 400 m at the maximal aerobic running speed was converted into an approximately 35-min run including five repetitions of 400 m at the maximal aerobic running speed). Throughout the entire study, the same sport scientist was responsible for coaching and controlling the training loads of all subjects. To avoid injuries, particular attention was devoted to daily feedback obtained from the

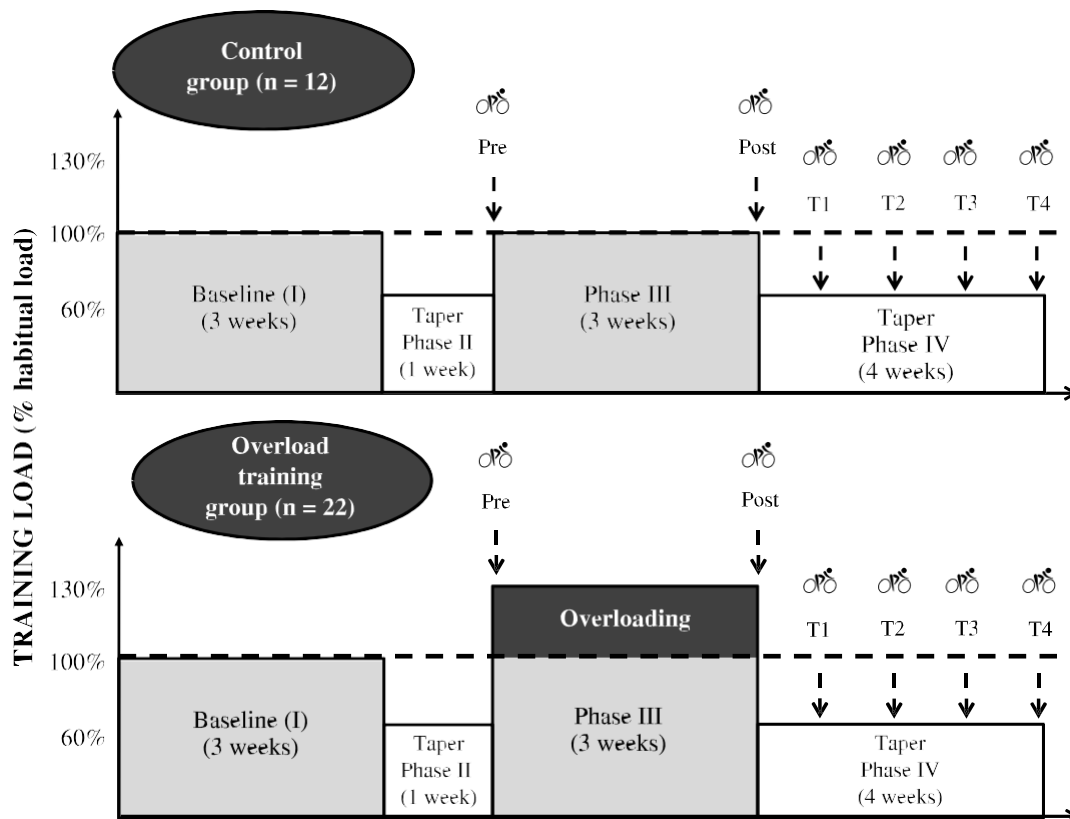


FIGURE 1—Schematic representation of the experimental protocol. Bicycle symbols represent maximal incremental cycling tests. During phase IV, the subjects performed a test at the end of each week (T1, T2, T3, and T4).

triathletes. During phase I, the subject reported to the laboratory to become familiarized with the testing used during the protocol (described below). At the end of phases II (Pre) and III (Post), and each week during the 4-wk taper period (phase IV; T1, T2, T3, and T4), the triathletes performed a maximal incremental cycling test in a laboratory. To ensure that performance variations during the maximal incremental tests were due to the global training regimen and not to the training session(s) performed the day before each test, the subjects were required to respect a 24-h rest period before each laboratory session.

During the 48 h before each maximal oxygen uptake ($\dot{V}O_{2max}$) test, the subjects were required to follow a nutritional plan to ensure adequate muscle glycogen stores. They were instructed to eat until satiety was reached during each meal. Breakfast consisted of a variety of macronutrients from both solid and liquid energy sources. The selected foods included an assortment of cereals, bread, fruit, yogurt, milk, juice, ham, and cheese. For lunch and dinner, the subjects consumed a mixed salad as starter, then white meat during lunch and fish during dinner. The side plate consisted of a mix of 50% carbohydrates (i.e., pasta, rice, and noodles) and 50% of vegetables (i.e., green beans, broccoli, and tomatoes). One piece of fruit and 125 mL of yogurt were added as dessert, at both lunch and dinner. To ensure the subjects were well hydrated on each testing day, they were instructed to follow a hydration plan with two glasses and 500-mL intake of water

during and between each meal, respectively. They were asked to drink more if they observed their urine to be dark. The participants were reminded of these recommendations before each test by e-mail or phone call.

