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Overtraining and the Endocrine System—Part 2: Review of the Scientific Studies

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Introduction

Based on the available literature, this meta-analysis will summarize the possible role of the previously examined hormones in connection with an overtraining syndrome. It will focus especially on the usefulness of single hormones as indicators for overtraining. Various sports will be considered separately in order to deal with the effects of different kinds of strain and load specifically. Studies only available as abstracts were not included.

The majority of subjects examined in the course of the studies were competitive athletes with different performance levels, some studies included soldiers. Soldiers did not focus their training on certain sport competitions demanding highest performance levels in specific macrocycles and microcycles, though they exposed themselves to extreme physical strain nevertheless.

Since not only the kind of sport might have different influences on the neuroendocrine system in connection with the overtraining syndrome, but also probably individual aspects of the athletes and the training performed, further explanations on the subjects as well as the respective study design including duration of the study, course of the training, and examination times have been included in the review tables. Part 1 of this publication on the terminology of overtraining revealed that there is no uniformity in the definition of the criteria for determining a case of overtraining. Therefore, the definitions used in the respective studies were also included in the tables in connection with the corresponding test procedures. The authors applied different criteria for determining an overtraining syndrome. Moreover, they conducted various load tests and further analyses such as blood and urine tests, stimulation tests, and so on, which are also listed in the respective tables.

The individual studies are critically evaluated briefly in connection with the respective presentation, and a summary discussion is given separately for the various endocrine systems.

Review of the Studies With Athletes From Different Sports

Examinations in Individuals Exercising Recreational Sports

Study 1. The publications by Fleck (5), Lehmann et al. (22), Lehmann et al. (23), and Gastmann et al. (12; see Table 1 in the appendix) present different partial aspects of the same study each. The authors investigated the hypotheses that hypothalamic and pituitary dysfunctions, decreased testosterone levels, or elevated cortisol levels exist in connection with an overtraining syndrome. Gastmann et al. (12) in

their analysis aimed at demonstrating a training-induced adaptation of the sympathoadrenergic regulation, catecholamine sensitivity, and a possible catecholamine threshold concentration. The objective of this intervention study was to induce an overtraining syndrome in individuals exercising recreational sports by high training loads. However, none of the authors stated precisely which criteria were used in the study to determine an overtraining syndrome.

In the study design, six individuals exercising recreational sports were chosen as subjects who covered 4 units per week of high intensity endurance training (intensity of at least 90% of the initial 4-mmol lactate performance) and 2 training units per week of interval training (3 to 5 runs for 3 to 5 min at an intensity of at least 110% of the initial 4-mmol lactate performance) on a bicycle ergometer for a period of 6 weeks. The examinations included the effects of the training on basal hormone levels, on hormone levels at submaximal and maximal load, as well as on changes in hormone levels after exogenous stimulation with releasing hormones. Moreover, a subjective symptoms' index was determined. The investigations were carried out before the training (I1), after 3 weeks of training (I2), after 6 weeks of training (I3), and after a 3-week recreation period (I4). For assessment of catecholamine sensitivity, stimulation tests with 0.5, 1.0, 2.5, and 5.0 $\mu g \cdot min^{-1}$ intravenous norepinephrine were performed for 6 min each at I1, I3, and I4. A combined pituitary function test with elevated administration of releasing hormones was also performed at I1, I3, and I4. No data were available on the exact doses of the releasing hormones.

Performance of the subjects, assessed by their performance at 2 and 4 mmol/L lactate in the incremental treadmill test, increased from I1 to I2 and remained elevated till I4 as compared with the baseline value. Performance at 2 mmol/L lactate was reduced at I3 and I4 as compared with I2. This means that physical load was high, but that as a whole, according to the definition, no clear overtraining could be induced, since this would have been accompanied by a reduction in performance.

Neither for the basal hormone levels nor for the hormone levels after maximal load in the course of the investigation did the authors find any significant changes in ACTH, cortisol, LH, FSH, testosterone, TSH, prolactin, ADH, renin, aldosterone, hGH, and insulin. The combined pituitary stimulation test did not reveal any changes in prolactin, TSH, and hGH release at I3 and I4 as compared with I1. However, a significant increase in ACTH secretion was observed at I3 and I4 as compared with I1. In contrast to ACTH, cortisol secretion decreased significantly after stimulation at I4 as compared with I1. LH secretion was also significantly reduced at I3 and I4, while FSH secretion had increased at I3. Testosterone increase was not significantly changed.

Sensitivity to catecholamines was not significantly changed by the training. Norepinephrine secretion, however, was reduced over the day, while nocturnal basal excretion remained unchanged. In the view of the authors, this would indicate a training-induced adaptation of the sympathoadrenergic system. The norepinephrine threshold level for stimulation of the sympathoadrenergic effector system, measured by a significant increase in blood pressure, was determined to be about 1 $ng \cdot ml^{-1}$ blood norepinephrine concentration. The subjective symptoms' level remained unchanged in the course of the intervention.

In summary, no state of overtraining could be induced in this study evaluated by several authors. According to the authors, this is most likely due to a too short training period and too small training units. In connection with the high training load, no essential changes of the sympathoadrenergic regulation and of subjective

well-being could be observed. However, the hypothalamo-pituitary-adrenal axis showed some increase in the pituitary sensitivity and simultaneous decrease in adrenal sensitivity—that is, a change in the feedback regulation of the adrenal axis on high training load. In the area of the gonadal axis, pituitary secretion of LH was reduced, but that of FSH was elevated. Testosterone secretion was influenced thereby.

The authors, however, conclude that the partially observed hormonal changes in the investigated individuals exercising recreational sports are not unambiguously diagnostic with regard to a possibly beginning overtraining syndrome.

Examination of Weightlifters

Study 2. The publications by Fry et al. (9, 10) and Fry et al. (8; see Table 2a–b in the appendix) each present partial aspects of the same study. The authors examined the effects of overtraining in weightlifters, prevailingly caused by anaerobic training, on hormonal parameters at rest and load. Moreover, the investigation was intended to show whether a relationship between changes in the levels of selected hormones and a decrease in muscular strength can be found. The authors defined an overtraining whenever a decrease in performance associated with an increase in the extent of the training and/or the intensity of the training was seen. Seventeen weightlifters were divided into two groups. Eleven athletes went through a training at high intensity for 2 weeks, while the second group of 6 athletes served as controls. The daily training of the first group consisted in 10 sets of 1 run at 100% of maximum power on a power machine, mainly involving the muscle groups of hip and knee extensors. The control group did their training once a week at 3 sets of 5 runs at 50% of maximum power.

Performance and hormone examinations were carried out before (I1), during (I2), and after the training phase (I3). Blood samples were taken from the subjects during a 30-min resting period at 15 min and immediately prior to exercise. Afterwards, power endurance at 70% of maximum power was checked. Directly after this exercise and 5 min later, further blood samples were taken to examine the levels of catecholamines and further hormones. Other performance tests done were maximum power tests as well as tests of maximum isometric power and isokinetic power.

After the 2-week investigation, the daily trained group showed a significant drop in performance in both maximum power and isometric and isokinetic power tests as compared with the results of the control group. Power endurance remained unchanged. In the assessment of the authors, the athletes could be called overtrained.

The examinations of blood epinephrine and norepinephrine levels before the load did not reveal any significant changes in both groups. The comparison of the levels at rest showed no group difference between the two groups, either. However, both the load-induced increase in epinephrine and the increase in norepinephrine showed a significantly higher value in the group of the overtrained athletes at I2 and I3 as compared with I1, though this led to significantly higher values in the overtrained weightlifters as compared with the non-overtrained weightlifters only for norepinephrine in I3. In the group of the non-overtrained athletes, a positive correlation was found between the increase in isometric power from I2 to I3 and the increase in epinephrine and norepinephrine under load. The overtrained group showed a negative correlation between the change in maximum power and the increase in norepinephrine under load.

Load-induced increases in the concentration of total testosterone, free testosterone, and hGH could be observed in both groups. After the 2-week training, the concentrations of total testosterone and of the ratio of testosterone and cortisol were significantly elevated in the overtrained athletes at 5 min after load as compared with the baseline values, significantly reduced, however, for cortisol.

The behavior of hGH did not show any deviations between the overtrained and non-overtrained weightlifters in the course of the study. In the comparison of the overtrained group with the non-overtrained one, the ratio of total testosterone and cortisol, and partly of free testosterone and cortisol, was reduced prior to load. The after-load values showed a reduction in the overtrained athletes for the ratio of total testosterone and cortisol at I2 only.

It should be noted critically here that, as described in Part 1 of the review, a 2-week period of high physical load is too short to induce some definite long-term overtraining. Therefore, "only" a short-term overtraining or overreaching could have been induced in the weightlifters examined in the study by Fry et al. (9, 10) and Fry et al. (8). In the opinion of the authors, the discrete and partly nonuniform changes in testosterone, free testosterone, cortisol, and hGH under intensified power training are not suitable as indicators of a beginning overtraining syndrome. However, the load-induced increases in the epinephrine and norepinephrine levels indicate some elevated activity of the sympathoadrenal system. According to the authors, this could be an indication of an already existing or impending overtraining, in this study caused by a high percentage of intensive power training. This would also be supported by the negative correlation between the load-induced activation of the sympathetic nervous system and the achieved maximum power.

Examination of Runners

Some studies available from different working groups (studies 3, 4, 5, and 6) have examined runners as subjects (see Table 3 in the appendix).

Study 3. Barron et al. (2) aimed at demonstrating an assumed disturbance in the hypothalamus-pituitary system as a consequence of overtraining. According to the authors' definition, an athlete was overtrained if apart from physical symptoms such as weight loss and the sensation of "heavy legs" or mental changes such as lethargy and apathy, also a decrease in physical performance occurred, and this condition lasted for at least 3 weeks.

During a study time of 4 months, 6 marathon runners trained according to their individual training programs. A few days prior to a competition, the authors detected symptoms of an overtraining syndrome in 1 of the 6 athletes, which, however, were not specified in detail. The affected marathon runner had to cancel his participation in the run, but continued his training. After another 6 weeks, the symptoms had become clinically manifest, and he was doubtlessly diagnosed as overtrained. The authors found further athletes to be overtrained according to the above characteristics in 2 runners and 1 walker. The affected athletes were examined within 72 hours of the occurrence of the above symptoms. Another examination followed after a 4-week training break. The 5 remaining non-overtrained marathon runners participated in a 42-km, 56-km, and 92-km run. Hormone tests were done before the first run and after the second and third run.

Using a combined pituitary test, the authors examined the hypothalamo-pituitary function by intravenous injection of insulin, TRH, and LHRH to the athletes.

The insulin injection was intended to induce a hypoglycaemic stress reaction with a corresponding hormonal response. Two athletes diagnosed as overtrained received an insulin injection only, and the insulin-stimulated prolactin secretion was examined.

The non-overtrained athletes did not show any changes in their hormone levels of hGH, ACTH, cortisol, LH, FSH, TSH, and prolactin at any time. hGH, ACTH, and cortisol secretion following insulin administration were significantly lower in the 4 overtrained athletes at the time of diagnosing than after a 4-week recreation. The combined pituitary test in the two overtrained athletes examined accordingly did not reveal any peculiarities with regard to LH, FSH, TSH, and prolactin secretion as compared to the non-overtrained athletes. However, obviously impaired was the prolactin secretion in the 2 overtrained athletes, who had only received insulin. After a 4-week training break, prolactin secretion was back to normal in these athletes. Moreover, in these athletes hGH and ACTH secretion were reduced after sole insulin administration, but cortisol secretion including the basal cortisol level was elevated. Since after insulin administration the blood glucose level dropped only by 2 mmol/L, in the opinion of the authors this discrete hypoglycaemia could not be the sole cause of the hormonal changes. Nevertheless, the authors concluded that the changed hormonal response to the insulin injection observed in individual athletes could indicate some pituitary disturbance and be useful in the identification of overtraining.

It should be critically noted, though, that this study examined only very few allegedly overtrained athletes, in which also different endocrine tests were used.

Study 4. Adlercreutz et al. (1) also examined runners. They tried to find a hormonal parameter to identify overtraining in their study.

The authors divided a non-specified number of runners into two groups. The first group continued with their regular training program, while the second group, according to the authors, performed very intensive training for 1 week. After this week of training, the athletes were divided into three groups based on the results of non-specified physiological tests: *non-overtrained, overtrained, and undetermined.* The parameters leading to this classification were not specified. In particular, any definition of *overtraining* is missing.

The hormonal parameters determined were the blood levels of free testosterone, cortisol, the corresponding ratio of free testosterone and cortisol, the concentrations of SHBG and hGH, as well as saliva analyses for the calculation of the respective ratio of testosterone and cortisol.

Finally, the authors considered the ratio of free testosterone and cortisol in blood the most suitable parameter to diagnose an overload and thus an impending overtraining syndrome. Ranking next in suitability supposedly was the ratio of total testosterone/cortisol.

The threshold values for the ratio of free testosterone/cortisol as an indicator of overtraining were defined as follows: The decrease in the ratio had to be 30% or more, or the value of the quotient had to range below $0.35 \cdot 10^{-3}$ (free testosterone in nmol/L and cortisol in μmol/L). Any decrease in this ratio could not be observed in any of the athletes of the non-overtrained group. In the undetermined and overtrained groups, the authors found values of this ratio reduced by 30% at least in all runners but one.

According to the authors, all other parameters, in particular also the ratio of free testosterone and cortisol in saliva, were not suitable as indicators of an overtraining condition.

For this study, it should be noted that according to the definitions given in Part 1, no overtraining condition can be induced after only 1 week of intensive training load so that the athletes examined here were only exposed to some short-term overload. The chosen classification into groups of non-overtrained, undetermined, and overtrained thus appeared to be rather arbitrary, just as the resulting definition of the threshold values of the decrease in the ratio of testosterone and cortisol by more than 30% and its absolute value of below $0.35 \cdot 10^{-3}$, respectively.

