REVIEW ARTICLE

Sports Med 2005; 35 (7): 597-617
0112-1642/05/0007-0597/$34.95/0

Monitoring of Performance and Training in Rowing

Jarek Mäestu, *Jaak Jürimäe* and *Toivo Jürimäe*

Institute of Sport Pedagogy and Coaching Sciences, University of Tartu, Tartu, Estonia

Contents

Abstract 597
1. Characteristics of Rowing Performance 598
2. Characteristics of Rowing Training 603
3. Selected Biochemical Indices of Monitoring Training in Rowing 604
4. Selected Psychometric Instruments of Monitoring Training in Rowing 607
5. Studies on Monitoring Training in Rowing 608
6. Multi-Level Approach of Training Monitoring 611
7. Future Investigations and Recommendations 613
8. Conclusions 613

Abstract

Rowing is a strength-endurance type of sport and competition performance depends on factors such as aerobic and anaerobic power, physical power, rowing technique and tactics. Therefore, a rower has to develop several capacities in order to be successful and a valid testing battery of a rower has to include parameters that are highly related to rowing performance. Endurance training is the mainstay in rowing. For the 2000m race, power training at high velocities should be preferred to resistance training at low velocities in order to train more specifically during the off-season. The specific training of the international rower has to be approximately 70% of the whole training time. Several studies have reported different biochemical parameters for monitoring the training of rowers. There is some evidence that plasma leptin is more sensitive to training volume changes than specific stress hormones (e.g. cortisol, testosterone, growth hormone). In rowing, the stress hormone reactions to training volume and/or intensity changes are controversial. The Recovery-Stress Questionnaire for Athletes measures both stress and recovery, and may therefore be more effective than the previously used Borg ratio scale or the Profile of Mood States, which both focus mainly on the stress component. In the future, probably the most effective way to evaluate the training of rowers is to monitor both stress and recovery components at the same time, using both psychometric data together with the biochemical and performance parameters.

In the world of sport, athletes and coaches push themselves harder and harder in order to achieve the best results in competition. However, by increasing either the frequency, duration or intensity of training, they risk creating excessive fatigue that may lead to functional impairment, described as 'overtraining syndrome', 'staleness' or 'burnout'.[1] The aim of sport training is to accustom the human body through different training loads and competitions, at the same time minimising the risk of illness, injury and fatigue in the period leading up to the competition. Thus, an athlete's body must become accustomed to training loads that are intense enough to displace the homeostasis of an athlete. Once the adaptation to a certain training load has occurred, a greater load must be applied to get further improvement and stressful high-intensity training periods are necessary to obtain high performance in sports.[2] It has been shown that systematic recovery periods in the training process are necessary to prevent an overtraining syndrome and/or staleness.[3] Training should be organised in periods of stressful heavy training to induce sufficient training response followed by a period of reduced load to allow recovery and an increase in performance.[4,5] A problem for coaches is that athletes respond differently to the same training loads. A load that is too high for one athlete may have no training effect at all to another. It is evident, however, that underestimation or overestimation of performance level, trainability and insufficient recovery will lead to: (i) inappropriate training response of the athlete; or (ii) overreaching and eventually staleness, burnout syndrome or overtraining.[6-8] Hoffman et al.[9] pointed out that peak athletic performance depends on the proper manipulation of training volume and intensity as well as providing adequate rest and recovery between practice sessions.

Overtraining is a state of overexertion, which may be attained when the training load and the associated disturbances in homeostasis are not matched by recovery.[5] The first phase of overtraining is quickly reversible and is referred as 'overreaching'.[10,11] Overreaching is characterised by underperformance, which is reversible within a short-term recovery period of 1–2 weeks and can be rewarded by a state of supercompensation (an increase in performance ability allowing 1–2 weeks of regeneration after a short-term phase of overtraining).[10,11] The term 'staleness', is the unwanted end result of overtraining,[11] and 'overtraining syndrome' should have the same meaning.[10]

Repetition of a training stimulus will result in a weaker response and, after a time, responses to training will asymptotically reach a limit. Further increases in performance can be reached by increasing intensity and/or duration of training.[12] For rowers, it has been demonstrated that training kilometres rowed are positively related to success in championships.[13,14] However, the risk of overtraining increases with training volume, particularly with monotonous training.[6,8,15]

A problem in studying training effects is the complexity of the goals of training, because different capacities (e.g. aerobic, anaerobic, strength) of the athlete have to be developed and improved,[5,16] so it also makes the monitoring process complicated. As a typical power endurance sport, rowers need physical strength to achieve high power per stroke, endurance to sustain this power for 2000m, as well as special motoric and tactical skills.[13,16-18] Mood state also seems closely related to performance.[4,17,19]

Evaluation of the actual trainability and diagnosis of possible overload and overtraining are already among the most complicated tasks in sports medicine and sports psychology.[6,7,20,21] The monitoring process is effective if it has profound scientific foundations. The aim of the current review article is to give an overview of the methods used to monitor training in rowing and to provide some future suggestions to make the training monitoring process more effective and achieve better performance results during competitions.

1. Characteristics of Rowing Performance

Rowing is primarily a strength-endurance type of sport. The typical rowing competition takes place on a 2000m course and lasts, depending on a boat type and weather conditions, 5.5–7.0 minutes. During a race, muscle contraction is relatively slow and about 32–38 duty cycles per minute are used. In international rowers, the power per stroke may reach as high as 1200W and the average power per race is about 450–550W.[14] During competition, a rower depends mainly on his or her aerobic metabolism because energy stores and glycolysis are limited to cover the energy demand only for approximately 1.5–2.0 minutes.[14] Aerobic power can be defined as the maximal oxygen consumption ($\dot{V}O_{2max}$) as estimated during a performance that lasts from 2 to 10 minutes.[22] Aerobic and anaerobic energy contributions on a 2000m rowing race in different studies are presented in table I. According to Roth et al.,[23] the energy of the 2000m race was provided 67% aerobically and 33% anaerobically, 21% alactic and 12% lactic. Secher et al.[24] found that the aerobic energy contribution may be up to 86%.

Many factors affect physical performance during rowing. Power depends on aerobic and anaerobic energy supplies balanced by efficiency or technique.[22] Efficiency is expressed as the relationship between energy expenditure and boat velocity and it depends on the technical skill of the rower. Efficiency varies from as much as 16% to 21%, even during ergometer and tank rowing.[29,30] Differences in efficiency between rowers and non-rowers have been demonstrated, while no differences were observed between elite lightweights selected for the World Championships team compared with those who did not make the team.[30] This indicates that efficiency on an ergometer is only a rough estimate of technique in the boat.[22]

Testing an athlete is an attempt to evaluate his or her sport-specific performance. The easiest way of doing this is to measure the shortest time needed to cover a particular rowing distance. However, this is rather complicated, because external factors such as wind, water currents and temperature may influence the result. Furthermore, a need may exist to evaluate the individual contribution to a boat, including as many as eight rowers.[22] Accordingly, rowing ergometers are commonly used to measure individual performance parameters in rowers and training changes. Although rowing an ergometer does not require the same skills as on-water rowing, it has been observed that the ergometer simulates the biomechanical and metabolic demands of on-water rowing.[31] The dynamic rowing ergometer Rowperfect seems to more closely reflect the on-water rowing technique than the commonly used Concept II rowing ergometer.[32] Stroke angle/length, which did not vary with rate, was similar for both forms of rowing. The mean trunk, thigh and lower leg angles at the catch and finish of the stroke were also similar across the stroke rates.[32] However, rowing technique is a very complex task and consists of components such as balance, efficiency, and maintaining the boat speed during the recovery phase, which cannot be measured on an ergometer. Thus, estimating rowing technique as a complex on a rowing ergometer is of little value in analysing on-water technique.

Rowing ergometers should be considered valuable tools in testing, but they should be used with care when developing endurance during the preparation period because they may seriously affect the technique of on-water rowing.

Many researchers (see table II) have found performance-predictive parameters for rowers to predict 2000m rowing ergometer performance[28,33-39] and two of them[35,36] also developed performance-predictive parameters for 2000m single scull distance. These studies used rowers of different levels, classification (i.e. scullers, sweep rowers) and sex. This may be a reason why each study had different equations of performance-predictive parameters. However, all these studies reported either $\dot{V}O_{2max}$ in L/min or maximal aerobic power (P_{max}) in W obtained on incremental test to exhaustion,[33-39] or during standardised 2000m all-out rowing ergometer test,[28] to be an important parameter in predicting performance over a 2000m rowing ergometer dis-

Table I. Mean contribution of aerobic and anaerobic energy during rowing in different studies using elite heavyweight male rowers

Studies	No. of subjects	Aerobic energy (%)	Anaerobic energy (%)
Hagerman et al.[25]	310	70	30
Messonnier et al.[26]	13	86	14
Mickelson and Hagerman[27]	25	72	28
Roth et al.[23]	10	67	33
Russell et al.[28]	19	84	16
Secher et al.[24]	7	70–86	14–30

Table II. Performance predictive parameters for rowers on 2000m ergometer distance in different studies

Study	Classification	Parameters	SEE	Comments
Cosgrave et al.[33]	13 M college level rowers	$\dot{V}O_{2max}$ Lactate 5 min after 2000m ergometer all-out	0.87	May be due to homogenous group. Rowing economy was not found to be an important predictor to rowing success
Ingham et al.[34]	41 M and F international level. Also lightweights	P_{max} $\dot{V}O_2$ at 4 mmol/L Power at 4 mmol/L Maximal power	0.98	May be not specific enough because both M and F and also lightweights were used
Jürimäe et al.[36]	10 M national rowers	P_{max} La_{350W} CSA of thigh Height Muscle mass	0.99	Compares on-water and rowing ergometer performance parameters
Riechman et al.[38]	12 F international level	Power of 30 sec all-out $\dot{V}O_{2max}$ Fatigue	0.96	A 30-sec Wingate test, with fatigue measure was developed to predict 2000m rowing performance
Russell et al.[28]	19 elite schoolboys	Height Body mass Skinfolds	0.78	Sweep rowers were used, who are known to be taller and heavier than scullers
Womack et al.[39]	10 M college rowers	$\dot{V}O_{2max}$ Peak velocity Velocity at 4 mmol/L $\dot{V}O_2$ at 4 mmol/L	0.81	The rest period in the incremental test could have too an big influence on the $\dot{V}O_{2max}$ value

CSA = cross-sectional area; **F** = female; **La_{350W}** = lactate concentration corresponding to power at 350W; **M** = male; **P_{max}** = maximal aerobic power; **SEE** = standard error of estimate; **$\dot{V}O_{2m}$** = oxygen consumption; **$\dot{V}O_{2max}$** = maximum oxygen consumption.

tance. For example, Ingham et al.[34] and Womack et al.[39] found that $\dot{V}O_{2max}$, P_{max}, and oxygen consumption ($\dot{V}O_2$) at a power eliciting a blood lactate concentration of 4 mmol/L were closely related to the 2000m ergometer performance time. In contrast, Riechman et al.[38] found that 2000m rowing ergometer performance time is best characterised by the mean power of an all-out 30-second ergometer test (i.e. a measure of anaerobic lactic power) and $\dot{V}O_{2max}$. Similar results were obtained by Jürimäe et al.,[36] who reported P_{max} and mean power of 40 seconds of work (i.e. a measure of anaerobic lactic power) to be the best predictive parameters of 2000m rowing ergometer performance.