Measurements

Profile of mood state. Before exercise testing, subjects were asked to complete the profile of mood state (POMS) questionnaire to assess overall mood disturbance (17). The POMS questionnaire is a 65-item Likert scale questionnaire, which provides measures of six specific mood states: vigor, depression, fatigue, anger, anxiety, and confusion. These factors can also be combined to create composite measures of mood and fatigue. Energy index represented the difference between the scores of vigor and fatigue (13). This questionnaire was chosen because it has been found to be sensitive to overreaching detection (6).

Performance and $\dot{V}O_{2max}$. Maximum oxygen uptake was assessed on an electronically braked cycle ergometer (Excalibur Sport, Lode®, Groningen, The Netherlands) equipped with standard 170-mm cranks. The ergometer was equipped with clip-in pedals, and each athlete used their own shoes for cycling testing. Handlebar position and seat height were matched to the athlete's typical competition bike settings. The settings were kept constant for all subsequent tests. The test was performed until complete exhaustion to

estimate $\dot{V} O_{2\max}$ and cycling performance. The completion of the test was confirmed by the criteria described by Howley et al. (12)—that is, a plateau in $\dot{V} O_2$ despite an increase in power output, a respiratory exchange ratio value of 1.15, or a heart rate (HR) over 90% of the predicted maximal HR. The exercise protocol started with a warm-up of 5 min at a workload of 100 W, followed by 5 min at 150 W and 5 min at 200 W. Thereafter, further increments of 25 W were added every 2 min until volitional exhaustion. Subjects wore a face mask covering their mouth and nose for breath collection (Hans Rudolph, Kansas City, MO), and oxygen and carbon dioxide concentration in the expired gas was continuously measured and monitored as breath-by-breath values (Quark, Cosmed[®], Rome, Italy). The gas analyzers and the flowmeter of the applied spirometer were calibrated before each test.

After the test, breath-by-breath values were visually inspected and averaged over 30 s. The highest 30-s average value was taken as $\dot{V} O_{2\max}$. The performance was calculated as performance = $W_{\text{compl}} + 25 (t/120)$, where W_{compl} is the last completed workload and t is the number of seconds in W_{compl} (15).

Blood lactate concentration. A fingertip blood sample (5 μL) was collected and blood lactate concentration ($[\text{La}^+]_b$) was determined (Lactate Pro; ARKAY, Kyoto, Japan) at the end of each cycling step, immediately at exercise cessation and each 90 s until $[\text{La}^+]_b$ reached its peak value. The accuracy of the analyzer was checked before each test using standards. The suitability and reproducibility of this analyzer have been previously established throughout the physiological range of 1.0 – 18.0 mmolL^{-1} (20). The HR values associated with a blood lactate concentration of 2 mmolL^{-1} and the LT assessed according to the modified D-max method (4) were determined.

Perceived exertion. The RPE was measured verbally using the Borg 6 – 20 scale (2) immediately at the end of the maximal cycling test. Its correct use was reminded to the subjects before each incremental test throughout the experiment.

Training Monitoring

Training volume and intensity were calculated on the basis of recordings from HR monitors (Polar, Kempele, Finland). For all subjects, HR was measured every 5 s during each training session over the entire protocol. The endurance time distribution was subsequently calculated using three HR zones: 1) eHR at 2 mmolL^{-1} , 2) between HR at 2 mmolL^{-1} and HR at LT, and 3) HR values superior to HR at LT. Given that the relation between $[\text{La}^+]_b$ and HR values during exercise can be influenced by a heavy training load program (16), the reference HR values were reassessed after each incremental cycling test.

Illness Symptoms

During each week of phase III (i.e., 3-wk overloading) and phase IV (i.e., 4-wk taper) of the study, the subjects

completed a health questionnaire (upper respiratory tract infections (URTI) symptoms and gastrointestinal (GI) discomfort symptoms) each day according to methods described previously (8,9). While the subjects were not required to abstain from medication when they were experiencing illness symptoms during the study period, they were required to report any unprescribed medication taken, visits to the doctor, and any prescribed medications on a weekly basis. The illness symptoms listed on the questionnaire were sore throat, inflammation in the throat, runny nose, cough, repetitive sneezing, fever, joint aches and pains, and headache. Two usual items (i.e., muscle soreness and sleep quality) were measured but not taken into account for URTI diagnosis because they could be potentially influenced by training overload and not necessarily the signs of illness (10,15). The numerical ratings of light, moderate, and severe were scored as 1, 2, and 3, respectively. In any given week of total symptom, score Q12 was taken to indicate that a URTI was present. This score was chosen because it would require the subjects to report at least three moderate symptoms lasting for Q2 d or two moderate symptoms lasting for Q3 d in a given week. A single URTI episode was defined as a period during which the weekly total symptom score was Q12 and separated by at least 1 wk from another week with a total symptom score Q12. The GI-discomfort symptoms listed on the questionnaire were loss of appetite, stomach upset, vomiting, abdominal pain, and diarrhea. These symptoms were rated and scored the same way as the illness symptoms.