Study 5. Three publications by Lehmann et al. (18, 19, 21) summarized the results of two studies, where runners were subjected to an increase in their training volume for about 5 weeks and, in the second part of the study, to an increase in training intensity for about 4 weeks. Their objective was to gather further knowledge of the vegetative and hormonal regulation in an overtraining condition. Both parts of the study intended to train the participating athletes into an overtraining condition. Overtraining was defined here as a decrease in performance in connection with high training load.

An incremental treadmill test up to subjective exhaustion was done before, during, and after the training weeks in the studies. The parameters measured were oxygen intake, blood lactate concentration, blood hormone concentration, and the maximum distance covered. In addition, the athletes assessed their subjective symptoms using a 4-point scale every 4 days. Also, the catecholamine and cortisol excretions in nocturnal urine and 24-hour urine were measured.

In the first part of the study with an increase in training volume, the training volume of 8 medium-distance and long-distance runners was raised from 86 to 177 km per week. In the second part of this study with an increase in training intensity, training regime was characterized by an increase in interval and speed races from 9.8 km to 22.6 km per week. Nine subjects took part in this study, 7 of whom were also included in the prior high-volume investigation.

Despite the pronounced training interventions, in both overall groups no significant decrease in maximum and submaximum performance and thus no clear overtraining could be induced. The intensive load even yielded some slight increase in performance. A significant increase in the subjective symptoms as compared with the baseline values could be found in both partial studies from the first training week each.

In the study part with increased training volume, no significant changes in free plasma catecholamines could be seen, except for an increase in the norepinephrine level under submaximal load by the end of the training period. The other extensive blood hormone tests (aldosterone, prolactin, LH, testosterone, cortisol, TSH, T_3, T_4, insulin, hGH) showed a significant decrease only for cortisol after submaximal load in the last test as compared with the baseline value. All other hormonal parameters remained unchanged during the intervention.

By the end of the training period, nocturnal catecholamine excretion showed significantly decreased levels as compared with the baseline values. For dopamine, nocturnal excretion was reduced by 47%, for norepinephrine by 53%, and for epinephrine by 48%. Cortisol excretion in 24-hour urine was only reduced during the first training week; afterwards it did not differ from the baseline value.

In the study part with increased training intensity, dopamine concentration remained unchanged. No major deviations were found for the norepinephrine level before and after maximum load and for the epinephrine level exclusively after maximum load. Contrary to the increased norepinephrine level under submaximal

load in the high volume study, the level decreased significantly in the intensity study. This applied similarly to the epinephrine level before and during submaximum load.

At the very end of the training period, nocturnal catecholamine excretion in urine showed a significant decrease in the norepinephrine level by 19%, but no changes in dopamine and epinephrine excretion. Also unchanged was the cortisol excretion in 24-hour urine and all other above-mentioned hormones in the blood.

It must be critically noted that though the athletes were under high load, they were not overtrained so that the partially observed hormonal changes must not be attributed to overtraining. The authors themselves concluded that as a whole, there were no remarkable hormonal changes. Further examinations should check whether the observed elevation in norepinephrine increases under sub maximum load and simultaneous reduction of nocturnal catecholamine excretion after an intensive training period could possibly help diagnose an addisonoid overtraining syndrome.

Study 6. Braumann and Brechtel (3) tried in a prospective study with runners to evaluate parameters for an objective diagnosis of the overtraining syndrome. An overtraining syndrome was defined as a decrease in the treadmill-ergometric maximum performance, combined with other typical symptoms such as performance drop, reduced endurance, quick tiring in training and in everyday life, frequent nonspecific, vegetative symptoms relating to the abdominal organs, sensation of heavy legs, apathy, or mental alterations in the sense of a depressive mood.

After a 7-week training intervention with an increase in the training volume from 70 km to 75–102 km per week and simultaneous increase in the volumes with high intensities by 24–45%, all 6 examined athletes were diagnosed as being overtrained. However, signs of a so-called sympathicotonic overtraining, accompanied by feelings of restlessness, sleep disorder, and euphoric emotions, were found in the first half of the study only.

After 1 week, a significant decrease in the blood IGF 1 level by 20% could be seen. The ratio of free testosterone and cortisol initially increased during the first weeks, but decreased then significantly until the end of the intervention. During the last 2 weeks of the training period, the increase in free blood catecholamines induced by maximum load and shown as the ratio of maximum and basal catecholamine levels before load, decreased significantly. The ratio of maximum and basal catecholamine levels was inversely proportional to the share of intensive training kilometers in the training extent.

The authors concluded that a decrease in IGF 1 concentration, a reduction of the ratio of free testosterone and cortisol, and the decrease in the load-induced catecholamine increase are suitable criteria for diagnosing an overtraining syndrome.

It should be noted critically here that the IGF 1 concentration was reduced already after only 1 week of load, although no distinct overtraining could have been present then—a short-term overload at best. In this phase, the ratio of free testosterone and cortisol was even elevated. Consequently, any possible use of these parameters for an unambiguous definition of overtraining is doubtful.

Examination of Oarsmen

Study 7. Only one study (see Table 4 in the appendix) is available that examined oarsmen in connection with endocrine changes and overtraining or high training

load. This study by Vervoorn et al. (40) was in particular aimed at gathering new findings on the behavior of the ratio of free testosterone and cortisol in oarsmen over one season.

Following Adlercreutz et al. (1; study 4), the authors defined an athlete as *hormonally overtrained* if a decrease in the ratio of free testosterone and cortisol by 30% at least or a value of the ratio of less than $0.35 \cdot 10^{-3}$ (free testosterone in nmol/L and cortisol in μmol/L) was determined. Where other symptoms, such as increase in the morning heart rate, weight loss, impaired concentration, delayed recreation heart rate, and emotional instability, were observed in addition to the hormonal changes, the authors called those athletes *overtrained.*

For a period of 9 months, 6 oarsmen underwent a number of examinations at intervals of 5 weeks. During that time the athletes additionally attended a 2-week training camp, where the examinations were done every 4 days (I3–I5). Their specific performance was checked by tests on a rowing ergometer.

With most of the oarsmen, the ratio of free testosterone and cortisol decreased by 5 to 50% during the training camp involving high physical load. The 30% limit defined by Adlercreutz et al. (1) was exceeded in a total of 19 out of 51 examinations. However, since great individual variations were present, the values of the group did not reach a level of significance. No case showed any decrease of the ratio below $0.35 \cdot 10^{-3}$ (free testosterone in nmol/L and cortisol in μmol/L). In comparison of the ratio of free testosterone and cortisol with the respective preceding examinations, a significant decrease was observed from I7 to I8 and a significant increase in turn from I8 to I9.

The performance check at 4 mmol lactate showed significant increases in I3, I4, I5, I6, and I8 as compared with the baseline test I1. So, performance increased at the training camp (I3–I5), indicating that no overtraining was present here. A significant decrease in performance, however, was observed in I8 as compared with the preceding diagnosis in I7. That was the period when also a significant decrease in the ratio of free testosterone and cortisol occurred. Any significant changes in maximum performance did not occur during the entire examination period. Neither could correlations between maximum or submaximum performance and the hormonal parameters over the entire examination period be deduced.

In the opinion of the authors, the results showed that the ratio of free testosterone and cortisol was a suitable parameter for early indications of hormonal overload. However, they interpreted the partly observed decrease in the ratio of more than 30% during the training camp phase as a temporally incomplete recreation phase rather than as overtraining. Thus, they disassociated themselves from the limits for overtraining diagnosis defined by Adlercreutz et al. (1).

Examinations of Swimmers

A total of two studies (see Table 5 in the appendix) were conducted on the relationships between hormonal peculiarities and overtraining in swimmers. Both studies included male and female athletes.

Study 8. Hooper et al. (15, 16) intended in their study to demonstrate changes in hormonal parameters in 14 competitive swimmers that could be useful in the diagnosis of overtraining.

An athlete was considered overtrained in this study if any increase in performance was lacking after an intensive training phase for several weeks (I3) and, in

addition, the subjective feeling of the athlete—in particular in the assessment of the parameter of tiredness—was assessed higher than 5 on a 7-point scale. Moreover, any organic disease had to be excluded for diagnosing an overtraining syndrome.

Nine female and 5 male subjects, whose competitive discipline was either short or medium distance, kept a training diary over the study period of 6 months. They recorded their training program as well as their subjective feelings. Performance was checked by a maximum swimming test. The medium-distance athletes swam 400 m in this test, the sprinters 100 m.

Individual training schedules were set up for each athlete in agreement with the trainers. In phases of different training quality, hormonal blood tests were conducted and performance-related parameters were checked. The first examination was done 2 to 3 weeks after a prevailingly aerobic training (I1), the next one after increasing intensity 9 to 12 weeks later (I2). The third examination was done also under intensive training 5 to 6 weeks prior to important competitions (I3). Some days before and during tapering and few days after the competition the study-relevant parameters were checked again (I4 and I5).

In the view of the authors, 3 female swimmers fulfilled the conditions defined in advance to be considered as overtrained. In contrast to the athletes considered as non-overtrained, the results of the swimming test on the third day of examination did not show any improvement for those swimmers. The subjective assessment of tiredness according to the definition was significantly increased in the overtrained athletes as compared with the non-overtrained ones on 3 different days of examination. As a total group, the hormonal tests did not show any significant changes in the resting blood levels of cortisol and norepinephrine for the 14 swimmers. However, in the last examination immediately after a competition, a significant decrease in the epinephrine level could be demonstrated. The comparison of the overtrained and non-overtrained athletes did not reveal any difference for the cortisol and epinephrine levels. The resting level of norepinephrine, though, was significantly increased in the overtrained athletes during the tapering phase immediately before the competition as compared with the baseline values and also as compared with the values of the non-overtrained athletes.

The authors found positively significant correlations between the volume of training and norepinephrine and epinephrine resting levels in the entire group.

In summary, the authors considered the resting norepinephrine blood level as a possible indicator for diagnosing an overtraining condition but recommend confirmation of their findings in a larger number of athletes. Thus, they pointed out a critical aspect, namely that a supposed overtraining existed in only 3 athletes.

Study 9. The objective of the study by Mackinnon et al. (29) was to compare hormonal reactions of male and female athletes, who showed symptoms of a short-term overtraining, with those of athletes with no short-term overtraining. Herein, the authors assumed that the symptoms of short-term and long-term overtraining would be similar. The difference would lie in the quicker resolution of a short-term overtraining by recreation periods as compared with the regeneration period for long-term overtraining. An athlete was considered as overtrained if the following conditions were met: In addition to lacking improvement in performance in a standardized swim test after a 4-week training load, the self-assessment of tiredness had to be higher than 5 on a 7-point scale for 5 successive days. Moreover, negative comments associated with the subjective feeling concerning the training must have been recorded in the training diary. Another condition was the exclusion of any organic disease.

Within 4 weeks, 8 female and 16 male swimmers increased the volume of their swim training by 36.5% and that of their land training by 22.2% or more. Tests were done before the beginning of the training (I1), after 2 weeks (I2), and at the end of the increased training volume (I3). Six female and 2 male swimmers were considered as short-term overtrained by the authors. As the only parameter, nocturnal norepinephrine excretion in urine showed significantly lower values in the short-term overtrained athletes as compared with the non-overtrained athletes already before the intensive training period and also in the course of the study. For all other hormonal parameters such as plasma levels of norepinephrine, cortisol, and free testosterone as well as the ratio of free testosterone and cortisol, no significant differences could be detected between the two groups.

Therefore, the authors considered only a reduced nocturnal norepinephrine excretion in urine to be a useful indicator of overload or short-term overtraining. Since excretion was diminished before the actual training program already, the authors assumed that neuroendocrine changes precede a clinically detectable short-term or long-term overtraining and could possibly contribute to the manifestation of the syndrome. However, the norepinephrine excretion being reduced already before the actual training intervention questions the whole study design as obviously not the intervention training, but other pre-existing factors have caused the reduced values. The intervention itself caused no hormonal changes in the non-overtrained athletes nor in the overtrained ones.

Examination of Soldiers

Two studies (see Table 6 in the appendix) are available from the literature that involved soldiers as subjects in their examinations.

Study 10. The objective of the study by Fry et al. (11) was to investigate endocrine and other physiological parameters associated with a short-term overtraining. Hormone levels showing significant changes after a 10-day intensive training program and not having returned to their baseline values even after a subsequent 5-day recreation period could, in the opinion of the authors, be correlated with the etiology of an overtraining syndrome. Criteria for a short-term overtraining were the diminished performance after the training program and in a subsequent phase of active recreation as compared with the performance before the training.

Five soldiers of a special unit of the Australian army participated in two training units daily for 10 days. The unit in the morning consisted of 15 sprints of 1 min each at an individual speed between 18 and 21 km/h, interrupted by 2 min for recovery each. In the afternoon, the soldiers did 10 sprints of 1 min each with a recovery period of 1 min each between the sprints. The speed was the same as in the morning. The 10 training days were followed by 5 days of active recreation at moderate load (slow running or walking).

The performance of the soldiers was determined by three 3-stage incremental treadmill tests on days 1, 11, and 16. Stage 1 was a 4-min run at 12 km/h. After a 3-min break the speed was increased to 15 km/h in stage 2. After another break of 3 min, the speed was raised to 18 km/h, which had to be run until subjective exhaustion. The total run time was the essential criterion for measuring performance. Blood samples were taken on days 1 (I1, before the training), 6 (I2, during the training), 11 (I3, immediately after the training), 12 (I4), 13 (I5), 14 (I6), 15 (I7), and 16 (I8).

On day 11, a significant decrease in total run time was observed. On day 16, however, the baseline level was reached again.