It is now possible to determine aerobic capacity on the water due to solid-state portable measurement equipment, but to our knowledge there are no studies of the use of this type of apparatus in rowing. These results, in a rower's natural environment can be interesting, e.g. how high can $\dot{V}O_{2max}$ be on water compared with ergometer testing? However, these tests are logistically difficult to organise and they are probably more time consuming than laboratory testing. Presently, the testing procedures of rowers in their natural environment are conducted by our laboratory and are focused mostly on anaerobic threshold and $\dot{V}O_{2max}$ differences between ergometer and on-water rowing.

Jürimäe et al.[36] compared ergometer rowing with on-water rowing and found that from different anthropometric and body composition characteristics only muscle mass was correlated to 2000m single scull distance time, while almost every anthropometric variable was related to 2000m rowing ergometer distance time. Similarly, Russell et al.[28] reported that anthropometric parameters predicted the 2000m rowing ergometer distance best when compared with metabolic parameters and a combination of categories. Thus, care should be taken when interpreting the rowing ergometer results to predict on-water rowing performance, because anthropometric variables may have too big an influence on the result. In smaller and lighter rowers, on-water rowing speed is usually compensated by higher physiological parameters, which is clearly indicated by the fact that in international regattas some lightweights may easily compete with their heavier peers.

The accurate analysis and assessment of various components of performance within the training context is an important process for coaches and sport scientists to include as an integral aspect of the training and competition programme of a rower. Determinants of competitive success include various psychological attributes such as self-motivation,[40] technical skills (including balance),[41] coordination with other crew members,[42] in addition to the physiological characteristics of muscular endurance, aerobic power, anaerobic power and strength.[43] It is difficult to rate these parameters, although everything depends on appropriate physiological characteristics. Some of these parameters can be compensated with others, for example, good technique may compensate for lower physiological parameters. If a rower has no coordination with team members he/she can still be a good single sculler. These parameters must be viewed together to allow better understanding of a rower's state. Therefore, a good testing battery for a rower needs to consist of several parameters to determinate his or her performance and to make the selection process more effective. A key aspect to consider regarding a physiological test is the extent to which it is actually correlated with rowing performance.[44]

Changes in performance capacity can be analysed during all-out rowing tests in a rowing boat over various distances or on a rowing ergometer. P_{max} during a standardised test (e.g. 2-, 6- and 7-minute all-out, 500, 2000, 2500 and 6000m all-out tests) can be used for evaluation of the exercise capacity.[22,25,26,35,36,39,44-50] However, Steinacker et al.[20] argued that P_{max} is subject to motivation of the rower tested and, therefore, may not be sensitive enough to monitor a complete rowing season. A question was then raised by the authors that more reliable test programmes, such as fast ramp tests could be used for measuring rowing performance, because they may fit into a training programme more easily. However, our experience (unpublished data) has showed that 1 minute of maximal rowing on a rowing ergometer has no relationship with changes in rowing ergometer performance over 2000m after heavy training periods. This is supported by the study of Smith,[44] who found no changes in 500m rowing ergometer time nor power after 3 weeks of overload training with a 33% increase in the frequency and a 30% increase in training volume and the following tapering week in international male and female rowers. This may be explained by the fact that anaerobic energy production may have too big an influence on the test results and it is well known that in successful rowers anaerobic capacity trainings are <10% of the whole training time.[14]

Endurance capacity is an important result of training and regeneration.[16,27] Higher performance at a fixed or individual lactate threshold means higher maximum performance, but there is a wide scattering of individual data of rowers. In successful rowers, the 4 mmol/L lactate threshold is in the range of 75–85% of their P_{max}.[14,17] It should be taken into account that different testing protocols and different types of ergometers used may contribute different levels of 4 mmol/L blood lactate levels. For example, Lormes et al.[51] found higher lactate levels for a given heart rate on the Gjessing than on the Concept II rowing ergometer, possibly because of power losses in the transmission system of the Gjessing rowing ergometer. Maximal lactate values decrease with higher lactate threshold, as an indicator of increased endurance capacity.[14] However, using fixed or individual lactate threshold values measured on a rowing ergometer as guidelines for training intensity must be viewed with caution because they do not exactly mirror the blood lactate at steady-state for rowers.[52] Lactate threshold and maximum lactate values are also influenced by preceding exercise and muscle glycogen stores.[14] Thus, all variables must be standardised before testing the athlete to avoid difficulties in interpretation of the test results. In a glycogen-deficient state, maximum lactate and performance are depressed and lactate threshold virtually increased, but in the state of overreaching or overtraining without glycogen deficit, maximum lactate and performance capacity, and lactate threshold are decreased or lactate threshold unchanged.[16,20,53]

Nowadays, the blood lactate response to exercise is a commonly accepted tool for performance assessment and training prescription.[14,53] The blood lactate response has been thoroughly investigated and described using variety of terms and definitions.[54,55] The anaerobic threshold has been one of the most commonly used terms for describing the blood lactate response. Anaerobic threshold can be defined as the workload that can be performed by the oxidative metabolism and at which blood lactate production and release are balanced during continuous exercise.[14,54-56]

To determine anaerobic threshold, numerous concepts and definitions have been published in the last decades.[57-63] However, although a number of competing models exist to fit blood lactate concentration data during incremental exercise, there has been little comparison between different concepts in rowers.

Steinacker[14] and Wolf and Roth[64] have reported that the submaximal aerobic capacity measured as the power that elicits a blood lactate level of 4.0 mmol/L is the most predictive parameter of competition performance in trained rowers, especially in small boats such as singles and doubles. However, some authors have questioned the physiological significance of a fixed blood lactate value of 4.0 mmol/L, which does not take into account the individual kinetics of the lactate concentration curve.[65,66] Moreover, power at a blood lactate level of 4.0 mmol/L has not been reported to represent a steady-state workload in rowing.[52,67] Different anaerobic threshold concepts (fixed blood lactate values of 2, 3 and 4 mmol/L, D_{max},**1** modified D_{max}, LT_{LOG},**2** increases of 1 mmol/L and over the resting level [for further explanation see Jürimäe et al.[70]]) and their relationships to rowing performance were studied by Jürimäe et al.[70] using 21 male national standard rowers. The results of this study indicated the anaerobic threshold value to be 3.7 mmol/L determined by the LT_{LOG} method, which was lower than the suggested 4 mmol/L value by different authors[14,52,64] and may therefore be a better indicator for selecting training intensities without accumulation of blood lactate. The authors concluded that LT_{LOG} represented the 2000m all-out rowing ergometer performance best. Moreover, a deflection point using the LT_{LOG} method was very easily detected, allowing more accuracy for each athlete. Thus, the LT_{LOG} value, which detects the anaerobic threshold with less subjectivity, may be a more appropriate measure of training modality in rowing; however, it must be still confirmed in future studies.

Coen et al.[71] described an on-water graded exercise test battery to measure individual anaerobic threshold and sport-specific performance on coxless pairs. The results of the study indicated that heart rates and performance on individual anaerobic threshold were significantly related between ergometer and on-water rowing. Furthermore, a graded incremental exercise test on water was strongly related to competition results over 2000m, especially when seat positions were considered,[71] which seems expected. However, performing on-water graded incremental exercise was extremely time consuming and the weather conditions may have too big an influence to make proper conclusions. Therefore, for reliable longitudinal data, the rowing ergometer is still the best apparatus for testing the performance parameters of rowers.

In summary, aerobic and anaerobic capacities both seem to be important parameters in competitive rowing, despite factors such as the level, sex, and body mass. Also, both capacities are important to measure to better understand the performance of a rower. For anaerobic threshold level, the LT_{LOG} method may represent the threshold intensity better than the commonly used 4 mmol/L blood lactate concentration. It should be considered that a 2000m rowing ergometer performance is more suitable for

1 D_{max} is the point on the blood lactate concentration curve that yields the maximal perpendicular distance to the straight line formed by the two end datapoints.[68]

2 LT_{LOG} is the power output at which the blood lactate begins to increase when the log (blood lactate) is plotted against the log (power output).[69]

rowers who compete in big boats such as fours and/ or eights, to ensure a similar performance time. When performance of rowers in small boats is measured, a 2500m ergometer distance appears to more closely reflect the metabolic effort of on-water rowing on singles and doubles.[22,26,36,72]

2. Characteristics of Rowing Training

During rowing competition, anaerobic alactic and lactic as well as aerobic capacities are stressed to their maximum.[16] Therefore, the training of successful rowers has to be built up with a focus on aerobic training with the proper relationship of strength training and anaerobic training.