Data Analysis

Assessment of overreaching. The subjects in the overload group were distributed into two subgroups according to their response to the overload period and during the subsequent taper. The triathletes who demonstrated decreased performance (vs Pre) and high perceived fatigue (‘ ‘very tired’ ’ to ‘ ‘extremely tired’ ’ on the POMS scale) at Post with subsequent performance supercompensation were diagnosed as functionally overreached (F-OR group) (18). To be diagnosed as overreached at Post, athletes of the overload group had to show a performance decrement larger than the smallest worthwhile change (SWC). This ‘ ‘OR threshold’ ’ was calculated using the typical variation (coefficient of variation (CV)) of performance during the maximal cycling test in trained subjects. The CV of performance was calculated in the control (CTL) group during the normal training period (Fig. 1). The changes in Pre to Post performance values in the CTL group were indeed representative of the typical variation of performance in trained subjects, without training load manipulation. As proposed by Hopkins et al. (11), 0.3CV was selected to represent the SWC. The remaining subjects in the overload group, who maintained or increased their performance after phase III despite high perceived fatigue, were considered only acutely fatigued (AF) (18).

Two analyses were performed. First, the effect of the training group on performance, physiological, and perceptive

parameters over the whole training protocol was analyzed. Second, the performance supercompensation between the three groups (CTL, AF, and F-OR) was compared, examining the peak performance achieved during taper (Best).

Statistical Analysis

A Shapiro – Wilk test was used to verify the normality of the data. Heteroscedasticity (i.e., systematic error) was verified by plotting the absolute differences of each parameter against the individual means (i.e., Bland – Altman plot) and calculating the correlation coefficient to test if the slope was significantly different from the zero value. Despite no variable exhibited nonuniformity of error, data were log transformed before analysis to reduce the tendency ($P < 0.10$) of some parameters (i.e., performance and perceived fatigue) to demonstrate a skewed distribution (11). The data were then analyzed using the magnitude-based inference approach recommended for studies in sports medicine and exercise sciences (11). We used this qualitative approach because traditional statistical approaches often do not indicate the magnitude of an effect, which is typically more relevant than any statistically significant effect to infer clinical recommendations. The magnitude of the within-group changes, or between-group differences in the changes, was interpreted by using values of 0.3, 0.9, 1.6, 2.5, and 4.0 of the within-athlete variation (CV) as thresholds for *small*, *moderate*, *large*, *very large*, and *extremely large* differences in the change between the trials (11). The practical interpretation of an effect is deemed *unclear* when the magnitude of change is substantial when the 90% confidence interval (CI) (precision of estimation) could result in positive and negative outcomes (1,11).

RESULTS

During the 11-wk experimental period, seven subjects (two and five for control and OT groups, respectively) did not follow the prescribed training because of injury or personal obligations and were excluded from subsequent analyses. The final samples were $n = 10$ and $n = 23$ for control and OT groups, respectively.

Assessment of the OR Syndrome

At baseline, all subjects reported low fatigue index at rest (i.e., all subjects responded ‘not at all’ or ‘alittle’ on the POMS fatigue item at Pre), confirming that they were not already in an OR state. Ten of the 23 overload subjects demonstrated a decrease in performance after the overload period (372 T 36 vs 363 T 35 W at Pre and Post, respectively, Fig. 2) followed by a performance supercompensation effect during the taper (382 T 37 W at peak performance, Fig. 2). For all of these subjects, the performance decrement reached the ‘OR threshold’ at Post (0.6% of performance value at Pre). Their characteristics are presented in Table 1. These 10 subjects reported a *very large* to *extremely large* decrease in energy index at the end of the OT (14 T 6 at Pre vs 4 T 7 at

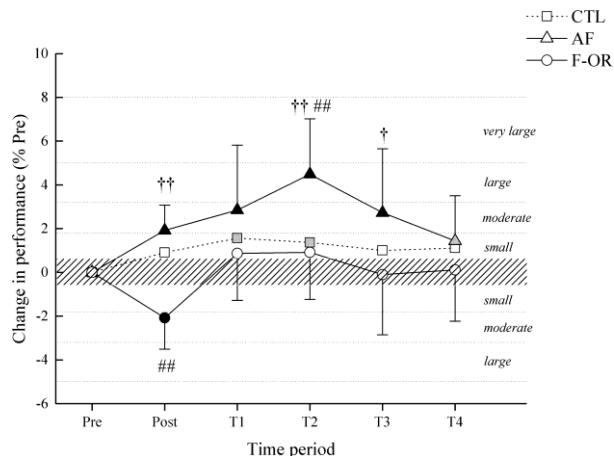


FIGURE 2—Changes in performance from baseline (mean T 90% CI) during the maximal incremental cycling test after the overload period (Post) and each week of the tapering period (T1–T4) for the control group (CTL), the AF group, and the F-OR group in response to the overload program. Gray symbols stand for likely within-group difference vs. Pre, while black symbols stand for within-change expected to be very likely to almost certain vs. Pre. Between-group difference in the change during the taper versus CTL: Lsmall to large; LLsmall to very large. Between-group difference in the change during the taper versus F-OR: † small to large; † † small to very large. The shaded area represents the SWC (see Materials and Methods). 90% CI was not presented for CTL to ensure visual clarity.