Among the endocrinological parameters, only a decrease in cortisol concentration observed on days 12 to 15 reached a level of significance as compared with day 1. All other hormone values such as LH, FSH, testosterone, SHGB, and the ratio of testosterone/cortisol, remained unaffected by the training.

In summary, the authors concluded that the observation of hormonal parameters could be useful in the recognition of a short-term overtraining syndrome. However, this alone would not be sufficient to unambiguously identify overtraining.

Study 11. Chicharro et al. (4) also assumed in their study that not only athletes would be faced with the problem of overtraining, but also soldiers. The authors investigated this hypothesis by means of the analysis of the ratio of free testosterone and cortisol. Following Adlercreutz et al. (1) they defined a soldier as being overtrained if the ratio of free testosterone and cortisol was lower than $0.35 \cdot 10^{-3}$ (free testosterone in nmol/L and cortisol in μmol/L) and/or this value had decreased by more than 30%. Forty-two soldiers of a special unit of the Spanish army took part in this examination. Haematological and hormonal tests were done before and after an 8-week training program. In addition, numerous performance-diagnostic tests were conducted.

For 10 soldiers, an overtraining was diagnosed at the final examination due to a decrease in the ratio of free testosterone and cortisol by more than 30%. However, with none of the subjects did the value drop below $0.35 \cdot 10^{-3}$. The maximum treadmill test did not give any indication as to a reduced performance of the supposedly overtrained subjects as compared with the baseline test. On the contrary, run speed at 4 mmol/L blood lactate as the parameter of submaximal performance even increased in both groups. In the remaining tests, performance was nonuniform. It remained unchanged in most of the tests; in some, the performance of the non-overtrained subjects increased, but not that of the supposedly overtrained soldiers. With bench pressing, it was vice versa.

Free testosterone levels before the onset of the training did not differ between the supposedly overtrained and non-overtrained soldiers. After completion of the training phase, the concentration of free testosterone of the non-overtrained subjects, however, was significantly higher than that of the overtrained ones. While in the soldiers defined as non-overtrained, the free testosterone levels had significantly increased from onset to end of training, soldiers defined as overtrained showed no changes in this parameter. Cortisol concentration behaved contradictory. It reached a significant increase after training in the group of the supposedly overtrained soldiers, while it did not change in the non-overtrained group.

As a whole, though, such a behavior of the examined hormones could be expected with the chosen group assignment according to the definition by Adlercreutz et al. (1). The authors concluded from their results that the observation of the ratio of free testosterone and cortisol and of performance parameters would offer a chance for the early recognition of overtraining. Summing up, it must, however, be pointed out that the crucial criterion of overtraining, namely a reduction of performance, was found in the fewest of the performed tests in the group of the supposedly overtrained soldiers, that partly even increases in performance could be observed. Therefore, the study design in general is doubtful. The observed hormonal changes can be interpreted as an intra-individual response to high physical load, but without unambiguously indicating overtraining.

Examinations of Subjects From Different Sports

Some examinations (see Table 7 in the appendix) are available that investigated mixed groups of male and female subjects from various sports. However, all examinations chose male and female endurance athletes from the disciplines of cycling, long-distance-, cross-country-, and orienteering running, triathlon, swimming, and cross-country skiing as subjects.

Study 12. The intention of the study by Hackney (13) was to collect further knowledge of neuroendocrine parameters at rest in connection with an overtraining condition. Athletes were defined to be overtrained if they showed a decrease in both physical and mental performance in correlation with an increase in their training activities and complained of non-specific symptoms such as apathy, lethargy, sleeplessness, muscle problems, gastro-intestinal trouble, and a sensation of heavy legs.

The author examined a total of 8 cyclists and runners. He tested their blood levels of LH, testosterone, cortisol, and prolactin at rest. The ratio of testosterone and cortisol was calculated. Venous blood samples were taken from the athletes before the intervention training (I1), after 8 weeks of intensive training (I2), and another 10 to 12 days later (I3).

In the opinion of the author, 4 out of the 8 athletes were overtrained after the intensive training phase. Their hormonal parameters were compared with those of the 4 athletes classified as non-overtrained, who had undergone a similar training, but showed none of the above signs of overtraining.

Before the beginning of the training, no significant differences in the examined hormones could be found between the two groups. The values of the athletes considered as non-overtrained remained unchanged during and after the training intervention. In the group considered as over-trained, the examinations after completion of the training showed a significant decrease in the testosterone level and in the ratio of testosterone and cortisol, while prolactin concentration had increased significantly.

In the author's opinion, the results as a whole support the theory of a neuroendocrine dysfunction in the overtraining condition. It must be noted critically, however, that a decrease in performance as an essential indicator of an overtraining syndrome was not analyzed differentiatedly. Therefore, the presented findings can be considered as neuroendocrine changes in connection with high training load rather than as an unambiguous parameter in the diagnosis of overtraining.

Study 13. In a prospective longitudinal study, Urhausen (35) and Urhausen et al. (36) examined, among others, the role of hormonal parameters in the diagnosis of an overtraining syndrome.

The exclusion of any organic disease provided, an athlete was considered as overtrained if the classical symptoms such as decrease in performance, diminished endurance, and rapid tiredness were present, accompanied by more or less pronounced vegetative complaints.

Over a period of 19 months, 17 triathletes and racing cyclists were examined five times on 2 days each. In 15 athletes, overtraining was diagnosed at least temporarily.

Apart from blood and urine tests, an incremental bicycle-ergometric test for the determination of the individual anaerobic threshold was conducted, as well as a so-called maximum stress test on the bicycle ergometer, in which the load was 110% of the performance on the individual anaerobic threshold till subjective exhaustion,

and a 30-s test, in which a performance of 600–650 W had to be maintained on the bicycle ergometer for 30 s. After the 30-s test, a venous blood sample was taken to determine the blood catecholamine levels. Those parameters obtained in athletes during supposed overtraining were individually compared with the test results of the same athletes in non-overtrained condition.

Maximum performance in the incremental test and the individual anaerobic threshold were unchanged in the athletes classified as overtrained, just as the performance in the 30-s test. However, in these athletes, a significantly reduced exercise time in the maximum stress test under the assumed overtraining condition was striking as compared with the non-overtrained condition.

Extensive endocrinological diagnostic measures did not reveal any significant differences between the overtrained and non-overtrained athletes—neither for the resting blood levels of LH, FSH, total testosterone, free testosterone, SHBG, ACTH, cortisol, hGH, insulin, β-endorphine, nor for nocturnal catecholamine excretion in urine. The calculated ratios of testosterone and SHBG, testosterone, and cortisol, and free testosterone and cortisol remained unchanged as well.

At the 10th minute of the stress test, blood levels of cortisol, insulin, hGH, and epinephrine were normal in the intra-individual comparison between overtrained and non-overtrained condition; those of norepinephrine, however, increased. The maximum load-induced levels of ACTH, hGH, and insulin after the stress test were significantly lower in the overtrained condition than in the non-overtrained condition, while the values of cortisol and β-endorphine remained unchanged. The blood levels of the catecholamines did not show any significant differences between both conditions, neither in the 30-s test nor in the stress test after maximum load.

The authors conclude that the study could not reveal any hormonal indicators for the unambiguous diagnosis of an overtraining syndrome. The reduced increase in some hormones in intra-individual comparison and the involvement of mental stress factors, however, would offer promising approaches for further longitudinal studies.

Study 14. Flynn et al. (6) examined cross-country runners and swimmers in their study. The authors were of the opinion that the spontaneous endocrine reactions in the course of a competitive season with different training sections would differ from those under experimentally elevated training volumes and/or training intensities for only a few days or weeks, as was the case with most of the previously conducted intervention studies. The main intention of the authors was therefore to record endocrine parameters in connection with typical changes in the training macro-cycle and examine them with regard to their potential relevance as indicators of overtraining. For this purpose they observed the behavior of selected hormones during a complete competitive season. For the involved 8 cross-country runners, the season lasted for 12 weeks, and for the 5 involved swimmers, for 21 weeks.

Blood samples were taken and performance-diagnostic tests were done with the runners before the beginning of their specific training (I1), after 3 weeks of increased training (I2), 3 weeks before a competition (I3), and finally 4 days after this competition (I4). The first examination of the swimmers was done after 9 weeks of moderate training (I1), followed by another examination of a 2-week training camp (I2), and after another 6 weeks of hard training (I3). The last day of examination was 4 weeks later and 1 week after a competition, respectively (I4). Resting levels of total and free testosterone, and cortisol were determined. The ratios of total testosterone and cortisol and of free testosterone and cortisol were calculated. Criteria

for overtraining were not defined. The performance of the swimmers in a maximum 365.8-m swim test was significantly decreased at I2 as compared with I4. The maximum swim velocity test over 22.9 m showed a significantly lower speed at I2 as compared with I1 and I4. The performance of the runners related to the duration in a run test at 110% of $\dot{V}O_{2max}$ was significantly increased at I2 as compared with all other examinations.

Cortisol levels of the swimmers did not differ significantly from those of the runners at the respective days of examination and remained unchanged over the course of the examination. Striking in the swimmers was a significant decrease in total testosterone levels at I2 to I4 as compared with I1. Moreover, the level of total testosterone was higher at I4 than at I2 (i.e., on the very day with the lowest performance). In contrast, no significant changes between the days of examination were observed in the runners. Neither for the swimmers nor for the runners did the ratios of total or free testosterone and cortisol show any significant changes in the course of the examination period.

Summing up, the authors could not confirm the suitability of the behavior of the blood cortisol level and of the ratio of testosterone and cortisol as possible indicators of overtraining as claimed in other studies, since they did not show any significant changes in any training phase neither with the swimmers nor with the runners. A decrease in the free testosterone level and a reduction of total testosterone could, according to the authors, indicate some overtraining. Though the authors notified that an essential increase in the training intensity and/or the training volume was necessary to actually induce significant changes in these hormones, this would restrict the usefulness of these hormones for diagnosing overtraining.

Study 15. In a study with cyclists and cross-country runners, Mackinnon (29) intended to verify the assumption postulated by Hooper et al. (15, 16) and others that an increase in the plasma norepinephrine level in swimmers could serve as an indicator of overtraining. At the same time, applicability to other sports should be tested.

An overtraining syndrome was defined if improvement in performance in the course of one season was lacking, combined with the increased occurrence of high rates of tiredness on 7 consecutive days. In addition, any organic disease was excluded.

The examination included 9 cross-country runners and 10 cyclists of both sexes. Within 5 to 6 months of preparation for an important competition, 4 examinations were done with the runners (I1–I4) and 3 examinations with the cyclists (I1–I3). Another examination was done with each after the competition (I5 and I4, respectively).

Characteristics on an overtraining syndrome occurred with 3 female runners and 1 male runner and with 3 male cyclists. From the beginning of the season till after the competition, performance of the overtrained athletes dropped with the runners by 1 to 5% and with the cyclists by 1 to 4%. The non-overtrained athletes in the runners' group, on the contrary, achieved an increase in performance between 1 and 6%, and in the cyclists' group, between 1 and 12%.

Resting blood tests of the male and female cyclists did not show any significant changes in the levels of cortisol, total testosterone, free testosterone, and norepinephrine, neither in comparison of the examination time points nor in comparison between overtrained and non-overtrained athletes. This also applied to the male and female runners, with the exception that the male runners defined as overtrained

showed significantly higher ratios of free testosterone and cortisol at I3 and I4 as compared with all other examination time points.

With these results, the author could not confirm the results from the study by Hooper et al. (15, 16), namely elevated resting levels of norepinephrine in 3 female swimmers defined as being overtrained. Therefore the author suggested the frequent checking of performance parameters and of subjective tiredness as the most reliable indicators so far for recognizing an overtraining syndrome.

Study 16. The study by Uusitalo et al. (38) aimed at investigating the behavior of various hormonal parameters in female endurance athletes during a specifically increased training load. Female runners, cross-country skiers, and triathletes participated in the study.

The criteria for determining overtraining were defined as follows: decrease in maximum oxygen uptake by at least 2 ml · kg^{-1} · min^{-1}, decrease in maximum performance in the standardized treadmill test, a feeling of inability and aversion to continuing the training. These symptoms had to be accompanied by some further symptoms such as depressive moods, sleep problems, lack of appetite, irregular menstruation, tremor, sweating, or other psychosomatic symptoms. Any organic diseases, injuries, or other reasons that could explain a decrease in performance had to be excluded.

Fifteen female endurance athletes were divided into an experimental intervention group (group A) and a control group (group B) who did their training completely at their own discretion. Nine athletes of group A increased their overall training volume by 80% during the 6 to 9 weeks of intervention, namely by means of an 98% increase in the training extent at low intensity and an increase in intensive training by 130%. Strength training was reduced by 54% herein. The retrospective analysis of the training of group B showed a slight increase in the overall training volume by 6%, including an increase in the low intensity training by 5%, in the intensive training by 10%, and in strength training by 21%.

Blood and urine tests for hormone levels as well as ergometric tests were done before the onset of training (I1), after 4 weeks (I2), and after a total of 6 to 9 weeks of the training program (I3). Based on the mentioned conditions for determining an overtraining, 5 athletes of group A were defined as overtrained.

The catecholamine levels in urine did not show any significant changes in the course of the training for either group. However, a major inter-individual variation of the proportional changes of catecholamine excretion were observed. The individual changes in norepinephrine excretion from I1 to I3 ranged between –161% and +6423% in the 5 women defined as overtrained, in group A overall between –54% and +21%, and in group B between –14% and +91%. Regarding the changes of epinephrine excretion, the overtrained group showed values between –93% and +586%, group A showed values of 0% to +8400%, and group B of –53% to +700%.