Endurance training (training at blood lactate concentration of 2–4 mmol/L) is the mainstay of success in rowing.[14,17,47,73-75] Training of successful athletes is characterised by extensive as well as intensive endurance training with approximately 70–80% of the time spent on the water.[75-77] Intense endurance training above the anaerobic threshold may be important for improvement of $\dot{V}O_{2max}$ during the competitive season, but should not amount to >10% of the training volume.[14] Over a year, the percentage of specific rowing training time on the water is approximately 52–55% for an 18-year-old, 55–60% for a 21-year-old, and up to 65% for the older athlete.[78] However, the amount of time of specific rowing training must increase together with the qualification of a rower. Strength training is approximately 20% for an 18-year-old and 16% for an adult athlete, and general athletic training is in the range of 26–33%.[78] It is important to increase specific rowing training with increased training experience.[16]

The preparation period of rowers usually starts in October, where the main goal of training is to build up a base through extensive aerobic endurance training (90% of the total training time).[79] It appears that during the preparation period, rowers should deemphasise resistance training at low velocities and emphasise power development at higher velocities (i.e. train more specifically for the types and velocities of movements used in the rowing technique and at speeds necessary to mimic the competitive pace).[46] The main period for developing strength-endurance is from January to March. The competitive period usually starts in March or April and culminates for elite rowers in late August or early in September with the World Championships. During the competition period, aerobic training is still the most important (about 70% of total training). Approximately 25% of the training during the competitive season is aerobic-anaerobic (blood lactate concentration 4–8 mmol/L) training and the rest is purely anaerobic (blood lactate concentration >8 mmol/ L) training.[79] Steinacker et al.[53] investigated the time course of rowing velocity and ergometer results of a coxed eight during the training camp before the Junior World Championships in 1995. Such a preparatory training programme typically has a duration of approximately 4 weeks: 2 weeks high-intensity/high-volume training, tapering for 1 week and in the last week special preparation for the finals. The slowest boat speed of the 2000m distance was observed during the high-volume/high-intensity training, and the fastest boat speed was observed after the tapering period and at the World Championships, indicating that the rowers had overcome the over-reaching state after the high-intensity period and realised their performance capacity, indicating no overtraining.

In rowing, the problem with studying training effects is the complexity of the goals of training because different capacities (aerobic, anaerobic, power, strength, tactical skills) have to be improved.[16] This causes timing problems because several capacities cannot be developed at the same time. For example, endurance and sprint training are not appropriate to develop in the same training session. For rowers, one of the most important tasks is the maintenance of strength gains while training to enhance aerobic endurance simultaneously,[80] as resistance training is one physical performance factor of a complete annual training programme.[13,17] Research has shown that a sequence of resistance training prior to endurance training may be preferred for the off-season of rowing.[81,82] Bell et al.[80] found significant strength gains with a training frequency of three times per week for 10 weeks and was maintained for at least 6 weeks where the main goal was to develop aerobic endurance, and strength training was conducted only once or twice per week.[80] Whether strength gains can be maintained beyond 6 weeks while performing endurance training is not known[80] and needs further research. Bell et al.[81] also showed that organising strength and endurance training into sequential programmes can influence the physiological adaptation to training in rowers.

Most rowers also use unspecific and cross training to increase training tolerance and to avoid overtraining. During cross training, different muscle groups are recruited, which may allow partial recovery of other muscle groups and, therefore, the advantages of cross training seems to be 'peripheral' effects, enhancing or maintaining strength in power training and 'central' effects by decreasing the monotony of training.[16]

3. Selected Biochemical Indices of Monitoring Training in Rowing

In the world of training and coaching, different biochemical indices in blood are measured to prevent and to diagnose overtraining syndrome as an unwanted result of an athlete's training regimen. However, to date there are still no valid diagnostic tools that would help us to prevent overtraining. Different hormonal responses were often proposed for monitoring overreaching and overtraining situations and also for the recovery period.[7,8,20,49,53,83-87] Endogenous hormones are essentially involved in exercise-induced short- or long-term adaptations and influence the regeneration phase through the modulation of anabolic and catabolic processes after exercise.[88] Hormonal mechanisms that help mediate both short-term homeostatic control and long-term cellular adaptations to any type of stress are imposed on humans. For example, cortisol and growth hormone exert an essential role both in short-term (control of utilisation of energy substrates, mobilisation of protein resources) and prolonged stable (amplification of the translation process, supply of protein synthesis by 'building materials') adaptation to exercises.[89]

When planning the hormone sampling, the timing of sampling must always be considered because most of the hormones exhibit circadian rhythms and different aspects may have an influence on the result.[90-92] Numerous investigations have studied the effects that different types of prolonged physical stress have on the hormones of hypothalamus-pituitary-adrenocortical axis.[5,83,93] Prolonged heavy endurance training has been found to cause the increase and decrease in the morning basal levels of cortisol and testosterone, respectively.[93] While resting levels of cortisol have reported to be unchanged[94] or decreased[95] after endurance training in male athletes.

In rowers, the further improvement of performance capacity was associated with increased growth hormone and cortisol levels and elite rowers have higher values of cortisol and growth hormone compared with national and medium performance level rowers.[49] These results are somewhat in contrast to Steinacker et al.,[96] who reported higher cortisol values for athletes who were not selected to the National Junior team of Germany, indicating higher catabolic activity. At an early stage during the training camp in 1996 in the German Junior Team when the training load was highest, basal cortisol levels increased by 18% and decreased slightly afterwards.[53] Elevated basal cortisol levels are often seen as a normal stress response to high-intensity training.[16,96] For example, the increase in cortisol level was found in junior rowers after anaerobic training during the last days before blood sampling.[96] There were no changes in plasma cortisol and testosterone concentrations after 2 hours of rowing at an intensity of 75% of anaerobic threshold.[97]

Steinacker et al.[5] found a 10% increase in human growth hormone from baseline during a high-load training phase (training load approximately 180 min/day for 2 weeks), and a decrease of 30% during the tapering phase where training volume was reduced for about 30%, while the intensity was maintained. The fact that not only the training intensity but also the volume may alter testosterone and growth hormone levels was supported in a study by Mäestu et al.[84] This study showed that almost doubling the training volume caused significant increases in fasting testosterone and growth hormone concentrations, which returned to the pre-stress level after the second tapering week, indicating a lag period. In summary, the results of these studies may suggest that the hormone responses of the hypothalamus-pituitary-adrenocortical axis are not specific and do not exactly mirror the amount of physical stress in rowing.

Adlercreutz et al.[98] and Härkonen et al.[99] stated that a condition of overstrain might exist in an athlete if at least one of the following two criteria are fulfilled: (i) free testosterone/cortisol ratio lower than 0.35×10^{-3}; and/or (ii) a decrease in the free testosterone/cortisol ratio of ≥30%. During a rowing season, no significant relationships were found between the free testosterone/cortisol ratio and rowing ergometer performance parameters in male rowers.[93] However, a decrease in the free testosterone/cortisol ratio was observed after the training camp (range 4–40%), but these changes were not significantly related to performance parameters.[93] The authors concluded that the criterion of a decrease in the free testosterone/cortisol ratio of ≥30% or the free testosterone/cortisol ratio lower than 0.35×10^{-3} cannot be regarded as a first sign of overtraining.[93] In contrast, a significant decrease in the free testosterone/cortisol ratio as a result of an intensive training period and a slight increase after reduction of training intensity was observed in international-level junior rowers.[96] Meanwhile, the rowing ergometer performance was improved. Therefore, the free testosterone/cortisol ratio seems to be more useful as an indicator for a status of insufficient time to recover from training.[93]

Catecholamines stimulate cardiovascular and metabolic reactions and indicate physical and psychological stress.[100-103] All-out rowing is associated with extremely high plasma catecholamine levels: 19 nmol/L and 74 nmol/L for adrenaline and noradrenaline, respectively.[104,105] Higher noradrenaline concentrations were noted during endurance training at similar heart rate on the Gjessing ergometer compared with rowing in the boat,[106] but adrenaline values were not statistically different. The authors concluded that, because of the higher sympathoadrenergic activation when exercising on the ergometer, the intensity of ergometer rowing should be set carefully.[106]

The plasma leptin level is identified as an adipocyte-derived hormone and its receptor has highlighted the regulation of appetite, thermogenesis and metabolism.[107] For a review see Friedman and Halaas,[107] and Flier.[108] However, it has become evident that leptin does not act only as an ‘adipostatic hormone’,[109] but it also profoundly affects hypothalamic neuroendocrine function as a result of negative energy flux.[85] Several studies showed that endurance exercise sessions decrease the plasma leptin concentration after 48 hours, in association with a preceding decrease in insulin,[110] while short-term exhaustive exercise has no immediate or delayed effect on circulating leptin concentration.[111] However, it has been recently demonstrated that a 30-minute all-out rowing ergometer test caused an immediate decrease in plasma leptin levels, probably by the involvement of all major muscle groups of the human body.[112] In the literature, the responses of plasma leptin to training are controversial. It has been suggested that fasting plasma leptin is not regulated in a dose-response manner in competitive male athletes,[113] while it has shown to be decreasing in heavy training in highly trained rowers[85,114] and increasing when training load is decreased. These differences could be explained by the differences in physical stress, as the training regimen of the swimmers in the Noland et al.[113] study was intensive interval training, while in Mäestu et al.[114] it was low-intensity high-volume training. Accordingly, it could be suggested that fasting plasma leptin response during prolonged heavy training stress may depend on the total amount of the physical stress.[114]