Post, Table 2), with a systematic concomitant high perceived fatigue (i.e., ‘quite bit’ to ‘extremely’ on the POMS fatigue item at Post). On the basis of this analysis, these 11 triathletes were considered as ‘functionally OR’ (F-OR) (18). One subject from the overload group demonstrated a decrease of performance associated with high perceived fatigue at Post, but his performance only restored during the taper (i.e., without supercompensation). This triathlete was diagnosed as ‘nonfunctionally OR’ (18). The data for this participant were excluded from subsequent analyses because of insufficient sample size to characterize the nonfunctionally OR response. The 12 other subjects in the OT group, who preserved their performance level during the overload period despite a *large* to *extremely large* increase in perceived fatigue (4 T 3 at Pre vs 9 T 5 at Post, Table 2), were diagnosed as AF. Thus, the subsequent results are presented for 10 F-OR subjects (F-OR group), 12 AF subjects (AF group), and 10 control subjects (CTL group) (Table 1). Between-group difference in performance at baseline were *unclear*.

Compliance to the Training Program

Changes in weekly average training volume, the distribution of the relative training time spent in the intensity zones, and the number of training sessions per week in the three disciplines during the four phases of the protocol are presented in Table 3.

Performance

Performance changes throughout the protocol in the three groups are shown in Figure 2.

TABLE 1. Age, competitive experience (experience), maximal oxygen uptake ($\dot{V}O_{2max}$), and maximal aerobic power before (Pre) the intervention period for the control (CTL), the AF, and the F-OR groups.

	CTL (n = 10)	AF (n = 12)	F-OR (n = 10)
Age (yr)	37 T 6	33 T 6	36 T 5
Body mass (kg)	75 T 7	74 T 7	73 T 9
Body height (cm)	183 T 6	179 T 6	180 T 6
Experience in endurance sport (yr)	13 T 11	15 T 7	12 T 6
Maximal aerobic power (W)	355 T 26	354 T 27	372 T 36
$\dot{V}O_{2max}$ (mL O ₂ ·min ⁻¹)	4300 T 359	4349 T 480	4543 T 416

Values are presented as mean T SD. Between-group difference at baseline were *unclear* for all parameters.

Given that the CV of performance in the CTL during the normal training phase was 2.0%, outcomes were assessed by using the following scale: *trivial*, 0.0%–0.6%; *small*, 0.6%–1.8%; *moderate*, 1.9%–3.2%; *large*, 3.3%–5.0%; *very large*, 5.1%–8.0%, and *extremely large*, 98.0% change in performance.

Overload period. During the overload period, the F-OR group demonstrated a *moderate* decrease in performance (j2.4% T 0.6% with 372 T 36 vs 363 T 35 W at Pre and Post, respectively), whereas the AF group showed a *small* to *moderate* increase in performance (+1.9% T 0.6% with 354 T 27 vs 360 T 29 W at Pre and Post, respectively). The effect of the normal training period for the CTL group was *unclear* (0.9% T 1.3% with 355 T 26 and 358 T 25 W at Pre and Post, respectively).

Tapering period. The CTL group demonstrated a *trivial* to *moderate* performance supercompensation at T1, when compared with Pre value. At T2, T3, and T4, performance changes from Pre were *unclear*. The performance increase in the AF group was *small* to *large* at T1, *large* to *very large* at T2, *small* to *large* at T3, and *trivial* to *moderate* at T4, compared with Pre. In contrast, performance changes from baseline in F-OR were *trivial* to *moderate* at T1, *small* to *moderate* at T2, and *unclear* both at T3 and T4. Differences in change between the CTL and F-OR groups were *unclear* throughout the tapering period. In contrast, the difference in performance supercompensation in the AF group compared with the F-OR group was *trivial* to *large* at T1, *small* to *large* at T2, *small* to *very large* at T3, and *unclear* at T4, respectively. The difference in performance change between the AF and CTL groups was *unclear* throughout the taper phase, except at T2 with a *small* to *very large* greater performance supercompensation in the AF group.

Peaking performance. Individual data points and group means for peak performance and $\dot{V}O_{2max}$ after each training phase are presented in Figure 3A, B. The AF group demonstrated a *small* to *large* greater peak performance supercompensation than the F-OR group and the CTL group. Difference in performance supercompensation was *unclear* between the F-OR and CTL groups. Of the peak performances, 60%, 83%, and 73% occurred within the two first weeks of taper in CTL, AF, and OR, respectively (Fig. 3C). Maximum oxygen uptake demonstrated a *small* to *large* increase from baseline at peak performance in the CTL group (4300 T 359 vs 4447 T 433 mL O₂·min⁻¹ at Pre and Best, respectively) and a *moderate* to *large* increase in the AF group (4349 T 480 vs 4525 T 407 mL O₂·min⁻¹ at Pre and Best, respectively). The change in $\dot{V}O_{2max}$ observed in the F-OR group was *unclear* (4517 T 405 vs 4460 T 447 mL O₂·min⁻¹ at Pre and Best, respectively). The chance for the CTL and the AF groups to demonstrate larger improvement in $\dot{V}O_{2max}$ at peak performance than the F-OR group were 81% and 97%, respectively. The AF group showed a 68% chance to show a larger increase in $\dot{V}O_{2max}$ at Peak compared with the CTL group. All within-group changes and between-group differences in change of $[La^j]_{max}$ were *unclear*.