By the end of the training phase, the results of the blood tests for group A showed significantly decreased blood levels of epinephrine at maximum load and of norepinephrine at submaximum load as compared with the results before the onset of training. In group A, cortisol level at maximum load dropped significantly already at I2 as compared with I1. The decrease continued to I3. With the 5 overtrained women of group A, the epinephrine levels at maximum load decreased significantly already during the first 4 weeks. No significant changes between the individual tests could be observed in the control group. The results of the blood tests showed pronounced intra-individual variations generally in all groups.

Summing up, the authors stated that, if the corresponding resting values are used for comparison, load-induced hormonal reactions would be suitable to indicate some elevated training load, which under certain circumstances could lead to the development of an overtraining syndrome or which could be observed in connection with an overtraining syndrome. The described changes in the hormone levels, according to the authors, indicated a decreasing sympathoadrenal and/or adrenocortical activity or an exhaustion of the adrenals or of the central nervous system. The great inter-individual variations in hormonal reactions during exercise should give rise to the set-up of an individual hormonal profile in order to follow-up training effects and to prevent the potential development of overtraining.

Discussion

The following part will discuss the behavior of the evaluated hormones of athletes who were overtrained according to the respective definitions by the authors or who were exposed to high physical load with the aim to reach an overtraining syndrome in the course of some specific intervention. First, the behavior of the respective hormones will be considered according to their associations with the respective hypothalamo-pituitary axes. This will be followed by the discussion of calculated values, such as the ratio of testosterone and cortisol. Finally, the behavior of the catecholamines and the sympatho-adrenal system will be discussed.

The Hormones of the Hypothalamo-Pituitary-Adrenal Axis (HPAA)

Studies Examining Both ACTH and Cortisol. Only two of the available studies examined the resting levels of ACTH (studies 1 and 13). In study 1, which was evaluated by various authors, the ACTH resting level remained unchanged on average after high endurance training load as compared with their baseline values. Cortisol resting levels also remained unchanged after the intervention in this study. The same applies to the increase in ACTH and cortisol after maximum load. However, the authors found an increased ACTH secretion after stimulation with corticotrophin-releasing hormone (CRH) by the end and after the intensive training phase while, in contrast, the CRH-induced cortisol elevation by the end of the intervention was reduced. Overtraining, though, could not be induced in this study. Urhausen (35) and Urhausen et al. (36; study 13) also found unchanged ACTH and cortisol levels in endurance athletes at rest under supposed overtraining. In this study, however, the maximum load-induced ACTH increase in the state of overtraining was reduced in an intensive endurance test with simultaneously reduced maximum performance in this test. Maximum cortisol increase, though, remained unchanged in the state of overtraining.

In another study that used a combined stimulation test (TRH and insulin) as function test, Barron et al. (2; study 3) found no differences in the behavior of the HPAA in 2 athletes in overtraining as compared with non-overtrained athletes. However, they found a reduced ACTH and cortisol response after a regeneration phase after a state of overtraining in comparison with their own, intra-individual values. With 2 other athletes, ACTH secretion was reduced with sole insulin stimulation in overtraining; cortisol secretion, including the cortisol basal baseline value, however, was elevated. It seems important in the interpretation of these results that only a very small number of overtrained athletes were examined. Because of the

physiologically high inter-individual variability in the stress response of the HPAA (30), caution is required in the interpretation of these results.

As a whole, these studies show a non-uniform picture of the HPAA regulation in connection with high training load and overtraining. The resting level of ACTH seem to be largely unaffected, though it should be noted here that ACTH is secreted pulsatively, but single blood samples were taken in the studies described. Thus, training-induced effects on the ACTH behavior may possibly not be revealed sufficiently. The reduced ACTH response in the so-called stress test described by Urhausen (35) and Urhausen et al. (36) needs not be inadvertently the cause of the reduced performance in this test, but may also be considered as a consequence of the overall lower performance, since the lower performance does not require such a high metabolic mobilization of energy carriers. However, since the cortisol response remained high and unchanged, the results can be interpreted in the sense of a shifted feedback regulation with exceeding cortisol secretion and with simultaneously reduced ACTH levels. The results by Barron et al. (2) are similar to some degree with a reduced ACTH response and exceeding cortisol secretion in the insulin stress test with individual athletes in overtraining and with a reduced ACTH and cortisol response in the combined TRH-insulin test with another 2 overtrained athletes. This, however, is contradicted by the results of the study by Lehmann et al. (22; study 1), who found an elevated ACTH secretion, but a reduced cortisol release after exogenous stimulation with releasing hormone. Importantly, the athletes in this study were exposed to a high training load but were not overtrained.

These few, contradictory findings on the behavior of ACTH and cortisol considered together should first be complemented by adding the discussion of those studies that have only investigated the behavior of cortisol.

Studies Investigating Cortisol Alone. The majority of the available studies found resting levels in the state of overtraining to be unchanged as compared with the state of non-overtraining in the same athletes (studies 5, 8, 9, 12, 14–16). Furthermore, the inter-individual comparison of athletes classified as overtrained as compared with those classified as non-overtrained did not show any group differences with respect to the resting cortisol levels in the majority of the studies (studies 8, 9, 11, 12, 15). An increase in the resting blood cortisol level was only found by Braumann and Brechtel (3) in an intervention study (study 6), temporarily also by Vervoorn et al. (40; study 7) in a phase of high training load in oarsmen, and Chicharro et al. (4; study 11) in connection with high physical load in soldiers. Only in the examination of Fry et al. (11; study 10) did the authors find reduced resting cortisol levels in a small group of 5 soldiers in the days after short-term, intensive training load that was too short to induce a clinically manifest overtraining.

The load-induced behavior of cortisol showed no uniformity either. After an increase in training intensity, Lehmann et al. (18, 21; study 5) found unchanged blood cortisol levels in runners after maximum load in an incremental treadmill test, while after an increase in training volume, reduced cortisol levels were determined after maximum load. In both studies the athletes were under high load during training, but they were not overtrained, since performance was not significantly lowered. Interestingly, mean cortisol excretion in 24-hour urine was unchanged under both training interventions. Also Fry et al. (8–10; study 2) found reduced cortisol levels 5 min after strength-endurance load in overtrained weightlifters. Moreover, Uusitalo et al. (38; study 16) found significantly decreased cortisol levels after maximum load in female endurance athletes, but not during submaximum load after a phase of

high training loads. The subgroup of overtrained female athletes, though, did not show any changes in the load-induced cortisol behavior.

In summary, those studies having only examined cortisol behavior among the HPAA hormones, did not reveal any uniform picture in association with high training load or manifest overtraining. The majority of studies, however, indicate unchanged resting cortisol levels. The clinical relevance of changes in acute load-induced cortisol increments is, moreover, doubtful, since the average excretion in 24-hour urine in the same investigation by Lehmann et al. (18, 21) remained unchanged under both increases in the training volume and increases in the intensity.

Summary Discussion of the Behavior of ACTH and Cortisol. In response to any external stimulus that is perceived as a threat to homeostasis (stress), activation of the autonomic nervous system occurs and blood cortisol levels increase as a result of activation of the HPAA (41). Some authors in summarizing reviews try to explain the pathogenesis of overtraining by changes in the HPAA. Urhausen and Kindermann (37), for example, considered a cortisol-induced suppression of the hypothalamo-pituitary axis as a possible explanation of the genesis of overtraining. Herein, they referred to Adlercreutz et al. (1; study 4), who were the first to assume some possible relationship between hypercortisolism and overtraining in athletes, based on their experimental findings. Actually, though, the intensive load phase in the study by Adlercreutz et al. (1) lasted only 1 week and thus was much too short to induce some unambiguous overtraining (see Part 1 of this review paper for the definition of overtraining). In their review paper, Fry and Krämer (7) explained the assumed elevated cortisol secretion found in some human studies by an increased stimulation of the adrenal cortex by catecholamines. Just as Stone et al. (33), Kuipers and Keizer (17), and Häkkinen et al. (14), they named an increase in training intensity or an increase in strength training as a possible cause of the increase in the cortisol level at rest in the state of overtraining.

The few studies with athletes on the behavior of ACTH in connection with high load or overtraining, though, are contradictory indeed. Any definite response of the pituitary section of the HPAA cannot be definitely deduced from the few findings including only a very small number of subjects, neither for the behavior at rest nor during acute load or after exogenous stimulation. The majority of studies on the behavior of cortisol in connection with high load or overtraining in humans have found unchanged resting cortisol levels; few studies either found elevated or even reduced resting values. The load-induced behavior of cortisol also behaved non-uniformly, with either unchanged or even reduced levels under maximum load.

Contrary to the available detailed human-physiological studies on the problem of overtraining, a number of animal-experimental findings and further investigations on stress response and stress compensation do indicate changes in the feedback regulation of the HPAA (32). In this connection, it seems important that recently the possible inter-individual variability in stress response and stress compensation is more and more being pointed out (30). If the assumption holds true that due to high physical and/or mental load in the state of overtraining, changes in the HPAA feedback regulation occur, this inter-individual variability could be one of the reasons that such changes cannot be demonstrated on statistical average in small groups.

Because of the contradictory findings in the human-physiological studies mentioned here, it can in general neither be definitely excluded nor confirmed that repeated high training and competition loads result in changes of the feedback

regulation of the hypothalamo-pituitary-adrenal axis that may clinically lead to a state of overtraining.

Due to the considerable inter-individual variation of the behavior of the HPAA hormones, it may be necessary to investigate the individual courses and responses of the relevant hormones more intensively than in the previously conducted studies.

Renin and Aldosterone

The behavior of the renin-angiotensin-aldosterone system at rest and load-induced effects in connection with high physical training loads intended to induce a state of overtraining, using blood concentrations of renin and aldosterone as markers of the system, were reported by the authors who had published the results of study 1 and 5 (5, 18, 21, 22, 23). The authors could not find any significant changes in the resting renin or aldosterone levels after the interventions. The load-induced effects on renin and aldosterone also remained unchanged after the intensive training periods. Therefore, the behavior of the renin and aldosterone as a whole does not seem to be related with high training loads or even the problem of overtraining.

The Hormones of the Hypothalamo-Pituitary-Gonadal Axis

LH and FSH. The pituitary hormones LH and FSH did not show any significant changes in their resting values or their values after maximum load in an overtraining condition or after phases of high training load that were intended to cause overtraining (studies 1, 5, 10, 12, 13). However, pituitary responsiveness to gonadotropin-releasing hormone (GnRH) seemed to be changed after phases of intensive training. Lehmann et al. (23), in a pituitary function test, could not show any changes in FSH secretion after GnRH immediately after a 6-week training phase, but after a 3-week recreation period, FSH was significantly elevated as compared to the baseline values. In contrast to FSH release, maximum LH secretion in this examination was reduced after the 6-week training program and in the subsequent 3-week recreation period as compared to the baseline examination.

It seems to be important in the interpretation of the findings that with punctual, individual blood samples, the physiological pulsatile secretion of LH and FSH is not taken into account (39). Thus, possible overtraining effects on parameters of the pulsatile secretion pattern, such as pulse frequency and/or amplitude, will not be detected. The above described changes in the exogenously inducible LH and FSH release indicate that high training loads seem to influence the hypothalamo-pituitary level of the HPGA. However, the athletes in this study were not overtrained.

Total Testosterone and Free Testosterone. Total testosterone levels of overtrained athletes remained unchanged in the intra-individual comparison in most of the studies (Nos. 1, 5, 10, 14 (runners), 15, 16). Four overtrained athletes in the study by Hackney (13) (No. 12), however, showed a decrease in resting testosterone levels. Flynn et al. (6) (No. 14) obtained similar results in 5 swimmers in the course of the training season during which a decrease in performance was observed in connection with high training loads. The basal values of the biologically active free testosterone was not found to be significantly changed in the majorities of studies either (Nos. 6, 7, 9, 11, 13, 14 (runners)). Only Flynn et al. (6) (No. 14) found a reduction of free testosterone, just as for total testosterone, in the swimmers examined in the course of the season in connection with high training loads.

The load-induced increase in total testosterone and free testosterone remained just as unchanged in the weightlifters in the state of overtraining examined by Fry et al. (8–10; study 2) as the athletes under high training load examined by Lehmann (21). Neither did the female endurance athletes examined by Uusitalo et al. (38; study 16) show any changes in testosterone levels after training load. However, the authors found the major inter-individual differences in the individual athletes. Different phases of the menstruation cycle, though, were excluded as an explanation of these findings, since in the opinion of the authors the cycle does not influence testosterone secretion.

The exogenously stimulated increase in testosterone was reduced after high training load in the study by Lehmann et al. (22, 23; study 1). Since, however, LH secretion was reduced at the same time, the cause of the restricted testosterone increase should be seen in the reduced LH response rather than in a reduced gonadal responsiveness.

Summary Discussion of the Behaviour of LH, FSH, and Testosterone. As a whole, most of the studies did not show any essential changes in the hormones of the hypothalamo-pituitary-gonadal axis in highly loaded or overtrained athletes of both sexes. Since the pulsatile secretion of LH and FSH, though, was not examined adequately, load-induced changes at hypothalamic and/or pituitary level cannot be excluded. They could already be demonstrated in female athletes in correlation with high training load and a simultaneous hypocaloric diet (25, 27). The changes in the GnRH stimulation test described by Lehmann et al. (22, 23; study 1) make corresponding alterations in highly loaded athletes probable.

Although most studies did not find any changes in the resting levels of total or free testosterone, individual examinations suggest a possible suppression of testosterone production in the state of overtraining nevertheless. For women HPGA suppression has been known for quite a long time already, in particular under the combination of high training load and a non-adequate diet (31). To what extent a possible caloric deficiency may have contributed to the hormonal changes in the studies described here, remains unclear since no data at all have been provided in this respect.

Summing up, the available data on the HPGA hormones in humans is currently so contradictory as yet that none of the described parameters would be suitable as an indicator of some possibly existing or developing overtraining syndrome.