Jürimäe et al.[115] demonstrated a significant relationship between plasma leptin and training volume without changes in body mass. Furthermore, Simsch et al.[85] demonstrated a positive relationship between leptin levels and rowing performance. These results are in contrast to those of Petibois et al.[116] who argued that plasma leptin levels in top-level athletes parallel the changes in body fat and are not sensitive to an increase in training volume for trained individuals. Desgorces et al.[117] showed no changes in fasting plasma leptin concentration after 36 weeks of training. However, training volume might have been too low (i.e. 45 min/day in session 1 and 77 min/day in session 2) to induce a change in fasting leptin concentration. However, they showed the changes in post-exercise leptin concentrations, suggesting an improved regulation of energetic status after training (i.e. the better lipid availability). The hypothesis exists that leptin expression in the adipocyte is related to energy flux and triglyceride loss.[118] Further studies are needed to investigate the role of plasma leptin in highly trained athletes as a marker of training stress or overtraining. In addition to leptin, we have recently demonstrated that adiponectin could also be another adipocytokine to use as a marker of training stress in rowers.[119,120]

Recently, Urhausen and Kindermann[121] suggested that instead of resting hormone concentrations, maximal exercise-induced hormonal responses during and after a period of training overload should be studied to assess the adaptivity of the athletes. The elevation of hormone levels after rowing exercises performed at the maximal possible rate may be an overall expression of the dependence of hormone changes on the exercise intensity.[49] This means that there should be a wide reserve to increase the hormone responses to exercise. Only a sufficient performance capacity has to be achieved to evoke a correspondingly large rise in hormone concentrations.[49]

Despite the episodic character of growth hormone secretion, its response during exercise is characterised by a continuous increase of blood level during the exercise.[122] Growth hormone response to submaximal exercise has been found to decrease or disappear as a result of training.[123,124] There is also a possibility that fatigue may modulate growth hormone response.[122] For example, Urhausen et al.[86] demonstrated a decrease in exercise-induced rise of growth hormone in cyclists, while Lehmann et al.[16] and Mäestu et al.[114,125] found no change in resting nor exercise-induced values of growth hormone in runners and rowers, respectively. Therefore, the exercise-induced changes in growth hormone concentrations may have practically less value of training monitoring in rowers. However, in these studies, different exercise protocols and subjects were used and so they are not exactly comparable.

In the state of overtraining and overreaching, an intra-individually decreased maximum rise of cortisol[115,126] and insulin[126] has been found after a standardised exhaustive exercise test. Moreover, Jürimäe et al.[115] also demonstrated a significant decrease of exercise-induced (2000m all-out rowing ergometer test) leptin concentrations after a high-load training cycle in rowers. These studies may indicate that if hypothalamic downregulation exists during overreaching, analysis of exercise-induced cortisol and leptin concentrations may provide valuable information for detecting signs of overreaching, because in a state of fatigue the hypothalamic downregulation may be more sensitively detected. However, this is an area for future, well controlled research.

For several years, serum creatine kinase activity has been measured as a parameter of muscular stress in training-associated studies. A particularly important consideration relating to the use and interpretation of creatine kinase activity values in the sports sector is the dependence of this parameter on the nature of the stress.[127] Creatine kinase activity reflects training intensity and muscular strain only at the beginning of a training phase, decreasing creatine kinase activity levels suggest a muscular adaptation to training.[14,20,86] Morning levels of creatine kinase activity mainly represent its release during the previous day and are also influenced by creatine kinase activity clearance (50–80% per day).[96] Steinacker et al.[96] also found higher creatine kinase activity values in the junior rowers who were not selected for the national team despite their lower physical power.

In summary, it seems that there are a lack of valid biochemical markers of training stress in rowing. However, some recent studies[85,114,115] have reported the decrease of leptin in high-load training phases. It could be suggested that the maximal exercise-induced changes in leptin values may represent the more sensitive marker of overreaching for rowers.[115]

4. Selected Psychometric Instruments of Monitoring Training in Rowing

In addition to clinical findings, metabolic and hormonal values, the level of psychologically related stress and recovery seems to reflect well the clinical state of athletes.[2,5] Furthermore, mood state (e.g. motivation and striving for success) seems to be closely related to actual performance.[2,17,128-130] To date, the most common psychometric instruments used are: the one-item Borg ratio scale,[129] which was developed to subjectively measure the intensity of the exercise; the Profile of Mood States (POMS),[130] which measures only current stress; and the Recovery-Stress Questionnaire for Athletes (RESTQ-Sport),[131] which allows measuring both subjectively perceived stress and recovery.

Marriot and Lamb[132] found a highly consistent relationship between Borg ratio scale perceptions of exertion on a rowing ergometer and heart rate. When the rating of perceived exertion was used as a means of producing an appropriate training heart rate, it was satisfactory but only at the higher intensities of effort (ratings 15 and above). Urhausen et al.[133] found significantly higher ratings of subjective exertion during the 'stress test' at the intensity of 110% of individual anaerobic threshold until exhaustion in overtrained endurance athletes. However, the one-item construction of the Borg ratio scale cannot assess different aspects of recovery and stress.[10] Moreover, it is difficult to interpret what causes the change of the scale after standardised exercise and, therefore, proper intervention is complicated. Thus, the Borg ratio scale is not suitable for monitoring training in highly trained athletes.

There is convincing evidence that athletes can be distinguished on the basis of psychological skills and emotional competencies.[134] POMS was initially developed as an economical method of identifying and assessing transient, fluctuating affective state.[130] POMS consists of 65 items and it yields a global measure of mood, consisting of: tension, depression, anger, vigour, confusion and fatigue. An overall score is computed by summarising the five negative mood states and subtracting the positive mood state (vigour). POMS has been used to measure the mood state of rowers,[2,40] swimmers[128] and runners.[135] During a training programme, mood state (the POMS was used three times during the season) did not differ between those who adhered to the training programme and the dropouts; however, those who remained in training had higher self-motivation.[40] During training, mood state increased, but surprisingly remained elevated in those who did not make the team and decreased in those who were successful.[40] Verde et al.[135] concluded that resting heart rate, sleep patterns and hormonal changes do not provide a useful early warning that the peak of the performance has been passed, but the POMS does show a consistent pattern of loss of vigour and fatigue during heavy training for 3 weeks in runners. Morgan et al.[128] measured mood states of swimmers throughout the season. At the beginning, the swimmers exhibited the 'iceberg profile', an indicator of a mentally healthy state. In the high-load phase, mood disturbances increased and a profile reflected poor mental health. After reducing the intensity, the swimmers demonstrated the 'iceberg profile' again. However, it should be stated that five of the six scales of POMS measure the negative mood characteristics of tension, anger, fatigue, depression and confusion and, therefore, POMS only vaguely reflects recovery processes. Berger and Motl[136] argued that a decrease in a negative mood state may not necessarily indicate mood benefits. Thus, when using POMS as the psychometric tool to monitor the mood states of athletes, the main focus is on stress-related behaviour and it might be not appropriate to evaluate the recovery of athletes.

Restricting the analysis to the stress dimension alone is insufficient, especially in high-performance areas, since the management of training intensity and volume is tightly linked to outstanding performance.[5] A psychometrically based instrument to assess the recovery-stress state is the RESTQ-Sport.[131] The recovery-stress state indicates the extent to which persons are physically and/or mentally stressed, whether or not they are capable of using individual strategies for recovery as well as which strategies are used.[4] This questionnaire was created to get distinct answers to the question "How are you?"[10] and addresses physical, subjective, behavioural and social aspects using a self-report approach.[2] The theory behind the questionnaire is that an accretion of stress in everyday life, coupled with weak recovery potential, will cause a variation of the psychophysical general state.[10] A Likert-type scale is used with values ranging from 0 (never) to 6 (always), indicating how often the respondent participated in various activities during the past 3 days/nights. The mean of each scale can range from 0 to 6, with high scores in the stress-associated activity scales reflecting intense subjective strain, whereas high scores in the recovery-oriented scales mirror plenty of recovery activities.[4] However, it has to be considered that the RESTQ-Sport and the POMS are not direct measures of physiological states of the organism, both instruments reflect the subjective representation of these states.[2]

Several studies with rowers have showed that the POMS scales of depression, anger and fatigue are negatively correlated with recovery-associated scales of RESTQ-Sport, at the same time vigour is positively correlated and vice versa. A positive relationship exists between the stress-related scales of RESTQ-Sport and depression, anger and fatigue, while vigour appears to be negatively correlated with stress scales.[4,19,137] Longitudinal studies in athletes have shown that the RESTQ-Sport can sensitively monitor stress and recovery processes in training camps and throughout the season, and the 19 scores of the RESTQ-Sport have acceptable levels of reliability.[2,4,5,19,138] Moreover, a dose-response relationship was demonstrated between training volume (daily rowed kilometres) and the somatic components of stress and recovery.[4,5] These results together indicate that RESTQ-Sport could be a potential tool for monitoring the training of elite athletes using subjective stress and recovery indices. However, so far, RESTQ-Sport has mainly been used in German and American athletes, thus it would be beneficial if this questionnaire could be translated and modified into other languages to take into account the quiddity of the nation. The Estonian version of RESTQ-Sport has successfully been used on rowers during different training periods.[138-140]

In summary, through utilisation of the RESTQ-Sport, coaches and athletes can be informed of the importance of daily activities and how these activities are related to the recovery-stress state of an athlete compared with the frequently used one-item Borg scale or POMS, which generally measure the stress-related behaviour and, therefore, could not be sufficient in high-performance areas. Previous studies[4,19,53,85,138,139] utilising RESTQ-Sport suggest that it is appropriate to measure recovery-stress state changes during rowing training in highly trained male athletes.

5. Studies on Monitoring Training in Rowing

In the literature, there are not very many longitudinal studies that deal with training monitoring of rowers (table III). Most of them are 3–5 weeks in duration, i.e. one microcycle. Only some of them[33,49,50,93] are longer than one microcycle. However, these longer studies tend to monitor only one specific pattern or the time interval between two different testing batteries is too long, making the analysis more difficult.

Recently, a study reporting the changes in training and performance of top Norwegian rowers over the last 30 years was published.[141] They reported a 20% increase in training volume and nowadays their international medal winners train 1100–1200 hours/year.