Infection-Symptom Incidence

Ten subjects reported at least one episode of URTI ($n = 9$) or GI-discomfort symptoms ($n = 1$) during the training overload and/or tapering periods. The proportion of subjects who experienced symptoms of infection was higher in F-OR ($n = 7$, 70%) with one subject experiencing two URTI than that in AF ($n = 2$, 20%) and CTL ($n = 1$, 10%).

TABLE 2. Mean values (TSD) of resting perceived fatigue, vigor, and energy index (vigor - j fatigue) at baseline (Pre), after the overload period (Post), and each week of the tapering period (T1–T4) for the control group (CTL), the AF group, and the F-OR group in response to the overload program.

		Pre	Post	T1	T2	T3	T4
Fatigue (AU)	CTL	3.4 T 3.6	5.8 T 4.2	3.4 T 2.5	3.5 T 2.9	2.3 T 2.4	2.7 T 3.3
	AF	3.9 T 3.4	9.3 T 4.7**L	6.2 T 6.3	4.4 T 3.3	4.3 T 5.2	2.7 T 3.4
	F-OR	4.3 T 3.6	13.3 T 4.5**L†	5.3 T 5.1	3.6 T 5.2	2.3 T 3.2	2.4 T 2.8
Vigor (AU)	CTL	17.8 T 2.7	19.4 T 2.9	18.1 T 3.6	17.8 T 4.3	19.4 T 3.5	17.9 T 3.4
	AF	20.1 T 3.6	18.8 T 3.5	18.3 T 3.7	17.0 T 3.3	16.5 T 4.1	17.9 T 4.1
	F-OR	18.4 T 4.2	17.1 T 3.2	17.5 T 4.0	18.6 T 3.6	17.6 T 4.5	17.5 T 4.5
Energy index (AU)	CTL	14.4 T 3.8	13.6 T 2.7	14.7 T 4.4	14.3 T 6.0	17.1 T 4.0	15.2 T 5.4
	AF	16.2 T 4.6	9.4 T 5.9**L	12.1 T 9.4	12.6 T 5.2	12.2 T 8.2	15.3 T 6.3
	F-OR	14.1 T 6.3	3.8 T 6.8**L†	12.2 T 8.2	15.1 T 8.0	15.2 T 7.1	15.1 T 6.1

Within-condition difference from Pre, *very likely, **almost certain. Between-group difference in the change during the overload versus CTL, †very likely, ††almost certain. Between-group difference in the change during the overload versus F-OR, †very likely, ††almost certain.

TABLE 3. Weekly average training volume (mean \pm SD), distribution of training time in the intensity zones (see Materials and Methods), and number of training sessions per week in swimming, cycling, and running during the 11-wk protocol.

	Phase	Baseline (I)		Overload (III)			Taper (IV)			
		3	1	1	1	1	1	1	1	1
CTL group	Duration (wk)	3	1	1	1	1	1	1	1	1
	Weekly volume (h)	12 T 3	6 T 1**	12 T 2	12 T 2	12 T 2	6 T 1**	6 T 1**	6 T 1**	6 T 1**
	Distribution of training intensity in zones 1/2/3 (% of total training time)	62/30/8	67/26/7	67/26/7	66/26/8	65/27/8	64/28/8	63/28/9	62/28/8	66/26/8
	Weekly no. of swimming, cycling, running sessions	3/3/3	2/3/3	3/3/3	3/3/3	3/3/3	2/3/3	2/3/3	2/3/3	2/3/3
AF group	Duration (wk)	3	1	1	1	1	1	1	1	1
	Weekly volume (h)	13 T 3	7 T 1**	17 T 3** ^{LL}	17 T 3** ^{LL}	17 T 3** ^{LL}	7 T 1**	7 T 1**	7 T 1**	7 T 1**
	Distribution of training intensity in zones 1/2/3 (% of total training time)	65/26/9	64/26/9	65/26/9	65/27/8	65/27/8	60/30/10	61/29/10	61/29/10	60/30/10
	Weekly no. of swimming, cycling, running sessions	3/3/3	2/3/3	3/3/3	3/3/3	3/3/3	2/3/3	2/3/3	2/3/3	2/3/3
F-OR group	Duration (wk)	3	1	1	1	1	1	1	1	1
	Weekly volume (h)	14 T 3	7 T 1**	18 T 3** ^{LL}	19 T 3** ^{LL}	19 T 3** ^{LL}	7 T 1**	7 T 1**	7 T 1**	7 T 1**
	Distribution of training intensity in zones 1, 2, and 3 (% of total training time)	64/30/7	68/26/6	69/25/6	68/26/6	68/26/6	66/26/8	64/28/8	65/27/8	67/25/8
	Weekly no. of swimming, cycling, running sessions	3/5/3	2/4/3	4/5/3	4/5/3	4/5/3	3/4/3	3/4/3	3/4/3	3/4/3

No significant difference between groups were reported at baseline (phase I). Within-group difference in the change versus baseline: **very likely*, ***almost certain*. Between-group difference in the change from baseline versus CTL: ^L*very likely*, ^{LL}*almost certain*.