The Ratios of Total Testosterone and Cortisol (T/C) and Free Testosterone and Cortisol (Ft/C). The ratios of total testosterone and cortisol (T/C) and free testosterone and cortisol (fT/C) are being intensively discussed and examined as possible indicators of an overtraining syndrome. While cortisol has prevailingly catabolic properties, testosterone—due to its effects on metabolism, in particular on protein metabolism—is considered an anabolic hormone. Thus, the ratio of both hormones (T/C and fT/C, respectively) is supposed to reflect the anabolic/catabolic status of the athletes (33). From a physiological view, however, the formation of such a quotient is extremely problematic, since it suggests that the individual effects of these hormones would be quantifiable for any possible metabolic effect, and consequently the overall effect could be estimated by simply forming the quotient. For this, however, any experimentally verified basis is missing.

Adlercreutz et al. (1; study 4) suggested the fT/C ratio as the most sensitive indicator of physical overload. They defined the value for diagnosing overtraining by the decrease in the fT/C ratio by 30% at least or by a value of the ratio of below

$0.35 \cdot 10^{-3}$ (free testosterone in $nmol \cdot L^{-1}$ and cortisol in $\mu mol \cdot L^{-1}$). But in this study, due to the much too short load phase of only 1 week, no overtraining could have been induced—only a short-term overload at best. Moreover, distinct diagnostic criteria for the group assignment to the supposedly overtrained and non-overtrained athletes is missing so that, as a whole, the determined threshold values for the decrease in the ratio of testosterone and cortisol of more than 30% and its absolute value of below $0.35 \cdot 10^{-3}$ to recognize an overtraining condition, appear to be rather arbitrary. Whether such threshold values actually exist remains to be examined in a larger number of undoubtedly overtrained athletes.

Biological variability of the ratios also seems to be considerably high. Flynn et al. (6) (No. 14), for example, found an fT/C value in runners that was lower than the threshold value of $0.35 \cdot 10^{-3}$ defined by Adlercreutz et al. (1; study 4) in both overtraining and non-overtraining conditions.

Despite these obvious problems, some working groups used the definitions by Adlercreutz et al. (1) in recent years and examined one or both ratios in their studies (studies 2, 6, 7, 9–14), though with contradictory results. The examinations by Chicharro et al. (4; study 11) showed a decrease in the fT/C ratio by more than 30% in 10 of 42 subjects. In the examinations of 6 subjects by Vervoorn et al. (40; study 7), 19 out of 51 total blood tests fell below this threshold of 30%. A decrease below $0.35 \cdot 10^{-3}$, however, could not be observed in either of the two studies. A reduction of the T/C and fT/C ratios, respectively, in the state of overtraining was also found in studies 2, 6, 7, 11, and 12, while in studies 9, 10, and 13–15 (all in overtrained athletes but one), unchanged ratios were described.

Summing up, the available studies showed such a non-uniform picture that a final evaluation of the behavior of the fT/C and T/C ratios seems to be difficult. Therefore, the suitability of the T/C and fT/C ratios for diagnosing overtraining is doubtful in view of both the contradictory data and the mentioned physiological aspects.

The Hormones of the Hypothalamo-Pituitary-Thyroidal Axis (HPTA)

The thyroid hormones T_3 and T_4 have many different functions in the organism and influence, among others, the skeletal muscles. Therefore, it seems useful also to examine the behavior of the hormones of the hypothalamo-pituitary-thyroidal axis (HPTA) empirically under the aspect of overtraining. Among the studies considered in this meta-analysis, studies 1, 3, and 5 analyzed the thyroid function. In study 1 (5, 22, 23), the authors investigated TSH. In study 5 (18, 21), the authors also included T_3 and T_4. In both investigations, the resting levels and the levels after maximum load after a training intervention program remained unchanged, just as the TRH-induced TSH-increase in study 1. Also the resting levels of T_3 and T_4 were unchanged after intensive or extensive training load in study 5 (18, 21). In both studies (1 and 5), however, no overtraining could be induced, though the athletes underwent an unusually high training load. Barron et al. (2; study 3) found unchanged resting levels of TSH and normal TSH behavior in a combined pituitary function test in 2 overtrained runners.

Since in the studies mentioned first, no overtraining could be induced, and study 3 examined a total of 2 overtrained athletes only, the HPTA behavior in connection with overtraining cannot be assessed on the basis of our current knowledge. Findings of decreased peripheral thyroid hormone levels in female athletes

with disturbed menstruation (24, 26), however, also suggest some influence on HPTA in male athletes, in particular, if a latent hypocaloric condition results from high training load and not adequately increased nutritional intake. At present, though, no parameter of the hypothalamo-pituitary-thyroidal axis is suitable for diagnosing an overtraining syndrome.

The Growth Hormone (GH)–IGF1 Axis

The growth hormone (GH)–IGF1 axis regulates many processes in the organism, including metabolism and tissue adaptation processes. Therefore, it appears to be of interest also in view of the overtraining problem. Some of the present studies have examined the GH behavior. The team of Lehmann and colleagues (5, 12, 18, 21–23) did not find any changes in the resting levels nor in the exercise-induced GH increase in studies 1 and 5. In study 1 also the exogenously stimulated GH elevation remained unchanged after training intervention. The athletes, however, were not overtrained. Fry et al. (8–10; study 2) did not find any changes in GH under rest and load conditions in overtrained weightlifters either. Urhausen (35) and Urhausen et al. (36; study 13) also found unchanged GH levels in the state of overtraining at rest. Contrary to this, significantly reduced values of GH as compared with the state of non-overtraining were found in this study in the intra-individual comparison at maximum load during an existing overtraining condition. Barron et al. (2; study 3) found reduced GH secretion in a combined pituitary function test in 2 overtrained runners in the state of overtraining, and restricted GH secretion after insulin-induced hypoglycaemia in another 2 runners during overtraining.

Unfortunately, only one of the available studies on the overtraining problem (3; study 6) examined other factors relevant in this endocrine axis, such as IGF1. The authors already found a reduction in resting IGF1 concentration after 1 week of highly demanding training. As a whole, data on the role of GH in connection with the overtraining problem is rather insufficient. In particular, single blood samples will not adequately account for the physiological pulsatile secretion pattern of GH so that possible changes in the secretion pattern could have escaped detection. Generally speaking, as of our knowledge today, GH is no suitable indicator of possible overtraining.

Insulin

The behavior of blood insulin levels in connection with high training load or overtraining was examined in 3 studies (1, 5, and 13).

Lehmann et al. (22, 23; study 1) and Lehmann et al. (18, 21; study 5) who analyzed the insulin levels of athletes after unusually high training loads at rest and after maximal exercise could not find any significant changes after the training interventions. After a 3-week regeneration phase, a reduction in the insulin concentration after exercise as compared with the value before the load could be determined in study 1. Urhausen (35) and Urhausen et al. (36; study 13) found no changes in insulin levels at rest and after a 10-min exercise load either. They saw, however, reduced values after maximum load in a state of overtraining. Since no decrease in the glucose level could be observed at the same time, the authors excluded possible glycogen depletion as the underlying cause. Rather, he held a possible increase in the catecholamines with their inhibitory effect on insulin release responsible for this decrease, although the maximum catecholamine increases had remained unchanged.

Summing up, the insulin behavior after high training load or in the state of overtraining is non-uniform, with very few examinations, however, being available. A decrease in insulin levels under load as compared with the resting levels is physiological, since energy carriers are made available during exercise. Whether a possibly elevated decrease is some indicator of an overtraining syndrome can neither be confirmed nor excluded. Furthermore, since no exact information is given on the used diets, any concluding consideration is not possible at present.

Prolactin

Recently, Strüder and Weicker (34) in their excellent review described the possible associations between the neurotransmitter serotonin (5-HT) and central fatigue or overtraining. They pointed out that changes in the plasma prolactin levels permit conclusions to the activity of central systems, in particular of the serotonergic system.

Among the studies analyzed here, only studies 1 (5, 22, 23), 3 (2), 5 (18, 21), and 12 (13) examined the behavior of prolactin. Lehmann et al. (18, 21) and Fleck (5; study 1) found no changes in the prolactin levels at rest nor after acute exercise, nor in a pituitary function test after a training intervention program, which, however, had not caused an overtraining syndrome. In another study, the same team found no changes in the prolactin levels at rest or after acute exercise in a group of endurance athletes even after a phase of intensive or extensive training load. However, a state of overtraining could not be achieved here, either. In contrast to this, Hackney (13; study 12) found elevated prolactin resting values in 4 athletes in a state of overtraining. Barron et al. (2; study 3), in a stimulation test with TRH and LHRH, found a resting prolactin level and prolactin release, which were described as normal, in the 2 examined overtrained athletes. However, in 2 other athletes who had been subjected to an insulin stress test, induced prolactin secretion was reduced.

Summing up, the experimental findings in athletes are non-uniform, although Strüder and Weicker (34) in their review showed that prolactin could possibly be a marker for the overtraining syndrome. Before clear statements can be made in this respect, however, this hypothesis needs to be supported by further experimental findings in humans.

Catecholamines

Dopamine

Only the study by Lehmann et al. (18, 21; study 5) presented test results on dopamine. Neither the resting blood levels nor the blood levels after maximal exercise showed any changes after training interventions. Gastmann et al. (12) assumed that the nocturnal catecholamine secretion describes the basal metabolic rate. In study 5 (18, 21), nocturnal dopamine secretion was reduced after increases in the training volume at the very end of the intervention, but it remained unchanged after increasing training intensities.

Whether this single finding concerning dopamine secretion should be considered as clinically relevant with regard to the overtraining problem remains unclear, the more so since it had not been possible to overtrain the examined athletes.

Summing up, due to insufficient data, the evaluation of a potential role of dopamine in relation with overtraining is unclear and requires further examination.

Norepinephrine and Epinephrine

Resting Blood Levels. Among the studies having examined resting blood norepinephrine levels (studies 1, 2, 5, 8, 9, 13, 15, 16), only Hooper et al. (15, 16; study 8) could show a significant increase in the resting blood levels as compared with the values at all other examination times in 3 overtrained female athletes during tapering. Any possible influence of the menstruation cycle on the norepinephrine concentration cannot be excluded here. The authors themselves considered the raised (though not significantly raised) training level of the overtrained athletes as compared with the non-overtrained female athletes, as the cause of the elevated values during tapering. All other studies mentioned above showed unchanged resting levels in the overtrained athletes as compared with the non-overtrained ones, or no effect of the performed training interventions with unusually high loads.

Contrary to an increase in norepinephrine levels, the epinephrine levels did not differ in the overtrained and non-overtrained athletes in study 8. Among the other studies on the epinephrine level at rest (studies 2, 5, 13, 16), only the athletes in the sub-study with intensive training load in the study by Lehman et al. (18, 21; study 5) showed some decrease. The sub-study with increased training volume (study 5) and the other examinations with overtrained athletes (studies 2, 13, 16) revealed unchanged resting epinephrine values.

As a whole, any essential changes in resting norepinephrine and epinephrine levels do not seem to occur under overtraining conditions.

Blood Levels During and After Exercise. Some studies investigated the behavior of the catecholamines under submaximal exercise (studies 1, 5, 7, 13, 16) or maximal load (studies 2, 5, 13, 16). In the study by Uusitalo (38; study 16), submaximum loads did not cause any changes in the norepinephrine nor in the epinephrine levels in overtrained female athletes in the intra-individual comparison with the baseline examinations. Urhausen (35) and Urhausen et al. (36; study 13) found no changes in the epinephrine level in the intra-individual comparison in overtrained athletes after 10 min in the so-called stress test, but he saw an increase in norepinephrine. In study 1 (12, 22, 23), norepinephrine increase in athletes after unusually high training loads remained unchanged under submaximal exercise. The same group, however, found a contrasting behavior of norepinephrine under submaximal load in study 5 (18, 21). After the training volumes had been increased, the concentration of norepinephrine rose; after increasing the intensities, though, it decreased. Contrary to these findings, the epinephrine levels remained unchanged after increases in the volumes under submaximum load, but rose after an increase in the training intensities.

Scarcely any uniform behavior was observed of the catecholamines under maximal exercise. The intra-individual comparisons of athletes in the state of overtraining with the non-overtrained state resulted in both unchanged epinephrine levels (8, 10, study 2; 35, 36, study 13) as well as in decreased levels (38; study 16) under maximal exercise. Norepinephrine did not always show a behavior similar to epinephrine. The exercise-induced increases in the studies by Urhausen (35) and Urhausen et al. (36; study 13) and Uusitalo (38; study 16) remained unchanged in the state of overtraining, but it rose in the study by Fry et al. (8–10; study 2). Braumann and Brechtel (3; study 6) found a decrease in the ratio of maximum and basal catecholamine levels in supposedly overtrained runners. In the study by Lehmann et al. (18, 21), the athletes showed unchanged epinephrine and norepinephrine blood

levels under maximal exercise after both an increase in the training volumes and in the training intensities, which, though, had not resulted in overtraining.

It is assumed that a decrease in blood catecholamine levels under load could, for example, be some indication of a restricted glycolytic energy supply, which would result in a decrease in performance (17). Summing up, the behavior of blood catecholamine levels under load in the studies considered here is so contradictory that these parameters are not suitable for diagnosing overtraining. It remains also unclear at present whether changes in the blood levels actually reflect different neuronal activities and thus provide some information on the vegetative or sympathico/parasympathico balance. Moreover, based on today's knowledge, any statement concerning possible effects of the type of sport (strength training vs. endurance training) on the catecholamine behavior in the state of overtraining is not possible.