There is also a lack of studies that deal with rowing performance and resistance training. Bell et al.[80-82] have investigated high-velocity resistance training (HVRT) in relation to rowing training. However, they have compared HVRT to anaerobic power and reported no significant changes in anaerobic power after different training programmes.[142] High-intensity resistance training was also used in the study of Simsch et al.[85] and the stagnation in performance of an incremental ergometer test was

Table III. Studies involving training monitoring in rowers studies

Study	Subjects	Period	Design	Performance	Blood parameters	Mood state	Conclusions
Hagerman and Staron[13]	9 M		Changes from off-season to in-season. P_{max} 6 min all-out	Ve ↑, $\dot{V}O_2$ ↑, P_{max} ↑14%, HR ↔, leg strength ↑ from off-season to in-season			Although seasonal effects were expected, the unusually large differences in metabolic and strength capacities between IS and OS reflect a high degree of training specificity
Jürimäe et al.[139]	10 M	1wk	100% ↑ in load 2000m all-out (at the beginning and in the end) RESTQ-Sport	2000m time ↓	C ↑10.4%	Fatigue ↑ Social relaxation ↑	Overreaching state of rowers after 6d heavy training was reflected by similar change in perceived fatigue and catabolic stress hormones
Kellmann and Günther[4]	9 M 2 F	3wk	RESTQ-Sport 4 times			High training vol. is indicated by increased levels of stress and decreased levels of recovery	A dose-response relationship exists between the training vol. and the subjective assessment of stress and recovery
Mäestu et al.[84]	12 M	6wk	1 ref wk, 3wk high load (100%), 2wk taper (load 90% of ref wk) P_{max} 2000m all-out	Tend to ↓ after high load and tend to ↑ after taper	C tend to ↓ L ↓ in high load and ↑ after taper, GH and T ↑ in high load and ↓ after taper		Plasma leptin was the most sensitive hormone measured to reflect changes in training vol. A dose-response relationship was detected
Simsch et al.[85]	6 M	6wk	3wk RT 16.6 h/wk (55% RT) 3wk ET 14.3 h/wk P_{max} incremental test	AT_4 tend to ↓ in RT and ↑ in ET. $\dot{V}O_2$ tend to ↑. P_{max} ↑ in ET	L ↓27%, C ↓30%, TSH ↓23% in RT L tend to ↑, C tend to ↑, TSH ↑22% in ET		The ↓ of TSH and the peripheral thyroid hormones could be attributed to lower hypothalamus levels and is related to ↓ L levels. L – possible director of monitoring training
Smith[44]	10 M 8 F	4wk	3wk high load (33%↑ in frequency, 30%↑ in vol., 1wk taper (load ↓25%) P_{max} 500m all-out	HR ↓30% in overload F: 1% ↓ in P_{max} during overload and 2% ↑ in taper M: P_{max} ↔	La ↑16% in tests 3 and 4 Ammonia ↓29% at the end of the study		If an individual's 500m time was monitored regularly, such a change (2% of recent time) might be noteworthy for that particular athlete
Snegovskaya and Viru[49]	35 M	20mo	P_{max} 7 min all-out in group A Feb, Jun, Oct. In group B March, Jan, Jun	P_{max} ↑14.6% HR tend to increase	Post-exercise levels of C and GH ↑		Improvements in performance capacity was associated with increased GH and C

Continued next page

Table III. Contd

Study	Subjects	Period	Design	Performance	Blood parameters	Mood state	Conclusions
Steinacker et al.[5]	10 M	5wk	Vol. 56% in 2wk and 40% for 2wk (90% extensive rowing) P_{max} incremental test 2000m rowing on 8+ RESTQ-Sport	P_{max} ↑2.7%, La_{max} ↑3.3%, $LaAT_4$ ↑8%	In overload Hct ↔, C ↔, DHEAS ↔, FT ↔, ALD ↑, LU ↓10%, FSH ↓11%, GH ↑10%, ins ↓17% In taper Hct ↔, C ↑, DHEAS ↑, FT ↑10%, ALD ↑, FSH ↑9%, GH ↓30%, Ins ↑37%	Somatic complaints, general stress, somatic relaxation, self-regulation, fitness reveal a significant cubic trend of the dependant variables	Overreaching was indicated by decreases in P_{max} and increases in stress and deterioration in recovery values in RESTQ-Sport. This was also indicated by suppression of central and peripheral stress hormones
Steinacker et al.[96]	35 M	26d	P_{max} incremental test AT_4 and 6 min all-out 16d aerobic 119.6 min, Thr 6.5 min, anaerobic 2.3 min 10d aerobic 91.2 min, Thr 6.5 min, anaerobic 3.2 min	AT_4 (W) ↑4.6%	Load 128 min/day FTCR ↑24%, T ↑20%, Urea ↑20.8%, CK ↑25% Load 90 min/day C ↑23.5%, T ↑23.2%, FTCR ↑7.9%, urea ↓10.3%, CK ↓27%		AT_4 (W) 4.1% and P_{max} 3.4% higher in national team rowers than non-selected rowers
Urhausen et al.[86]	6 M 3 F	7wk			T, FTCR ↓, C ↔ Urea ↑ in first 2wk and then ↓		The findings suggest an increase in catabolic activity in periods of intensive physical strain, including competitions. Regenerative phases of training seem to reduce the anabolic-catabolic imbalance
Vermulst et al.[50]	6 F	9mo	Testing int. 5wk 5 min at AT_4, P_{max} 2 min all-out	AT_4 ↑ if vol. ↑150% (aerobic, submaximal intensity) AT_4 ↓ if vol. ↔ (70–75% aerobic, emphasis on intensive distance training P_{max} slight 5–10% increase	Not specified		AT_4 is a useful parameter for measuring aerobic capacity of the F rowers. P_{max} does not seem to give a valid estimation of the actual maximal power in F rowers
Vervoorn et al.[93]	6 M	9mo	Testing int. 5wk 5 min at AT_4, P_{max} 2 min all-out	P_{max} almost ↔ AT_4 ↑12% if load ↑110% Heavy int. AT_4 ↓8%	C, FT, FTCR almost ↔ Int. training-FTCR ↓40%, taper-FTCR ↑60%		5wk of training does not induce a change in La dynamics, when comparing AT_4 with preceding test in highly trained rowers

Continued next page

Table III. Contd

Study	Subjects	Period	Design	Performance	Blood parameters	Mood state	Conclusions
							FTCR may be a parameter of early hormonal overstrain with interpretation with training logs. Decrease of 30% is not regarded as overtraining
Womack et al.[39]	10 M	12wk	Each wk 5 sets of rowing (water, ergometer) and 3 sets RT P_{max} 2000m all-out Incremental test	P_{max} ↑, peak velocity ↔, $\dot{V}O_2$ ↔, HR ↔, $velocity_{AT4}$ ↑, HR_{AT4}↑	Not specified		Changes in $\dot{V}O_2$ were not significantly related to changes in P_{max}. Peak velocity during incremental testing may be a better indicator of changes in P_{max}

ALD = aldosterone; **AT_4** = anaerobic threshold; **C** = cortisol; **CK** = creatine kinase; **ET** = endurance training; **F** = females; **FSH** = follicule stimulating hormone; **FT** = free testosterone; **FTCR** = free testosterone cortisol ratio; **GH** = growth hormone; **Hct** = haematocrit; **HR** = heart rate; **HR_{AT4}** = heart rate at anaerobic threshold; **ins** = insulin; **int.** = intensive; **IS** = in-season; **L** = leptin; **La** = lactate; **$LaAT_4$** = lactate on anaerobic threshold; **LU** = leutenising hormone; **M** = males; **OS** = off-season; **P_{max}** = maximal performance; **ref** = reference; **RESTQ-Sport** = Recovery-Stress Questionnaire for Athletes; **RT** = resistance training; **T** = testosterone; **Thr** = threshold training; **TSH** = thyroid stimulating hormone; **Ve** = ventilation; **$velocity_{AT4}$** = velocity at anaerobic threshold; **vol.** = volume; **$\dot{V}O_2$** = oxygen consumption; **W** = power in watts; ↑ indicates significant increase; ↓ indicates significant decrease; ↔ indicates unchanged.

detected; however, the performance increased significantly after endurance training. It is known that building up the strength-endurance capacity during the off-season is one part of a rower's winter training programme. The impact of low-velocity resistance training (e.g. frequency, intensity) on rowing performance during the off-season needs some further research.

Achieving the maximal result during competitions is the major purpose of athletic training. A rower is not always in his or her best shape during major competitions, therefore, valuable information could be obtained from studies that deal with specific preparation for competitions at different levels of rowers. However, it has to be stated that these studies must not be case studies, but controlled ones (control group would benefit), which are difficult to prepare because most athletes do not want to experiment with their training prior to competition. Furthermore, the competition results are always difficult to analyse because they depend on factors such as the effects of counterparts and weather conditions.

6. Multi-Level Approach of Training Monitoring

The evaluation of the clinical state of an athlete, i.e. of current trainability and of the diagnosis of overload and overtraining, is already one of the most complicated tasks in sports medicine.[7,8,53,85,143] There is a cascade of various responses to prolonged training that can be used in training monitoring. It is also evident that only some of the parameters are reliable and specific enough. One should also distinguish between parameters in which the inter-individual response differs, such as creatine kinase activity, hormonal parameters or mood state, and parameters that are hard to tolerate, such as physical performance.[53] The hypothalamus acts as the central integrator of all afferent signals to the brain and has an important role in the regulation of the central responses to stress and training.[108] Such integration involves information from autonomic nerve system afferents, direct metabolic effects, hormones and also different information from different brain centres.

There is experimental evidence that all metabolic hormones have hypothalamic receptors.[144] Leptin and insulin depress the activity of excitatory neurons in the lateral hypothalamus[145,146] and have effects on energy expenditure, body mass control and sympathetic activity.[108] High levels of leptin have been found to inhibit activation of the hypothalamus-pituitary-adenocortical axis and inhibit cortisol release.[147] Therefore, studying the effects of leptin may have the advantage of knowing the amount of stress affecting the organism.