Perceptual Measures

All subjects' RPE ranged between *very difficult* and *very difficult* at exercise cessation during the whole experiment (range, 17 – 20). All within-group changes and between-group differences in change of the parameter were *unclear*.

Perceived fatigue, vigor, and energy index changes throughout the protocol in the three groups are depicted in Table 2. Both perceived fatigue and the energy index at rest decreased *almost*

certainly in AF and in F-OR at Post, but not in CTL. These two parameters were progressively restored to baseline value in AF and F-OR during the taper. Within-group changes and between-group differences in change in vigor were *unclear*.

DISCUSSION

In the present study, we compared performance changes in 33 well-trained triathletes after either 3 wk of OT and a

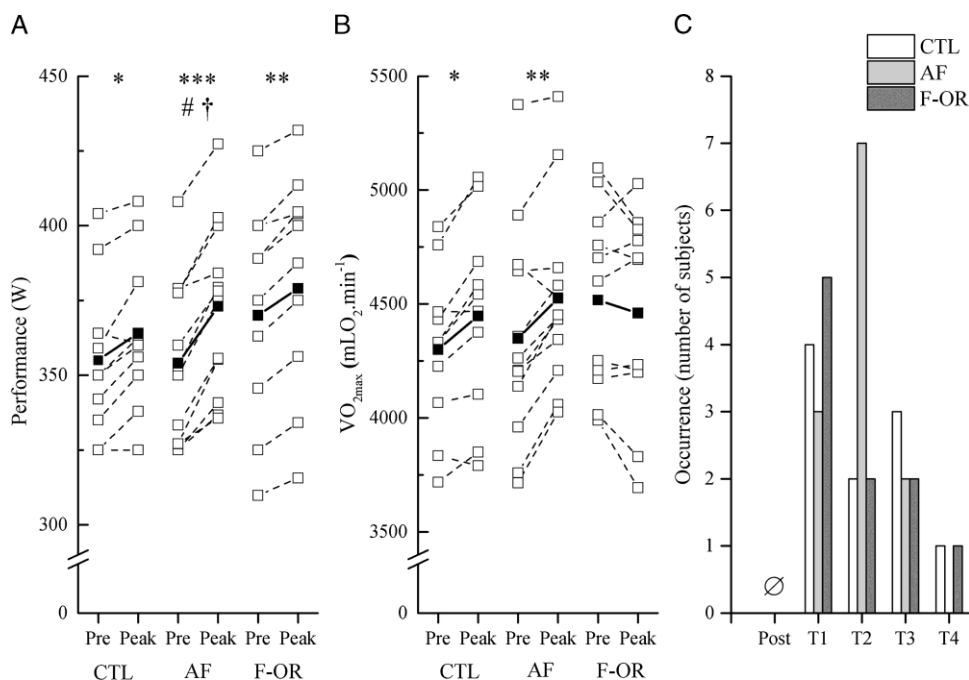


FIGURE 3—A, Individual changes (dashed lines) and group mean (straight lines) between Pre and Peak, the best performance during the taper. Within-group difference in the change versus Pre: **small to large*, ***moderate to large*, ****large to very large*. Between-group difference in the change versus CTL: ^L*small to large*. Between-group difference in the change versus F-OR: † *small to large*. B, Individual data points (dashed lines) and group mean (straight lines) for $\dot{V}O_{2max}$ associated with peaking performance during the taper for the control group (CTL), the AF group, and the F-OR group in response to the overload program. Within-group difference in the change versus Pre: **small to large*, ***moderate to large*. All between-group differences in change were *unclear*. C, Occurrence of the best performance during the taper (Peak) for the control group (CTL), the AF group, and the F-OR group in response to the overload program. Post, immediately after the overload period; T1–4, after 1, 2, 3, or 4 wk of tapering.

4-wk taper ($n = 23$) or 4 wk of normal training and a similar taper ($n = 10$). Ten triathletes from the OT group developed clear symptoms of F-OR (i.e., transient reduced performance associated with high perceived fatigue followed by the occurrence of a performance supercompensation), whereas 12 other triathletes did not. The main findings of this study were that 1) greater gains in performance and $\dot{V}O_{2\max}$ can be achieved when higher training load is prescribed before the taper but not if F-OR occurs, 2) peak performance is not delayed during taper when heavy training loads are completed immediately prior, and 3) F-OR is associated with poor performance supercompensation during tapering and provides higher risk for training maladaptation, including increased infection risks.