Catecholamine Excretion in Urine. The 24-hour excretion in urine is supposed to reflect the overall metabolic rate of catecholamines. It is also assumed that nocturnal excretion describes the basal metabolic rate (12). Neither Urhausen (35) and Urhausen et al. (36; study 13), nor Uusitalo (38; study 16), found any significant changes in nocturnal catecholamine excretion in overtrained athletes in intra-individual comparison with the non-overtrained state. However, Uusitalo (38; study 16) noticed major individual variations of nocturnal catecholamine excretion. Mackinnon et al. (29; study 9) did not find any changes in nocturnal norepinephrine excretion during overtraining syndrome in the intra-individual comparison, but compared with the excretion in non-overtrained athletes, norepinephrine excretion of overtrained athletes was reduced.

Gastmann et al. (12) and Lehmann et al. (22, 23; study 1) found a significant decrease in norepinephrine excretion in intra-individual comparison during the day after unusually high training load. Excretion in nocturnal urine, however, remained unchanged. The same team (18, 21; study 5), in another intervention study, found a reduction in nocturnal catecholamine excretion after increased training volumes, but a decrease only in norepinephrine excretion and unchanged epinephrine values after increased training intensities. Both interventions could not induce any overtraining. Nevertheless, the authors suggested a decrease in basal catecholamine excretion by 50% or more as an indicator of overtraining. However, experimental findings are completely missing to justify the assumption of such a threshold value. Therefore, based on current knowledge, such values should not be used for diagnosing overtraining.

Summing up, it can be said that the findings relating to the behavior of the catecholamines are extremely non-uniform with regard to both resting blood levels and blood levels at load as well as the excretion in urine. None of the parameters described is suitable for the diagnosis of overtraining syndrome. To what extent the determination of catecholamines in blood and urine in athletes actually reflects the vegetative or sympathico/parasympathico condition and the vegetative balance, remains unclear as well and needs further human-experimental examinations.

General Criticism of the Studies

In the studies included in this meta-analysis, a number of aspects restrict the interpretability of the available data. In particular, the chosen definitions of an overtraining syndrome, the study population and the different ways of data gathering play a

role in this connection. Missing data concerning the above items in individual studies complicate both the evaluation and interpretation.

Criticism of the Determination of Overtraining

Part 1 of the review paper deals with the problem of the definition of overtraining in detail. So far there is no generally valid definition of the overtraining syndrome. The authors of the studies partly chose different criteria for the definition of an overtraining syndrome. This considerably impaired the value and comparability of the results obtained from the athletes defined as overtrained under different conditions. Some studies attempted to induce some overtraining in the course of a training intervention, which was not achieved, since the performance of the athletes did not decrease, but even increased in some cases. These studies with unusually high training loads were included in the analysis, though the problem of non-overtraining was distinctly pointed out.

Subjects

The number of subjects was very small in most of the studies, which considerably restricts the chance of making a general statement on the behavior of the respective hormones that were examined. Moreover, only very few studies included a control group. In some studies, the subjects were re-examined after a regeneration phase of several weeks and thus represented their own control group. This procedure, though not unusual, is problematic since, on the one hand, recovery from an overtraining syndrome may take months and, on the other hand, a supercompensation may be the consequence of an induced short-term overtraining after an appropriate regeneration phase, and this could also affect the hormone status.

Furthermore, the subjects were rather inhomogeneous. They differed partly by sex and age and often had different training experiences. In female subjects, in addition, the rather complex reproductive endocrine system was often not taken into account.

Data Acquisition

A weakness in all studies are the long time intervals between the examinations, which allow only restricted conclusions concerning the behavior of hormonal parameters. Also, in the majority of studies, only single tests were carried out so that the pulsatile secretion pattern of many hormones was not accounted for. This may lead to wrong interpretations of the hormonal behavior in overtraining or under high training load. Moreover, some other factors that may influence the endocrine system were often not specified in detail. This applies in particular to the diets of the subjects.

Summary

Part 2 of this review paper on overtraining and the endocrine system summarizes the human studies available in the literature on this topic. As already mentioned above, the publications are rather heterogeneous, with frequently non-uniform results on the respective endocrine systems that were examined. As a whole, the available data

are so unclear that no unambiguous changes in the hypothalamo-pituitary-peripheral axes, parameters derived there from, the catecholamines nor other hormones, including the central transmitter system, can be demonstrated in the state of overtraining or after unusually high training load in these human-physiological studies. Particularly doubtful seems to be the differentiation between a sympathetic and parasympathetic overtraining, or the assumption of some anabolic/catabolic imbalance. The hypotheses concerning the pathogenesis of overtraining that assume a causal involvement of various endocrine systems can presently not be confirmed from the experimental data in humans—but cannot be disproved, either. Further systematic examinations are needed that take the above-mentioned critical issues into account.

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Legend of Tables

( ): value to which the other values refer
Δ: change
Ø: mean
→: no significant changes
↑: significantly higher
↓: significantly lower
—: no information is given
ACTH: adrenocorticotropic hormone
ADH: antidiuretic hormone
AMV: respiratory volume/min
C: cortisol
CK: creatininkinase
CRH: corticotropine releasing hormone
d: day
ex: exercise
f: female
FSH: follicle stimulating hormone
fT/C: ratio free testosterone/Cortisol
fT/SHBG: ratio free testosterone/SHBG
fT: free testosterone
GnRH: gonadotropin releasing hormone
h: hour
hGH: human growth hormone
HR: heart rate
I: investigation
IAS: individual anaerobic threshold
IGF: insulin-like growth factor
LH: luteinizing hormone
LHRH: luteinizing hormone releasing hormone
m: male
max: maximal
min: minutes
NOT: non-overtrained athletes
OT: overtrained athletes
p: power
p2: power corresponding to 2 mmol/L lactate
p4: power corresponding to 4 mmol/L lactate
POMS: profile of mood states
s: seconds
SHBG: sex hormone binding globuline
submax: submaximal
T/C: ratio testosterone/cortisol
T/SHBG: ratio testosterone/sex hormone binding globuline
T: testosterone
T_3: trijodthyronine
T_4: thyroxine
TRH: thyreotropin releasing hormone
TSH: thyreoidea stimulating hormone
v: velocity
v2: velocity corresponding to 2 mmol/L lactate
v4: velocity corresponding to 4 mmol/L lactate
$\dot{V}O_2$: oxygen uptake
$\dot{V}O_{2max}$: maximal oxygen uptake
vs.: versus
w: week
yrs: years

Table 1 Design and Results of a Study With Individuals Exercising Recreational Sports

Authors Study no.	Subjects (Gender, Age, Number)	a. Duration of the study b. Description of training c. Times of investigations	Overtraining syndrome a. Definition and criteria for determination b. Investigations and tests	Results of hormonal analyses	Other results
Gastmann et al. (1993), Fleck (1993), Lehmann et al. (1993bc) No. 1	6 Leisure time athletes, male, age: —	a. 9 w b. Endurance training: 4/w, 31–33 min at p4 Interval training: 2/w, 3–5 × 3 to 5 min W1: Endurance training at 90% of initial p4, interval training at 117% of initial p4 W2: Endurance training at 95% of initial p4, interval training at 124% of initial p4 W3: Endurance training at 96% of initial p4, interval training at 127% of initial p4 W4: Endurance training at 89% of p4 in W3, interval training at 115% of p4 in W3 W5: Endurance training at 89% of p4 in W3, interval training at 116% of p4 in W3 W6: Endurance training at 92% of p4 in W3, interval training at 110% of p4 in W3 W7–9: Recovery period c. I1: d0 I2: d21 I3: d42 I4: d63	a. — b. Incremental test on a bicycle ergometer: starting with 100 W, increase every 3 min with 50 W until exhaustion Blood analysis Urinary analysis Training diary **Subjective feeling** according to a 4-point scale **Stimulation test**	**Resting blood concentrations** U1 U2 U3 U4 LTH, FSH, LH, TSH, ACTH, ADH, hGH, Cortisol, Aldosterone, Renin, Insulin, Testosterone ( ) — → → Norepinephrine ( ) → → → Blood concentration at submax. exercise Norepinephrine ( ) — — → **Blood concentrations after exercise** LTH, FSH, LH, TSH, ACTH, ADH, hGH, Cortisol, Aldosterone, Renin, Insulin ( ) — → → Testosterone ( ) — ↓ — After exercise vs. resting values in blood ACTH, ADH, hGH, Aldosterone, Renin ↑ — ↑ ↑ LTH, LH, TSH, Cortisol → — → → Testosterone ↑ — → → Insulin → — → ↓ **Urinay concentration** Norepinephrine, day ( ) ↓ ↓ ↓ Norepinephrine, night ( ) → → → Stimulation test Norepinephrine ( ) — → — Pituitary function tests LTH, TSH, hGH ( ) — → → ACTH ( ) — ↑ ↑ Cortisol ( ) — → ↓ LH ( ) —↓ ↓ FSH ( ) —→ ↑	U1 U2 U3 U4 Index of feeling ( ) → → — Incremental test p2 ( ) ↑ ↑ ↑ p2 — ( ) ↓ ↓ p4 — ( ) → → p4 — ( ) → → total work (in kJ) ( ) → ↑ → — — ( ) ↓ Stimulation test (2.5 and 5 μg/min Norepinephrine) Systolic blood pressure ( ) — ↑ —

Table 2a Design and Results of a Study With Weightlifters

Authors Study no.	Subjects (Gender, Age, Number)	a. Duration of the study b. Description of training c. Times of investigations	Overtraining syndrome a. Definition and criteria for determination b. Investigations and tests	Results of hormonal analyses	Other results
Fry et al. (1994, 1998) No. 2	17 weightlifters (m) 22.0 ± 0.9 yrs, 11 OT, 6 NOT	a. 2 w b. W1–2:OT: 7 TR/W: 10 sets with 1 repetition at max power NOT: 1 TR/W: 3 sets with 5 repetitons c. 11: Prior to training I2: After W1 I3: After W2	a. Increase in TR volume and/or TR intensity, and decline in physiological capacity b. **Power tests** - Max power - Submax power at 70% of max power - Max isometric power - Isokinetic power	See Table 2b	**OT vs. NOT** U1 U3 Max power, isometric and isokinetic test → ↓ No. of repetitions at 70% of max power → → **Significant correlations** **- NOT** positive: between Δ isometric power from I2 to I3 and - Δ Epinephrine after ex. - Δ Norepinephrine after ex. - OT Negative: between Δ max. power from I1 to I3 and Δ Norepinephrine after ex. From I1 to I3 (r = –0.72) - OT, NOT Body weight ( ) →

Table 2b Results of Hormonal Analyses in a Study With Weightlifters (Study 2)

Results of hormonal analyses

Blood concentration	I1	I2	I3
NOT			
Epinephrine			
- directly after	( )	→	→
Norepinephrine			
- directly after ex.	( )	→	→
- directly after ex. vs. prior to ex.	↑	↑	↑
Testosterone			
- 5 min after ex. vs. prior to ex.	↑	↑	↑
- prior to ex.	( )	→	↑
- 5 min after ex.	( )	→	↑
free Testosterone			
- 5 min after ex. vs. prior to ex.	↑	→	↑
% unbound Testosterone			
- 5 min after ex. vs. prior to ex.	→	→	→
Cortisol			
- 5 min after ex. vs. prior to ex.	→	→	→
T/C			
- 5 min after ex. vs. prior to ex.	→	→	→
fT/C			
- 5 min after ex. vs. prior to ex.	→	→	→
hGH			
- 5 min after ex. vs. prior to ex.	↑	↑	↑

Blood concentration	I1	I2	I3
OT			
Epinephrine			
- directly after	( )	↑	↑
- directly after ex. vs. prior to ex.	→	↑	↑
Norepinephrine			
- directly after ex.	( )	↑	↑
	—	( )	↑
- directly after ex. vs. prior to ex.	↑	↑	↑
Testosterone			
- 5 min after ex.	( )	→	↑
- 5 min after ex. vs. prior to ex.	↑	↑	↑
free Testosterone			
- directly after ex. vs. prior to ex.	↑	→	↑
% unbound Testosterone			
- 5 min after ex. vs. prior to ex.	→	→	→
Cortisol			
- 5 min after	( )	→	↓
- 5 min after ex. vs. prior to ex.	→	→	→
T/C			
- 5 min after	( )	→	↑
- 5 min after ex. vs. prior to ex.	→	→	→
fT/C			
- 5 min after ex. vs. prior to ex.	→	→	→
hGH			
- 5 min after ex. vs. prior to ex.	↑	↑	↑

Blood concentration	I1	I2	I3
OT vs. NOT			
Epinephrine			
- prior to ex.	→	→	→
- directly after ex.	→	→	→
Norepinephrine			
- prior to ex.	→	→	→
- directly after ex.	→	→	↑
T/C			
- 15 min prior to ex.	→	→	↓
- directly prior to ex.	→	↓	↓
- 5 min after ex.	→	↓	→
fT/C			
- 15 min prior to ex.	→	→	↓
- directly prior to ex.	→	→	→
- 5 min after ex.	→	→	→