In the high-load training phases, which are essential to achieve improvements in performance through overreaching, decreases of steroid hormones could be observed,[16,91,93,96,98,148,149] suggesting that hypothalamic downregulation will occur in a state of overreaching. This was also demonstrated in experimental training by Lehmann et al.[150] and Barron et al.[151] At present, the mechanism by which the hypothalamus senses metabolic imbalance and fatigue in athletes is speculative.

Using 11 elite rowers during their preparation for the 1996 Atlanta Olympics, Kellmann and Günther[4] found that the alteration of extensive endurance training was well reflected in psychological measures using RESTQ-Sport. High duration was indicated by elevated levels of stress and simultaneously lowered levels of recovery. Moreover, the scales 'somatic complaints', 'lack of energy', 'fitness/injury' and 'fitness/being in shape' described the dose-response relationship with the training load. However, the different trends in the RESTQ-Sport scales may be explained by the different time courses of hormones and corresponding scales.[53] For example, 'somatic complaints' were highest with the highest training load and elevated cortisol concentrations as well as creatine kinase activity.

Steinacker et al.[5] found disturbance of the homeostasis after high-intensity, high-volume training for 3.2 hours/day after 18 days in male junior rowers. This disturbance was also reflected in psychometric scales, in performance, metabolic and hormonal parameters (depression of peripheral and steroid hormones), and was restored and supercompensated after tapering as indicated by the boat speed.[5] Therefore, psychometric scales, in which changes have known to be related to blood hormone concentration changes, may be an alternative measure of an athlete's current state.

Monitoring the current levels of both stress and recovery has the possible advantage that problems may be detected before symptoms of overtraining are likely to appear.[2] Steinacker et al.[5] found that both performance and hormonal indices of training were reflected by the scores of the RESTQ-Sport. One week of a heavily increased training volume (100% compared with previous week) indicated increased levels of stress and decreased level of recovery-associated activities with a significant changes in fatigue and social relaxation in male junior rowers.[139]

For monitoring, it is also important that mood is correlated to physical performance ability, hormonal parameters and metabolic data.[53,140] Naessens et al.[152] demonstrated a U-shaped relationship between subjective fatigue ratings and sympathetic tone (basal noradrenaline excretion). RESTQ-Sport allows monitoring of mood state in athletes, but different scales of RESTQ-Sport have different time courses that have to be taken into account.[2] Physical complaints, fatigue, and general stress[5,138] as well as conflicts/pressure[139] were highest with highest training load, elevated cortisol concentrations and high creatine kinase activity.[53] Sleep quality, personal accomplishment, self-efficacy and general well-being were lowest with the highest training volume.[138,139] Moreover, cortisol was found to be related to all of the stress scales (except disturbed breaks) of RESTQ-Sport after 3 weeks of high-volume training in male rowers.[138] Fatigue has also been found to peak together with sympathetic activation (noradrenaline secretion).[53] From the perspective of a biopsychological stress model,[53,153] recovery and stress should be treated using a multi-level approach dealing with psychological, emotional, cognitive behavioural/performance, and social aspects of the problem, considering these aspects both separately and together.[5]

In summary, it is suggested that investigating physiological and psychological aspects of rowers are an advantage of more effective training monitoring in highly trained rowers.

7. Future Investigations and Recommendations

To date, most of the studies on training monitoring in rowers have investigated only one microcycle and the following recovery period. To our knowledge, only the study of Simsch et al.[85] has used two consecutive microcycles and the recovery period between them. However, these two microcycles were different from each other. During the first training cycle the focus was mainly on resistance training and during the other microcycle the focus was on endurance training. In the future, the studies with two or more training cycles and recovery periods between them, could possibly provide the advantage of learning more about sustainable training load and different markers of monitoring in rowing training. However, these studies are difficult to control and are usually costly. Recent studies also confirm that recovery and stress should be monitored simultaneously in high performance areas to prevent athletes from overtraining.[4,5,19,53,137-139]

In addition, studies with individual analysis may have an advantage of so far used cluster analyses because athletes respond differently to similar training loads. For example, if after a high-load training cycle, some of the subjects show no change in performance, some of them improve and the rest have worsened performance. In this situation, the results of athletes with worsened performance, who may experience overreaching or even overtraining syndrome, disappear into the whole cluster, making the final analysis difficult and more speculative.

The main principle of testing is minimum testing – maximum reliable information. The more direct the link between a parameter and a specific performance, the more value the testing has.[122] As mentioned in section 1, testing a rower is a complex task. As it is known from the literature, rowers with similar $\dot{V}O_{2max}$ may have different rowing performance.[14] It appears that the $\dot{V}O_{2max}$ is not the best predictive parameter for rowers, but an ability to sustain high $\dot{V}O_2$ during competition (i.e. endurance capacity). Therefore, it is advisable to determine the $\dot{V}O_2$ during the simulated rowing ergometer race, either on 2000 or 2500m all-out rowing, and the average $\dot{V}O_2$ should be recorded.

8. Conclusions

Training monitoring studies in rowers should become more specific in their nature. There appears to be no single marker of training monitoring and possible overtraining in rowers. In the future, studies should focus on different fasting blood biochemical markers during different training periods. For example, some studies[84,85] indicate that the plasma leptin could be used as a marker of training stress during low-intensity training in rowers, while maximal exercise-induced stress hormone changes may indicate early signs of overreaching.[121] There are also supportive studies[3,4,11,19,121,139,142] that indicate psychometric data for training monitoring.

Acknowledgements

No sources of funding were used to assist in the preparation of this review. The authors have no conflicts of interest that are directly relevant to the content of this review.

References

1. Hooper SL, Mackinnon LT, Howard A, et al. Markers for monitoring overtraining and recovery. Med Sci Sports Exerc 1995; 27: 106-12
2. Kellmann M, Kallus KW. Mood, recovery-stress state and regeneration. In: Lehmann M, editor. Overload, performance incompetence, and regeneration in sport. New York: Kluwer Academic/Plenum Publishers, 1999: 101-17
3. Raglin JS, Morgan WP, O'Conner PJ. Changes in mood state responses during training in female and male college swimmers. Int J Sports Med 1991; 12: 585-9
4. Kellmann M, Günther KD. Changes in stress and recovery in elite rowers during preparation for the Olympic Games. Med Sci Sports Exerc 2000; 32: 676-83
5. Steinacker JM, Lormes W, Kellmann M, et al. Training of junior rowers before world championships: effects on performance, mood state and selected hormonal and metabolic responses. J Sports Med Phys Fitness 2000; 40: 327-35
6. Bruin D. Adaptation and overtraining in horses subjected to increasing training loads. J Appl Physiol 1994; 76: 1908-13
7. Kuipers H, Keizer A. Overtraining in elite athletes. Sports Med 1988; 6: 79-92
8. Lehmann M, Forster C, Keul J. Overtraining in endurance athletes: a brief review. Med Sci Sports Exerc 1993; 25: 854-61