The main finding of the current study was that performance supercompensation during tapering is maximized in endurance trained athletes, when training load is increased in the lead-up to taper in the absence of F-OR. Specifically, a greater performance improvement was observed in the AF group compared with the CTL group after the two first weeks of taper. Interestingly, the performance supercompensation in the AF group during the taper (5.4% \pm 2.1%, 90% CI) was in the upper range of taper-induced performance gains reported in the literature (i.e., 0.5% – 6.0%) (19). Interpreted together, these observations suggest that a greater pretaper training load potentiates the endurance performance adaptations with tapering. The likely explanation for these observations is that athletes who completed higher training loads in the absence of signs of OR before tapering elicit greater physiological adaptations. This hypothesis is supported by finding that the AF subjects had a 68% chance for a larger improvement in $\dot{V}O_{2\max}$ than the CTL group.

Deliberate F-OR before competition periods is often used strategically to enhance performance (18). This approach results in an acute decline in performance after heavy OT, but when appropriate tapering strategies are followed, it may elicit large increases in performance (7,18). These observations have provided the justification for precompetition ‘training camps’, which are commonly used in many endurance (18,21) or anaerobic sports (7). Both mathematical models of training responses to overload and tapering (21) and field-based results (16) suggest that greater training volume and/or intensity before the taper elicit greater performance gains in endurance athletes. However, to date, this hypothesis has not been empirically tested in trained athletes throughout an extended tapering period (i.e., 92 wk) using repeated performance evaluations. The present results demonstrated that the training load prescribed before tapering has strong influence on subsequent endurance performance supercompensation but failed to support the use of deliberate OR for greater performance changes. These results contradict our initial hypothesis, suggesting that overloading before the taper would allow bigger performance gains, particularly in the F-OR athletes.

There are three main mechanisms likely to underpin the small performance response in F-OR subjects. Specifically, persistent fatigue during tapering, lower training-induced physiological adaptations during the OT, and/or increased infections each might limit the performance outcomes with this training strategy. However, elevated fatigue during taper in F-OR subjects was not confirmed by the psychological parameters measured in the present study. Indeed, although a high perceived fatigue was observed with F-OR immediately after the OT, it returned to baseline level after 1 wk of tapering. In support of the concept of lower training-induced adaptations with F-OR, changes in $\dot{V}O_{2\max}$ were *unclear* during the study. We suggest that the lower physiological adaptations observed in F-OR subjects might explain the small performance supercompensation in this group during the taper. In contrast, both the CTL and AF groups demonstrated increased $\dot{V}O_{2\max}$ during the taper. Although the underlying reasons explaining this lower physiological response to training remain to be elucidated, this finding suggests that training-induced biological adaptations are inhibited when excessive training load is sustained. Further investigations are required to understand the underlying mechanisms beyond our current observations. Finally, the higher infection rate in the F-OR subjects during the present experiment may also explain the reduced performance response to tapering. Indeed, 7/10 athletes with F-OR reported increased URTI symptoms during the overload period or during the subsequent 4-wk taper period, whereas only two cases were observed in AF and one case in CTL during the same period. Given that five of these URTI episodes occurred during taper, we suggest that higher infection incidence in F-OR subjects is likely to have perturbed performance supercompensation in this group. This observation was in accordance with several studies, which have shown that other aspects of both innate and adaptive immunity are depressed during sustained periods of heavy training (for review, see reference (18)). Overall, these results suggested that performance supercompensation may be impaired during taper, when the balance between appropriate training stress and adequate recovery is disrupted in the lead-up to the taper and results in a state of F-OR.

In contrast to our initial hypothesis that a longer taper period may be required to reach peak performance after pretaper OT, we observed that 60%, 83%, and 73% of peak performances occurred within the two first weeks of taper in CTL, AF, and OR, respectively. Using mathematical modeling simulations on six trained swimmers to develop optimal tapering strategies, Thomas and Busso (21) predicted that a step load reduction of around 39% over 4 wk would be required after OT compared with a 31% reduction during 2 wk when no OT is performed. These authors predicted that OT before the taper causes a greater stress and therefore requires a longer period for full performance recovery. However, in contrast to this suggestion, the present results showed that most of the triathletes reached peak performance within the two first weeks of taper, irrespective

of the prior training (i.e., overloading or not) or training state before the taper (i.e., presence of functional overreaching or not). The present results are similar to our earlier work that showed performance supercompensation in F-OR triathletes after a 7-d taper (16). Collectively, these results show that the taper-induced performance supercompensation is not delayed in F-OR endurance athletes, despite these athletes showing higher perceived fatigue at the end of the OT period. Notably, similar to the recovery in performance, the perceived fatigue also returned to baseline within 2 wk—suggesting that only 1 or 2 wk of reduced training may be an appropriate tapering strategy. Overall, these observations agree with the meta-analysis of Bosquet et al. (3), which demonstrated that endurance performance is typically maximized with a 2-wk taper consisting in an exponential reduction of training volume (approximately 41% – 60%) without changing training intensity or frequency. Notably, the present study showed that endurance performance levels may be preserved during a 4-wk taper when the training intensity and frequency were maintained despite a large decrease in training volume. This finding may be particularly interesting in the context of multiple peaking, when the competitive season involves a series of events that can stretch over several weeks. Future work is required to identify optimal training periodization that allows athletes to capitalize on adaptations acquired during the previous training cycle and competitive stimuli, while optimizing recovery.