Table 3 Design and Results of Studies With Runners

Authors Study no.	Subjects (Gender, Age, Number)	a. Duration of the study b. Description of training c. Times of investigations	Overtraining syndrome a. Definition and criteria for determination b. Investigations and tests	Results of hormonal analyses	Other results
Barron et al. (1985) No. 3	6 marathon runners (m), 22–36 yrs, 1OT, 2 runners (m), 24–26 yrs, 2 OT, 1 walker (m), 26 yrs, 1OT	a. 4 months b. **NOT:** individual training between 110–190 km/w **OT:** Marathon runner: 8 w high distances,14 w training of velocity and interval training Runner 1: 12 w of heavy training 42-km marathon, followed by 7 days of training Runner 2: 12 w of heavy training in 11 days 4 street races (5–10 km) and 42-km marathon Walker: 8 w of heavy training with 30-km run each week c. **NOT:** I1: 1 month prior to a 42-km marathon I2: 24 hrs after 56-km run I3: 48 hrs after 92-km run **OT**: I1: 72 hrs after diagnosis I2: after 4 w of rest	a. Existence of the following symptoms for at least 3 w: - Apathy - Reduced performance in competition and training	**Blood concentration** I1 I2 I3 **Combined pituitary stimulation test** **NOT:** hGH, ACTH, Cortisol, LH, FSH, TSH, Prolactin ( ) → → **OT vs. NOT:** I1–I3 $I1_{OT}$, $I2_{OT}$**:** LH, FSH, TSH, Prolactin → $I2_{OT}$: hGH, ACTH, Cortisol → $I1_{OT}$ $I2_{OT}$ **OT**: hGH, ACTH, Cortisol ↓ ( ) **After Insulin and TRH-Injection** **OT:** prolactin normal ( ) **After Insulin** **OT:** prolactin unnormal ( ) **OT ($I1_{OT}$) vs. NOT** basal 15 30 45 60 75 90 hGH → → → ↓ ↓ → ↓ ACTH → ↓ ↓ → → → → Cortisol ↑ ↑ ↑ → → → →	

Authors Study no.	Subjects (Gender, Age, Number)	a. Duration of the study b. Description of training c. Times of investigations	Overtraining syndrome a. Definition and criteria for determination b. Investigations and tests	Results of hormonal analyses	Other results
Alderkreutz et al. (1986) **No. 4**	Runners (m), number:-, age:—, number OT:—, 2 groups (A, B)	a. 1 w b. A: Intensive training B: Normal training c. I1: After 1 w of training	a. — b. c. Physiological tests (no detailed information)	**Blood concentrations of all except 1 OT** fT/C decline of the ratio > 30% or ratio < $0.35 \cdot 10^{-3}$ (no significance: —)	
Lehmann et al. (1990), Lehmann et al. (1992ab) No. 5a (study: increasing volume)	8 middle- and long-distance runners (m), age: 33 ± 7 yrs	a. 4 w b. 6 days/w training Increase in training volume of 33%, from 85.9 ± 14.2 km to 174.6 ± 26.7 km/w, 93–98% at 50–70% of $\dot{V}O_{2max}$ c. **Blood samples and treadmill tests:** I1: d0 I2: d14 I3: d28 Urinary samples during the night d2 d6 d13 d20 d27 d34 24-h urinary samples d1 d5 d12 d19 d26 d33	a. Reduction in performance b. **Test to exhaustion on the treadmill** Starting velocity 10 km/h, duration/step 3 min, increase/step 2 km, gradient 1.5° **Nightly urinary samples** **24-h urinary samples** **Training documentation** **Index of individual symptoms** according to a 4-point scale	**Blood concentrations** I1 I2 I3 Dopamine, epinephrine prior to, submax exercise, max exercise ( ) → → Dopamine submax exercise — ( ) ↓ Norepinephrine prior to, submax exercise, max exercise ( ) → → submax exercise ( ) → ↑ Cortisol prior to exercise ( ) → → max exercise ( ) → ↓ Aldosterone, Testosterone, Insulin, hGH, Prolactin, TSH, LH prior to, max exercise ( ) → → T_3, T_4 prior to exercise ( ) → → urinary samples during night d2 d6 d13 d20 d27 d34 Epinephrine ( ) → → → ↓ ↓ Norepinephrine ( ) → → → → ↓ Dopamine ( ) → → → → ↓ 24-h urinary samples d1 d5 d12 d19 d26 d33 Cortisol ( ) ↓ → → → →	I1 I2 I3 Individual symptoms ( ) ↑ ↑ Body weight, morning HR ( ) → → Treadmill test: Lactate: prior to ex ( ) → → submax max ex ( ) ↓ → $\dot{V}O_2$-IAS, $\dot{V}O_2$-v4, $\dot{V}O_{2max}$ ( ) → → Significant correlation between basal norepinephrine excretion and index of individual symptoms (r = –0.88)

Authors Study no.	Subjects (Gender, Age, Number)	a. Duration of the study b. Description of training c. Times of investigations	Overtraining syndrome a. Definition and criteria for determination b. Investigations and tests	Results of hormonal analyses	Other results
Lehmann et al. (1990), Lehmann et al. (1992ab) No. 5b (study: increasing intensity)	9 middle- and long-distance runners, age: 34 ± 7 yrs	a. 5 w b. 56–62 km/w, increase of interval runs and intensive runs from 9.8 to 22.6 km/w c. **Blood analysis and treadmill test** I1: d0 I2: d14 I3: d35 **Urinary samples (night and 24 h)** W1 W2 W3 W4 W5	a. Reduction in performance b. **Test to exhaustion on the treadmill** Starting velocity 10 km/h, duration/step 3 min, increase/step 2 km, incline 1.5° **Nightly urinary samples** **24-h urinary samples** **Training documentation** **Index of individual symptoms** according to a 4-point scale	**Blood concentration** I1 I2 I3 Dopamine prior to, submax, max exercise ( ) — → Norepinephrine prior to, submax, max exercise ( ) — → submax exercise ( ) — ↓ Epinephrine prior to, submax, max exercise ( ) — ↓ Max. exercise ( ) — → Aldosterone prior to exercise ( ) — ↑ max exercise ( ) — → Cortisol, Testosterone, Insulin, hGH, Prolactin, FSH, LH, TSH prior to, max exercise ( ) → → T_3, T_4 prior to exercise ( ) → → **Urinary samples during night** W1 W2 W3 W4 W5 Epinephrine, Dopamine ( ) → → → → Norepinephrine ( ) → → → ↓ **24-h urinary samples** Cortisol ( ) → → → →	W1 W2–5 Individual symptoms ( ) ↑ I1 I3 Body weight ( ) ↓ HR **Treadmill test:** Lactate: prior to, max exercise ( ) → submax ex ( ) ↓ $\dot{V}O_2$v2, $\dot{V}O_2$v4 ( ) ↑

Authors Study no.	Subjects (Gender, Age, Number)	a. Duration of the study b. Description of training c. Times of investigations	Overtraining syndrome a. Definition and criteria for determination b. Investigations and tests	Results of hormonal analyses	Other results
Braumann and Brechtel (1994) No. 6	6 long distance runners (1 f, 5 m), age: 28.7 ± 2.7 yrs, 6 OT	a. 7 w b. Increase in training volume from 70 to 75–102 km · w^{-1}, and of training intensity (24–45% with high intensity) c. I1: prior to intervention I2–I8: weekly	a. Decline in maximal run time on a treadmill, typical symptoms (decline in performance, reduced trainability, tiredness, in training and daily life, unspecific vegetative symptoms in abdominal organs, apathy, psychical depressive symptoms) b. Treadmill test (scheme according to BAL)	**Blood concentration at rest** I1 I8 fT ( ) decline 27% (significance:—) Cortisol ( ) ↑ fT/C, IGF 1 ( ) ↓ max Catecholamine concentration/ basal Catecholamine concentration ( ) ↓	**Positive significant correlation between:** - IGF1 and volume of intensive training (km) in I1–I2 **Negative significant correlations between:** - IGF1 and volume of intensive training (km) in I3–I8 - exercise induced increase in norepinephrine and the volume of intensive training in the week prior to catecholamine measurement **Treadmill test** I1 I6 I8 Run time ( ) ↑ ↓

Table 4 Design and Results of a Study With Oarsmen

Authors Study no.	Subjects (Gender, Age, Number)	a. Duration of the study b. Description of training c. Times of investigations	Overtraining syndrome a. Definition and criteria for determination b. Investigations and tests	Results of hormonal analyses	Other results
Vervoorn et al. (1991) No. 7	6 oarsmen (m), age: 20–26 yrs	a. 9 months b. Individual training program c. I1–2: 5-w intervals I3–5: every 4 days (training camp) I6–10: 5-w intervals	a. - fT/C-ratio < $0.35 \cdot 10^{-3}$ (fT in nmol/L, C in μmol/L) and/or decline of fT/C-ratio ≥ 30% b. Typical symptoms like increased testing heart rate in the morning, decline in body weight, problems to concentrate, reduced regeneration of heart rate after exercise, emotional instability c. **Rowing-ergometer test:** 3-min warm-up, 1-min rest 5-min at p4, 2-min rest 2-min max exercise **Blood parameters** **Training diary**	**Blood concentration at rest** I1 I2–7 I8 I9 I10 fT/C ( ) → → → → **vs. prior investigation** fT/C — → ↓ ↑ → fT — — ↓ ↑ — Cortisol — — ↑ — —	**Significant correlations between**: - fT/C and p4 in I4 and I9 - cortisol and p4 in I4, I5, and I7 - cortisol and max exercise in I1 - fT and power at p4 in I8 I1 I2 I3–6 I7 I8 I9–10 **Rowing-ergometer test:** p4 ( ) — ↑ — ↑ — p max ( ) → → → → → I2 I3–6 I7 I8 I9–10 **vs. prior investigation:** p4 — — — ↓ — p max → → → → →

Table 5 Design and Results of Studies With Swimmers

Authors Study no.	Subjects (Gender, Age, Number)	a. Duration of the study b. Description of training c. Times of investigations	Overtraining syndrome a. Definition and criteria for determination b. Investigations and tests	Results of hormonal analyses	Other results
Hooper et al. (1993ab) No. 8	14 swimmers (sprint and middle distance; 5 m, 9 f), age: 17.2 ± 1.5	a. 6 month 10–12 units/w, individual training plans c. I1: Aerobic training, 2–3 w after start of the season I2: Intensive training, 12–14 w after start of the season I3: Intensive training, 5–6 w prior to a competition I4: Tapering, 3–5 days prior to competition I5: 1–3 days after competition	a. - No increase in max performance in I3 vs. I1 - Subjective feeling of tiredness > 5 at 7 following days - No illness - Normal number of leukocytes - Normal blood sinking velocity b. **POMS questionnaire** **Training diary** **Max swim test:** sprinters: 100 m middle distance: 400-m freestyle	**Blood concentration at rest** I1 I2/I3 I4 I5 **OT and NOT** Cortisol, Norepinephrine ( ) → → → Epinephrine ( ) → → ↓ **OT** Norepinephrine ( ) → ↑ — Norepinephrine — — ↑ ( ) **OT vs. NOT** Cortisol, Epinephrine → → → → Norepinephrine → → ↑ →	**Significant correlations between training volume and:** Norepinephrine (r = 0.37) Epinephrine (r = 0.33) **OT, NOT I1 I2 I3 I4 I5** Performance in competition ( ) → → → → **OT vs. NOT** Δ performance → → ↑ → → Individual feeling of fatigue → ↑ → ↑ ↑

Authors Study no.	Subjects (Gender, Age, Number)	a. Duration of the study b. Description of training c. Times of investigations	Overtraining syndrome a. Definition and criteria for determination b. Investigations and tests	Results of hormonal analyses	Other results
Mackinnon et al. (1997) No. 9	24 swimmers, 100-m and/or 200-m (16 f, 8 m), age: 15–26 yrs, 8 OT (6 f, 2 m)	a. 4 w b. 12 units/w increase in - Swim volume from 28.5 to 38.9 km/w - Land training from 151.2 to 184.8 min/w c. I1: Prior to beginning of study I2: After 2 w I3: After end of study	a. - No increase in max performance in I3 vs. I1 - Individual feeling of fatigue ≥ 5 at 5 consecutive days - Negative comments concerning training adaptation - No illness b. **Blood tests** **Swim time** (200-m freestyle) **Urinary sampling (nightly)** **Training diary**	**Blood concentration at rest** I1 I2 I3 **NOT**: Norepinephrine, Cortisol ( ) → → **NOT (f):** fT, fT/C ( ) → → **NOT (m):** fT, fT/C ( ) → → **OT:** Norepinephrine, Cortisol ( ) → → **OT (f):** fT, fT/C ( ) → → **OT (m):** fT, fT/C ( ) → → **OT vs. NOT** Norepinephrine, Cortisol → → → **Male vs. female** fT ↑ ↑ ↑ Norepinephrine, Cortisol → → → **Nightly urinary excretion** **NOT:** Norepinephrine ( ) → → **OT:** Norepinephrine ( ) → → **OT vs. NOT:** Norepinephrine ↓ ↓ ↓ **Male vs. female** Norepinephrine → → →	I1 I2 I3 **OT** Performance ( ) — decline (6.5% (n.s.) **OT vs. NOT** Fatigue — — ↑ **Significant correlations between**: Concentrations of norepinephrine in blood and urine at I1–I3 (r = 0.26)

Table 6 Design and Results of Studies With Soldiers

Authors Study no.	Subjects (Gender, Age, Number)	a. Duration of the study b. Description of training c. Times of investigations	Overtraining syndrome a. Definition and criteria for determination b. Investigations and tests	Results of hormonal analyses	Other results
Fry et al. (1992) No. 10	5 soldiers (m), age: 31.6 ± 3.5 yrs	a. 16 days b. Day 1–10: 2 units/day (interval training) Day 11–15: active recovery (10 min/day slowly running or walking) c. I1: d1 I5: d13 I2: d6 I6: d14 I3: d11 I7: d15 I4: d12 I8: d16	a. Reduction of performance at I8 vs. I1 b. **Blood sampling** **3-step treadmill test:** 4 min at 12 km/h 3-min rest 4 min at 15 km/h 3-min rest 18 km/h until exhaustion	I1 I2–3 I4–7 I8 Blood concentration at rest FSH, Testosteron, LH, SHBG, T/C ( ) → → → Cortisol ( ) → ↓ →	I1 I3 I8 **3-step treadmill test** run time at 18 km/h ( ) ↓ → $\dot{V}O_2$ at steps 1–3 ( ) → → HR at steps 1 and 3 ( ) → → HR at step 2 ( ) ↑ ↑ Lactate at step 1–3 ( ) → →