9. Hoffman JR, Epstein S, Yarom Y, et al. Hormonal and biochemical changes in elite basketball players during a 4-week training camp. J Strength Cond Res 1999; 13: 280-5
10. Kellmann M. Underrecovery and overtraining: different concepts-similar impact? In: Kellmann M, editor. Enhancing recovery: preventing underperformance in athletes. Champaign (IL): Human Kinetics, 2002: 37-55
11. Raglin JS. Overtraining and staleness: psychometric monitoring of endurance athletes. In: Singer RB, Murphey M, Tennant LK, editors. Handbook of research on sport psychology. New York: MacMillan, 1993: 840-50
12. Bannister EW, Morton RH, Clarke JR. Clinical dose-response effects of exercise. In: Steinacker JM, Ward SA, editors. The physiology and pathophysiology of exercise tolerance. New York: Plenum, 1997: 297-309
13. Hagerman F, Staron R. Seasonal variables among physiological variables in elite oarsmen. Can J Appl Sports Sci 1983; 8: 143-8
14. Steinacker JM. Physiological aspects of rowing. Int J Sports Med 1993; 1: 3-10
15. Fry RW, Morton AR, Keast D. Cautions with the use of data from incremental work-rate tests for the prescription of work rates for interval training. Sports Med Train Rehab 1992; 3: 131-45
16. Lehmann M, Gastmann U, Petersen KG, et al. Training-overtraining: performance and hormone levels, after a defined increase in training volume vs intensity in experienced middle- and long-distance runners. Br J Sports Med 1992; 26: 233-42
17. Secher NH. The physiology of rowing. Sports Med 1993; 15: 23-53
18. Steinacker JM, Marx TR, Marx U, et al. Oxygen consumption and metabolic strain in rowing ergometer exercise. Eur J Appl Physiol 1986; 55: 240-7
19. Kellmann M, Altenburg D, Lormes W, et al. Assessing stress and recovery during preparation for the world championships in rowing. Sport Psychologist 2001; 15: 151-67
20. Steinacker JM, Lormes W, Lehmann M, et al. Training of rowers before world championships. Med Sci Sports Exerc 1998; 30: 1158-63
21. Lehmann M, Wieland H, Gastmann U. Influence of an unaccustomed increase in training volume vs intensity on performance, hematological and blood-chemical parameters in distance runners. J Sports Med Phys Fitness 1997; 37: 110-6
22. Jensen K. Test procedures for rowing. FISA Coach 1994; 5: 1-6
23. Roth W, Hasart E, Wolf W, et al. Untersuchungen zur Dynamic der Energiebereitstellung während maximaler Mittelzeitausdauerbelastung. Med Sport 1983; 23: 107-14
24. Secher NH, Vaage O, Jackson R. Rowing performance and maximal aerobic power of oarsmen. Scand J Sports Sci 1982; 4: 9-1
25. Hagerman FC, Connors MC, Gault JA, et al. Energy expenditure during stimulated rowing. J Appl Physiol 1978; 45: 87-93
26. Messonnier L, Freund H, Bourdin M, et al. Lactate exchange and removal abilities in rowing performance. Med Sci Sports Exerc 1997; 29: 396-401
27. Mickelson TC, Hagerman FC. Anaerobic threshold measurements of elite oarsmen. Med Sci Sports Exerc 1982; 14: 440-4
28. Russell AP, le Rossignol PF, Sparrow WA. Prediction of elite schoolboy 2000m rowing ergometer performance from metabolic, anthropometric and strength variables. J Sports Sci 1998; 16: 749-54
29. Bunc V, Leso J. Ventilatory threshold and work efficiency during exercise on a cycle and rowing ergometer. J Sports Sci 1993; 11: 43-8
30. Lakomy HKA, Lakomy J. Estimation of maximum oxygen uptake from submaximal exercise on a Concept II rowing ergometer. J Sports Sci 1993; 11: 227-32
31. Lamb DH. A kinematic comparison of ergometer and on-water rowing. Am J Sports Med 1989; 17: 367-73
32. Elliott B, Lyttle A, Birkett O. The RowPerfect ergometer: a training aid for on-water single scull rowing. Sports Biomech 2002; 1: 123-34
33. Cosgrave MJ, Wilson J, Watt D, et al. The relationship between selected physiological variables of rowers and rowing performance as determined by a 2000 m ergometer test. J Sports Sci 1999; 17: 845-52
34. Ingham SA, Whyte GP, Jones K, et al. Determinants of 2,000 m rowing ergometer performance in elite rowers. Eur J Appl Physiol 2002; 88: 243-6
35. Jürimäe J, Mäestu J, Jürimäe T, et al. Relationship between rowing performance and different metabolic parameters in male rowers. Med Sport (Roma) 1999; 52: 119-26
36. Jürimäe J, Mäestu J, Jürimäe T, et al. Prediction of rowing performance on single sculls from metabolic and anthropometric variables. J Hum Mov Stud 2000; 38: 123-36
37. Perkins CD, Pivarnik JM. Physiological profiles and performance predictors of a women's NCAA rowing team. J Strength Cond Res 2003; 17: 173-6
38. Riechman SE, Zoeller RF, Balasekaran G, et al. Prediction of 2000 m indoor rowing performance using a 30 s sprint and maximal oxygen uptake. J Sports Sci 2002; 20: 681-7
39. Womack CJ, Davis SE, Wood CM, et al. Effects of training on physiological correlates of rowing ergometry performance. J Strength Cond Res 1996; 10: 234-8
40. Raglin JS, Morgan WP, Luchsinger AE. Mood and self-motivation in successful and unsuccessful female rowers. Med Sci Sports Exerc 1990; 22: 849-53
41. Mester J, Grabow V, de Marees H. Physiologic and anthropometric aspects of vestibular regulation in rowing. Int J Sports Med 1982; 3: 174-6
42. Wing AM, Woodburn C. The coordination and consistency of rowers in a racing eight. J Sports Sci 1995; 13: 187-97
43. Shephard RJ. Science and medicine of rowing: a review. J Sports Sci 1998; 16: 603-20
44. Smith HK. Ergometer sprint performance and recovery with variations in training load in elite rowers. Int J Sports Med 2000; 21: 573-8
45. Gullstrand L. Physiological responses to short-duration high-intensity intermittent rowing. Can J Appl Physiol 1996; 21: 197-208
46. Hagerman FC. The physiology of competitive rowing. In: Garrett Jr W, Kirkendall DT, editors. Exercise and sport science. Philadelphia (PA): Lippincott Williams & Wilkins, 2000: 843-73
47. Mahler D, Nelson W, Hagerman F. Mechanical and physiological evaluations of exercise performance in elite national rowers. JAMA 1984; 252: 496-9
48. Peltonen J, Rusko H. Interrelations between power, force production and energy metabolism in maximal leg work using a modified rowing ergometer. J Sports Sci 1993; 11: 233-40
49. Snegovskaya V, Viru A. Elevation of cortisol and growth hormone levels in the course of further improvement of performance capacity in trained rowers. Int J Sports Med 1993; 14: 202-6

50. Vermulst LJ, Vervoorn C, Boelens-Quist AM, et al. Analyses of seasonal training volume and working capacity in elite female rowers. Int J Sports Med 1991; 12: 567-72
51. Lormes W, Buckwitz R, Rehbein H, et al. Performance and blood lactate on Gjessing and Concept II rowing ergometers. Int J Sports Med 1993; 14: 29-31
52. Bourgois J, Vrijens J. Metabolic and cardiorespiratory responses in young oarsmen during prolonged exercise tests on a rowing ergometer at power outputs corresponding to two concepts of anaerobic threshold. Eur J Appl Physiol 1998; 77: 164-9
53. Steinacker JM, Kellmann M, Böhm BO, et al. Clinical findings and parameters of stress and regeneration in rowers before world championships. In: Lehmann M, editor. Overload, performance incompetence, and regeneration in sport. New York: Kluwer Academic/Plenum Publishers, 1999: 71-80
54. Tokmakidis SP, Leger LA, Pilianidis TC. Failure to obtain a unique threshold on the blood lactate curve during exercise. Eur J Appl Physiol 1998; 77: 333-4
55. Bishop D, Jenkins DG, Mackinnon LT. The relationship between plasma lactate parameters, W_{peak} and 1-h cycling performance in women. Med Sci Sports Exerc 1998; 30: 1270-5
56. Kindermann W, Simon G, Keul J. The significance of the aerobic-anaerobic transition for the determination of workload intensities during endurance training. Eur J Appl Physiol 1979; 42: 25-4
57. Brooks GA. Anaerobic threshold: review of the concept and directions for future research. Med Sci Sports Exerc 1985; 17: 22-31
58. Yoshida T, Chida M, Ichioka M, et al. Blood lactate parameters related to aerobic capacity and endurance performance. Eur J Appl Physiol 1987; 56: 7-11
59. Coyle EF, Martin WH, Ehsani AA, et al. Blood lactate threshold in some well-trained ischaemic heart disease patients. J Appl Physiol 1983; 54: 18-23
60. Beaver WL, Wasserman BJ, Whipp BJ. Improved detection of lactate threshold during exercise using a log-log transformation. J Appl Physiol 1985; 59: 1936-40
61. Cheng B, Kuipers AC, Snyder HA, et al. A new approach for the determination of ventilatory and lactate thresholds. Int J Sports Exerc 1992; 13: 518-22
62. LaFontaine TP, Londeree BR, Spath WK. The maximal steady state versus selected running events. Med Sci Sports Exerc 1981; 13: 190-2
63. Föhrenbach R, Mader A, Hollmann W. Determination of endurance capacity and prediction of exercise intensities for training and competition in marathon runners. Int J Sports Med 1987; 8: 11-8
64. Wolf WV, Roth W. Validät Spiroergometricher Parameter für die Weltkampfleistung im Rudern. Med Sport 1987; 27: 162-6
65. Coyle EF. Integration of the physiological factors determining endurance performance ability. Exerc Sport Sci Rev 1995; 23: 25-64
66. Stegman H, Kindermann W, Schnabel A. Lactate kinetics and the individual anaerobic threshold. Int J Sports Med 1981; 2: 160-5
67. Beneke R. Anaerobic threshold, individual anaerobic threshold, and maximal lactate steady-state in rowing. Med Sci Sports Exerc 1995; 27: 863-7
68. Cheng B, Kuipers A, Snyder H, et al. A new method for the determination of ventilatory and lactate thresholds. Int J Sports Exerc 1992; 13: 518-22
69. Beaver W, Wasserman B, Whipp B. Improved detection of lactate threshold during exercise using log-log transformation. J Appl Physiol 1985; 59: 1936-40
70. Jürimäe J, Mäestu J, Jürimäe T. Blood lactate response to exercise and rowing performance: relationships in competitive rowers. J Hum Mov Studies 2001; 41: 287-300
71. Coen B, Urhausen A, Kindermann W. Sport specific performance diagnosis in rowing: an incremental graded exercise test in coxless pairs. Int J Sports Med 2003; 24: 428-32
72. Kramer JF, Leger A, Peterson DH, et al. Rowing performance and selected descriptive field and laboratory variables. Can J Appl Physiol 1994; 19: 174-84
73. Howald H. Leistungsphysiologiche Grundlagen des Ruderns. In: Steinacker J, editor. Rudern. Berlin: Springer, 1988: 3-8
74. Secher NH. The physiology of rowing. Int J Sports Med 1983; 1: 23-53
75. Steinacker JM. Methoden für die Leistungsdiagnostik und Trainingssteuerung im Rudern und ihre Anwendung. In: Steinacker J, editor. Rudern. Berlin: Springer, 1988: 39-54
76. Jensen K, Nielsen T. High altitude training does not increase maximum oxygen uptake or work capacity at sea level in rowers. Scand J Med Sci Sport 1993; 3: 56-62
77. Marx U. Untersuchungen zur Trainingssteuerung im Rudern mit einem Mehrstufentest und einem Zweistreckentest [dissertation]. Ulm: Fakultät für Theoretische Medizin, Universität Ulm, 1988
78. Altenburg D. The German talent-identification and talent-development program. In: Perry H, Dieterle I, editors. FISA's youth junior rowing and sculling guide. Lausanne: FISA, 1997
79. Nielsen T, Daigneault T, Smith M. FISA coaching development programme course. Lausanne: FISA, 1993: 13-8
80. Bell GJ, Syrotuik DG, Attwood K, et al. Maintenance of strength gains while performing endurance training in oarsmen. J Appl Physiol 1993; 18: 104-15
81. Bell G, Petersen S, Quinney H, et al. Sequencing of endurance and high-velocity strength training. Can J Sport Sci 1988; 13: 214-9
82. Bell G, Petersen S, Wessel J, et al. Adaptations to endurance and low velocity resistance training performed in a sequence. Can J Sports Sci 1991; 16: 186-92
83. Häkkinen K, Keskinen KL, Alen M, et al. Serum hormone concentrations during prolonged training in elite endurance trained and strength-trained athletes. Eur J Appl Physiol 1989; 59: 233-8
84. Mäestu J, Jürimäe J, Jürimäe T. Hormonal reactions during heavy training stress and following tapering in highly trained male rowers. Horm Metab Res 2003; 35: 109-13
85. Simsch C, Lormes W, Petersen KG, et al. Training intensity influences leptin and thyroid hormones in highly trained rowers. Int J Sports Med 2002; 23: 422-7
86. Urhausen A, Kullmer T, Kindermann W. A 7-week follow-up study of the behavior of testosterone and cortisol during the competition period in rowers. Eur J Appl Physiol 1987; 56: 528-33
87. Urhausen A, Gabriel H, Kindermann W. Impaired pituitary hormonal response to exhaustive exercise in overtrained endurance athletes. Med Sci Sports Exerc 1998; 30: 407-14
88. Urhausen A, Gabriel H, Kindermann W. Blood hormones as markers of training and overtraining. Sports Med 1995; 20: 251-76
89. Viru A. Hormones in muscular activity. Boca Raton (FL): CRC Press, 1985