REFERENCES

- Batterham AM, Hopkins WG. Making meaningful inferences about magnitudes. *Int J Sports Physiol Perform.* 2006;1(1):50 – 7.
- Borg G. Perceived exertion as an indicator of somatic stress. *Scand J Rehabil Med.* 1970;2(2):92 – 8.
- Bosquet L, Montpetit J, Arvisais D, Mujika I. Effects of tapering on performance: a meta-analysis. *Med Sci Sports Exerc.* 2007;39(8):1358 – 65.
- Cheng B, Kuipers H, Snyder AC, Keizer HA, Jeukendrup A, Hesselink M. A new approach for the determination of ventilatory and lactate thresholds. *Int J Sports Med.* 1992;13(7):518 – 22.
- Coutts AJ, Slattery KM, Wallace LK. Practical tests for monitoring performance, fatigue and recovery in triathletes. *J Sci Med Sport.* 2007;10(6):372 – 81.
- Dupuy O, Lussier M, Fraser S, Bherer L, Audiffren M, Bosquet L. Effect of overreaching on cognitive performance and related cardiac autonomic control. *Scand J Med Sci Sports.* 2014;24(1):234 – 42.
- Fry AC, Kraemer WJ. Resistance exercise overtraining and overreaching. Neuroendocrine responses. *Sports Med.* 1997;23(2):106 – 29.
- Gleeson M, Bishop NC, Oliveira M, McCauley T, Tauler P, Lawrence C. Effects of a *Lactobacillus salivarius* probiotic intervention on infection, cold symptom duration and severity, and mucosal immunity in endurance athletes. *Int J Sport Nutr Exerc Metab.* 2012;22(4):235 – 42.
- Gleeson M, Bishop NC, Oliveira M, Tauler P. Daily probiotic's (*Lactobacillus casei* Shirota) reduction of infection incidence in athletes. *Int J Sport Nutr Exerc Metab.* 2011;21(1):55 – 64.
- Hauswirth C, Louis J, Aubry A, Bonnet G, Duffield R, Le Meur Y. Evidence of disturbed sleep and increased illness in overreached endurance athletes. *Med Sci Sports Exerc.* 2014;46(5):1036 – 45.
- Hopkins WG, Marshall SW, Batterham AM, Hanin J. Progressive statistics for studies in sports medicine and exercise science. *Med Sci Sports Exerc.* 2009;41(1):3 – 12.
- Howley ET, Bassett DR Jr, Welch HG. Criteria for maximal oxygen uptake: review and commentary. *Med Sci Sports Exerc.* 1995;27(9):1292 – 301.
- Kentta G, Hassmen P, Raglin JS. Mood state monitoring of training and recovery in elite kayakers. *Eur J Sport Sci.* 2006;6:245 – 53.
- Kuipers H, Verstappen FT, Keizer HA, Geurten P, van Kranenburg G. Variability of aerobic performance in the laboratory and its physiologic correlates. *Int J Sports Med.* 1985;6(4):197 – 201.
- Le Meur Y, Hauswirth C, Natta F, Couturier A, Bignet F, Vidal PP. A multidisciplinary approach to overreaching detection in endurance trained athletes. *J Appl Physiol.* 2013;114(3):411 – 20.
- Le Meur Y, Pichon A, Schaal K, et al. Evidence of parasympathetic hyperactivity in functionally overreached athletes. *Med Sci Sports Exerc.* 2013;45(11):2061 – 71.
- Mac Nair D, Lorr M, Droppelman L. *Profile of Mood States Manual.* San Diego: Educational and Industrial Testing Service; 1971. p. 27.
- Meeusen R, Duclos M, Foster C, et al. Prevention, diagnosis, and treatment of the overtraining syndrome: joint consensus statement of the European College of Sport Science and the American College of Sports Medicine. *Med Sci Sports Exerc.* 2013;45(1):186 – 205.
- Mujika I, Padilla S. Scientific bases for precompetition tapering strategies. *Med Sci Sports Exerc.* 2003;35(7):1182 – 7.
- Pyne DB, Boston T, Martin DT, Logan A. Evaluation of the Lactate Pro blood lactate analyser. *Eur J Appl Physiol.* 2000;82(1 – 2):112 – 6.
- Thomas L, Busso T. A theoretical study of taper characteristics to optimize performance. *Med Sci Sports Exerc.* 2005;37(9):1615 – 21.

In conclusion, the present study showed that the magnitude of performance supercompensation during a taper is influenced by the training load imposed in the lead-up to taper. Specifically, the results demonstrated that increased training load before taper can maximize the positive response to training if the training stress does not exceed the recovery capacity of the athlete. To the best of our knowledge, this study is the first to show that F-OR before tapering may not be the most effective strategy to enhance performance. Further investigation is required to determine whether these findings apply to elite endurance athletes, who require high training stress to stimulate further physiological adaptations. From a practical perspective, the present results also highlight the importance of monitoring athletes for signs of OR during heavy training periods. Future studies should examine the effectiveness of different training models that use early markers of F-OR to inform adjustments in future training loads to maximize training and tapering responses.

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