Authors Study no.	Subjects (Gender, Age, Number)	a. Duration of the study b. Description of training c. Times of investigations	Overtraining syndrome a. Definition and criteria for determination b. Investigations and tests	Results of hormonal analyses	Other results
Chicharro et al. (1998) No. 11	42 soldiers (m), age: 20 ± 2 yrs, 10 OT	a. 8 w b. 5–6 units/w for 3 hrs including 10 km-run, power training, fight training, jumping c. I1: Prior to training program I2: After training program	a. - Reduction of fT/C ratio > 30% at I2 vs. I1 and/or fT/C < 0.35×10^{-3} - Decline in performance b. **-Blood sampling** - **Submax treadmill test** starting between 6 and 10 km/h, increase by 0.5 km/h until 4 mmol/lactate - **Max treadmill test** speed corresponding to 4 mmol/L lactate, gradient at beginning: 0°, increase by 2° every 2 min until exhaustion - **Wingate test**: 30 s supramaximal work - **Power test:** - isometric tests - bank pressing - jump tests - **Flexibility test:** “sit and reach”	**Blood concentration at rest** I1 I2 **OT vs. NOT** fT → ↓ Cortisol → → **OT** fT ( ) → Cortisol ( ) ↑ **NOT** fT ( ) ↑ Cortisol ( ) →	**OT** I1 I2 Leukocytes ( ) ↑ Erythrocytes, polymoph-nuclear Leukocytes, Monocytes, body weight ( ) → **NOT** Body weight ( ) ↓ Leukocytes, Erythrocytes, polymoph-nuclear Leukocytes, Monocytes ( ) → **Submax treadmill test** OT vs. NOT: v2, v4 → → OT: v4, NOT: v2, v4 ( ) ↑ **Max treadmill test** OT vs. NOT: $\dot{V}O_{2max}$ → → OT, NOT: $\dot{V}O_{2max}$ ( ) → **Wingate test** OT vs. NOT: Max and Ø performance ↓ ↓ OT: max and Ø performance ( ) → NOT: Ø performance ( ) ↑ max performance ( ) → **Power test** OT vs. NOT: Bank pressing, Jump test → → Isometric tests (hand, leg) → ↓ OT: Isometric test (legs) Bank pressing ( ) ↑ Jump test ( ) → NOT: Isometric tests (hands, legs), Bank pressing, Jump test ( ) → **Flexibility test** OT vs. NOT: → → OT: ( ) → NOT: ( ) ↑

Table 7 Design and Results of Studies With Athletes From Different Sports

Authors Study no.	Subjects (Gender, Age, Number)	a. Duration of the study b. Description of training c. Times of investigations	Overtraining syndrome a. Definition and criteria for determination b. Investigations and tests	Results of hormonal analyses	Other results
Hackney (1991) No. 12	8 cyclists and runners, age: —, 4 OT	a. 8–10 w b. Intensive training with high volumes (no detailed information) c. I1: Prior to beginning of training I2: After 8 w of training with high volume I3:10–12 days after end of training	a. Apathy, lethargy, loss of appetite, sleeplessness, mood changes, loss of body weight, decline in performance, reduced regeneration after exercise, muscle soreness, stomach symptoms, feeling of "heavy legs" b. **Questionnaire** **Blood sampling**	Blood concentration at rest **OT** I1 I2/I3 Testosterone, T/C ( ) ↓ LH, Cortisol ( ) → Prolactin ( ) ↑ **NOT** Testosterone, Cortisol, T/C, Prolactin ( ) → LH ( ) ↓ **OT vs. NOT** Testosterone → ↓ Prolactin, T/C → →	

Authors Study no.	Subjects (Gender, Age, Number)	a. Duration of the study b. Description of training c. Times of investigations	Overtraining syndrome a. Definition and criteria for determination b. Investigations and tests	Results of hormonal analyses	Other results
Urhausen (1993) and Urhausen et al. (1998) No. 13	17 triathletes and cyclists (m), age: 23.4 ± 1.6 yrs, 15 OT	a. 19 ± 3 months b. No detailed information (increase of training with high intensities, increase in number of competitions) c. I1–5: every 3–5 months; further investigations in case of overtraining	a. Exclusion diagnosis; classical symptoms of decline in performance, reduced endurance, elevated fatiguability, more or less vegetative symptoms b. **Urinary tests** **Blood tests** 30-s test 30 s for 120 U/min at 600–650 W with blood sampling 3 min after exercise for the determination of free catecholamines **Step test on a bicycle ergometer** Start: 100 W, increase every 3 min by 50 W for the determination of individual anaerobic theshold (IAS) **Stress test on a bicycle ergometer** 110% of IAS until exhaustion **Psychological questionnaire**	**Blood concentration** **OT compared intraindividually with NOT** **Resting values** Testosterone, SHBG, Cortisol, fT, Insulin, hGH, LH, FSH, β-Endorphine, fT/SHBG, T/SHBG/C, T/C, fT/C, Epinephrine, Norepinephrine, ACTH → **10-min stress test** Cortisol, Insulin, hGH, Epinephrine → Norepinephrine ↑ **After end of stress test** ACTH, hGH, Insulin ↓ Cortisol, Epinephrine, Norepinephrine, β-Endorphine → **After 30-s test** Epinephrine, Norepinephrine → **Urinary excretion (night)** Epinephrine, Norepinephrine →	**OT compared intraindividually with NOT** Subjective feelings and symptoms ↑ Body weight → **Resting values:** Blood pressure, HR, Lactate → **Treadmill test**: $\dot{V}O_{2max}$, v4, IAS Max HR, max Lactate → **Stress test:** In 10 min: Lactate, HR, Glucose → RPE ↑ Max test: Exercise time, HR ↓

Authors Study no.	Subjects (Gender, Age, Number)	a. Duration of the study b. Description of training c. Times of investigations	Overtraining syndrome a. Definition and criteria for determination b. Investigations and tests	Results of hormonal analyses	Other results
Flynn et al. (1994) No. 14	5 swimmers (m), age: —	a. 21 w b. W 1–9: 23.6 km/w, 76% high intensities W 10–11: 44.4 km/w, 74% high intensities W 12–17: 31.8 km/w, 67% high intensities W 18–21: 25.2 km/w, 54% high intensities c. I1: After 9 w of moderate training I2: After 2 w in a winter camp I3: After another 6 w of training I4: After another 4 w of training	a. – b. **POMS** **Blood sampling** **Submax swim test** 365.8 m at 90% of $\dot{V}O_{2max}$ **Max swim test I** 22.9 m max velocity **Max swim test II** 365.8 m max velocity	**Blood concentration at rest** I1 I2 I3 I4 Cortisol, T/C, fT/C ( ) → → → Testosterone ( ) ↓ ↓ ↓ Testosterone, fT — ( ) — ↑	I1 I2 I3 I4 HR at rest, Systolic and Diastolic Blood Pressure ( ) → → → CK activity ( ) ↑ ↑ → POMS ( ) ↑ — ↓ Submax swim test Lactate ( ) → → → **Max swim test I** 22.9-m test ↑ ( ) — ↑ Max swim test II 365.8-m test — ↓ — ( )
	8 cross-country-runners, age: —	a. 12 w b. W 1–3: increase from 78 to 93 km/w, 30% high intensity W 4–7: 101 km/w, 28% high intensity W 8–10: tapering, 67 km/w, 28% high intensities c. I1: Prior to training I2: After 3 w training I3: 3 w prior to competition or 4 w after intensive training I4: 4 days after competition	a. – b. **POMS** **Blood sampling** **Submax treadmill test** 7 min at 75% of $\dot{V}O_{2max}$ **Max treadmill test** 110% of $\dot{V}O_{2max}$ until exhaustion	**Blood concentration at rest** I1 I2 I3 I4 Cortisol, Testosterone, fT, T/C, fT/C ( ) → → →	I1 I2 I3 I4 **At rest** CK activity, POMS, HR, Blood pressure, Body weight ( ) → → → **Submax treadmill test** Lactate ( ) ↓ ↓ ↓ **Max treadmill test** Run time ( ) ↑ — —

Authors Study no.	Subjects (Gender, Age, Number)	a. Duration of the study b. Description of training c. Times of investigations	Overtraining syndrome a. Definition and criteria for determination b. Investigations and tests	Results of hormonal analyses	Other results
	9 cross-country-runners (4 f 5 m), age: 19–31 yrs, 4 OT (1 m, 3 f)	a. 21 w b. – c. I1: Start of season I2: Middle of season I3: End of season I4: Tapering I5: Latest 1 w after competition	a. - No increase in performance from I1 to I3 - Fatigue rating > 5 on a scale of 7 on 7 consecutive days - No illness b. **10-km run with maximal velocity** **Blood sampling** **Urinary sampling (night)** **Training diary**	**Blood concentration at rest** I1 I2 I3 I4 I5 **OT + NOT** Cortisol, Testosterone (m) + (f), fT/C (f), Norepinephrine ( ) → → → → **OT** fT/C (m) ( ) → ↑ ↑ → OT vs. NOT Cortisol, Testosterone (m) + (w), fT/C (f), Norepinephrine → → → → → fT/C (m) → → ↑ ↑ → **Male vs. Female** Testosterone, fT/C ↑ ↑ ↑ ↑ ↑ Cortisol, Norepinephrine → → → → →	
Mackinnon (1996) No. 15	10 cyclists (3 f, 7 m), age: —, 3 OT (3 m)	a. 22–23 w b. – c. I1: Start of season I2: Middle of season I3: End of season I4: After competition	a. No increase in performance from I1 to I3 - Fatigue rating > 5 on a scale of 7 on 7 consecutive days - No illness b. **1-km race at max speed** for sprinters (n = 8) **4-km race at max speed** for endurance athletes (n = 2) **Blood sampling** **Urinary sampling (night)** **Training diary**	**Blood concentration at rest** I1 I2 I3 I4 I5 **OT + NOT** Cortisol, Testosterone, fT/C (m + f) ( ) → → → → OT vs. NOT Cortisol, Testosterone (m)+(f), fT/C (m)→ → → → → **Male vs. Female** Cortisol, Norepinephrine → → → → → Testosterone, fT/C ↑ ↑ ↑ ↑ ↑	

Authors Study no.	Subjects (Gender, Age, Number)	a. Duration of the study b. Description of training c. Times of investigations	Overtraining syndrome a. Definition and criteria for determination b. Investigations and tests	Results of hormonal analyses	Other results
Uusitalo et al. (1998) No. 16	15 endurance athletes (f), 8 runners, 4 cross-country skiers, 3 triathletes, age: 19–27.3 yrs, Group A: 9, incl. 5 OT, Group B: 6	a. 14–19 w b. A: 7 individual units/w - Interval running (5–12 × 1 km, 2 min rest) - Fast running (5–12 km) - 50 min–3 h cycling, skiing, swimming with low intensity B: Training plan according to own feeling c. I1: Prior to training I2: After 4 w of training I3: After 6–9 w of training	a. - Decline in $\dot{V}O_{2max}$ > 2 ml · kg^{-1} · min^{-1} - Decline in performance - Missing motivation to train more, combined with further symptoms like mood changes, sleep problems, menstrual cycle irregularities, loss of appetite, sweating, other psychosomatic symptoms - No illness, injuries, or other factors that might explain decline in performance b. **Blood sampling** **Mood scale** (on a 4-point scale) **Urinary sampling** **$\dot{V}O_{2max}$ test** **Submaximal run test** (5 min at 9.9 km/h, 5 min at 11.7 km/h) **Maximal run test (runners)** 6.3 km/h, gradient 1°, every 3 min increase by 1.8 km/h, until 13.5 km/h, then increase of gradient by 1.4° until $\dot{V}O_2$ reached 60 ml · kg^{-1} · min^{-1} **Maximal run test (skiers)** start: 6 km/h, gradient 2.3°, Step 1–4: increase of velocity every 3 min by 0.3 m/s and of gradient by 1°, following steps: increase of gradient by 1.6°	**Urinary concentration** I1 I2 I3 Epinephrine: A, B, OT ( ) → → Norepinephrine: A, B, OT ( ) → → **Blood concentration** **A: At rest** Epinephrine, Norepinephrine, Cortisol, Testosterone **( )** → → **Submax exercise** Epinephrine ( ) ↓ ↓ Norepinephrine ( ) → ↓ — ( ) ↓ Cortisol, Testosterone ( ) → → **Max exercise** Epinephrine ( ) → ↓ Cortisol ( ) ↓ ↓ Norepinephrine, Testosterone ( ) → → **B: At rest, submax, and max exercise** Epinephrine, Norepinephrine, Cortisol, Testosterone ( ) → → **OT: At rest, submax exercise** Epinephrine, Norepinephrine, Cortisol, Testosterone ( ) → → **Max exercise** Epinephrine ( ) ↓ ↓ Norepinephrine, Cortisol, Testosterone ( ) → →	**Max test** I1 I2 I3 A, B: $\dot{V}O_{2max}$, HR_{max} ( ) → → OT: $\dot{V}O_{2max}$, HR_{max} ( ) → ↓ **Mood** A, OT: negative feeling ( ) — ↑ OT: positive feelings ( ) — ↓ **Significant correlations (A, B, OT) between I1 and I2** - Δ $\dot{V}O_{2max}$ and Δ cortisol (r = 0.63) - Δ intensive training and Δ submax testosterone (r = –0.73) - Δ moderate training and - Δ $\dot{V}O_{2max}$ (r = –0.62) - Δ max cortisol (r = –0.75) - Δ total training volume and - Δ $\dot{V}O_{2max}$ (r = –0.54) - Δ max cortisol (r = –0.71) - Δ submax testosterone (r = –0.72) - Δ max testosterone (r = 0.56) - **Between I2 und I3** - Δ total training and Δ norepinephrine at rest (r = 0.77) - Δ intensive training and Δ - testosterone at rest (r = –0.53) - Δ max testosterone (r = –0.61)