90. Fry RW, Morton AR, Garcia-Webb P, et al. Monitoring exercise stress by changes in metabolic and hormonal response over 24-h period. Eur J Appl Physiol 1991; 63: 228-34
91. Hackney AC, Sinning WE, Bruot BC. Reproductive profiles of endurance-trained and untrained males. Med Sci Sports Exerc 1988; 20: 60-5
92. Hoogeveen AR, Zonderland ML. Relationships between testosterone, cortisol and performance in professional cyclists. Int J Sports Med 1996; 17: 423-8
93. Vervoorn C, Quist AM, Vermulst LJ, et al. The behavior of the plasma free testosterone/cortisol ratio during a season of elite rowing training. Int J Sports Med 1991; 12: 257-63
94. Mackinnon LT, Hooper SL, Jones S, et al. Hormonal immunological, and hematological responses to intensified training in elite swimmers. Med Sci Sports Exerc 1997; 29: 1637-45
95. Flynn MG, Pizza FX, Boone JM, et al. Indicies of training stress during competitive running and swimming seasons. Int J Sports Med 1994; 15: 257-63
96. Steinacker JM, Laske R, Hetzel WD, et al. Metabolic and hormonal reactions during training in junior oarsmen. Int J Sports Med 1993; 14: 24-8
97. Jürimäe J, Jürimäe T, Purge P. Plasma testosterone and cortisol responses to prolonged sculling in male competitive rowers. J Sport Sci 2001; 19: 893-8
98. Adlercreutz H, Härkonen M, Kuoppasalmi K, et al. Effect of training on plasma anabolic and catabolic steroid hormones and their response during physical exercise. Int J Sports Med 1986; 7: 27-8
99. Härkonen N, Kuoppasalmi K, Näveri H, et al. Biochemical indicators in diagnosis of overstrain condition in athletes. In: Sports Med Exerc Sci Proceedings of Olympic Scientific Congress; 1984 Jul; Eugene (OR)
100. Euler US, Hellner S. Exertion of noradrenaline and adrenaline in muscular work. Acta Physiol Scand 1952; 26: 183-91
101. Galbo H. Hormonal and metabolic adaptation to exercise. Stuttgart: Thieme, 1983: 2-27
102. Kindermann W, Schnabel A, Schmitt WM, et al. Catecholamines, growth hormone, cortisol, insulin and sex hormones in anaerobic and aerobic exercise. Eur J Appl Physiol 1982; 49: 389-99
103. Lehmann M, Schmid P, Keul J. Plasma catecholamines and blood lactate accumulation during incremental exhaustive exercise. Int J Sports Med 1985; 6: 78-81
104. Holmquist N, Secher N, Sander-Jensen K, et al. Sympathoadrenal and parasympathietic responses to exercise. J Sport Sci 1986; 4: 123-8
105. Jensen K, Secher NH, Fiskerstrand A, et al. Influence of body weight on physiologic variables measured during maximal dynamic exercise. Acta Physiol Scand 1984; 121: 39-43
106. Urhausen A, Weiler B, Kindermann W. Heart rate, blood lactate, and catecholamines during ergometer and on water rowing. Int J Sports Med 1993; 14: 20-3
107. Friedman JM, Halaas JL. Leptin and the regulation of body weight in mammals. Nature 1998; 395: 763-70
108. Flier JS. Clinical review 94: what's in a name? In search of leptin´s physiologic role. J Clin Endocrinol Metab 1998; 83: 1407-13
109. Steinacker JM, Lormes W, Reissnecker S, et al. New aspects of the hormone and cytokine responses to training. Eur J Appl Physiol 2004; 91: 382-91
110. Essig DA, Alderson NL, Ferguson MA, et al. Delayed effects of exercise on the plasma leptin concentration. Metabolism 2000; 49: 395-9
111. Hickey MS, Considine RV, Israel RG, et al. Leptin is related to body fat content in male distance runners. Am J Physiol 1996; 271: 938-40
112. Jürimäe J, Jürimäe T. Leptin responses to short term exercise in college level male rowers. Br J Sports Med 2005; 39: 6-9
113. Noland RC, Baker JT, Boudreau SR, et al. Effect of intense training on plasma leptin in male and female swimmers. Med Sci Sports Exerc 2001; 33: 227-31
114. Mäestu J, Jürimäe J, Jürimäe T. Effect of heavy increase in training stress on the plasma leptin concentration in highly trained male rowers. Horm Res 2003; 59: 91-4
115. Jürimäe J, Mäestu J, Jürimäe T. Leptin as a marker of training stress in highly trained male rowers? Eur J Appl Physiol 2003; 90: 533-8
116. Petibois C, Cazorla G, Poortmans JR, et al. Biochemical aspects of overtraining in endurance sports. Sports Med 2002; 32: 867-78
117. Desgorces F, Chennaoui M, Gomez-Merino D, et al. Leptin response to acute prolonged exercise after training in rowers. Eur J Appl Physiol 2004; 91: 677-81
118. Considine RV. Weight regulation, leptin and growth hormone. Horm Res 1997; 48: 116-21
119. Jürimäe J, Hoffmann P, Jürimäe T. Plasma adiponectin response to sculling exercise at individual anaerobic threshold in college level male rowers. Int J Sports Med. In press
120. Jürimäe J, Purge P, Jürimäe T. Adiponectin is altered after maximal exercise in highly trained male rowers. Eur J Appl Physiol 2005; 93: 502-5
121. Urhausen A, Kindermann W. Diagnosis of overtraining: what tools do we have? Sports Med 2002; 32: 95-102
122. Viru A, Viru M. Biochemical monitoring of sport training. Champaign (IL): Human Kinetics, 2002
123. Buckler JMH. The relationship between changes in plasma growth hormone levels and body temperature occurring with exercise in man. Biomedicine 1973; 19: 193-7
124. Sutton JR, Coleman MJ, Casey J, et al. The hormonal response to physical exercise. Aust Ann Med 1969; 18: 84-90
125. Mäestu J, Jürimäe J, Jürimäe T. Hormonal response to maximal rowing before and after heavy increased training volume in highly trained rowers. J Sports Med Phys Fitness 2005; 45: 121-6
126. Urhausen A, Kindermann W. Monitoring of training by determination of hormone concentration in the blood-review and perspectives. In: Liesen H, Weiss M, Baum M, editors. Regulations-und Repairmechanismen. Köln: Deutcher Ärzte-Verlag, 1994: 551-4
127. Hartmann U, Mester J. Training and overtraining markers in selected sport events. Med Sci Sports Exerc 2000; 32: 209-15
128. Morgan WP, Brown DR, Raglin JS, et al. Physiological monitoring of overtraining and staleness. Br J Sports Med 1987; 21: 107-14
129. Borg G. Perceived exertion and pain rating scales. Champaign (IL): Human Kinetics, 1998
130. McNair DN, Lorr M, Droppelman LF. Profile of mood states: manual. San Diego (CA): Educational and Industrial Testing Service, 1992
131. Kellmann M, Kallus KW. The recovery-stress questionnaire for athletes: user manual. Champaign (IL): Human Kinetics, 2001
132. Marriott HE, Lamb KL. The use of ratings of perceived exertion for regulation exercise levels in rowing ergometry. Eur J Appl Physiol 1996; 72: 267-71
133. Urhausen A, Gabriel HH, Weiler B, et al. Ergometric and psychological findings during overtraining: a long-term fol-

low-up study in endurance athletes. Int J Sports Med 1998; 19: 114-20
134. Smith DJ, Norris SR, Hogg JM. Performance evaluation of swimmers. Sports Med 2002; 32: 539-54
135. Verde T, Thomas S, Shephard RJ. Potential markers of heavy training in highly trained distance runners. Br J Sports Med 1992; 26: 167-75
136. Berger BG, Motl RW. Exercise and mood: a selective review and synthesis of research employing the profile of mood states. J Appl Sport Psychol 2000; 12: 46-68
137. Kallus KW, Kellmann M. Burnout in athletes and coaches. In: Hanin Y, editor. Emotions in sport. Champaign (IL): Human Kinetics, 2000
138. Mäestu J, Jürimäe J, Jürimäe T. Psychological and biochemical markers of heavy training stress in highly trained male rowers. Med Sport (Roma) 2003; 56: 95-101
139. Jürimäe J, Mäestu J, Purge P, et al. Relations among heavy training stress, mood state, and performance for male junior rowers. Percept Mot Skills 2002; 95: 520-6
140. Jürimäe J, Mäestu J, Purge P, et al. Changes in stress and recovery after heavy training in rowers. J Sci Med Sport 2004; 7: 335-9
141. Fiskerstrand Å, Seiler K. Training and performance characteristics among Norwegian international rowers 1970–2001. Scand J Med Sci Spots 2004; 14: 303-10
142. Bell GJ, Peterson SR, Quinney HA, et al. The effect of velocity specific strength training on peak torque and anaerobic rowing power. J Sports Sci 1989; 7: 205-14
143. Foster C. Monitoring training in athletes with reference to overtraining syndrome. Med Sci Sports Exerc 1998; 30: 1164-8
144. Haas HS, Schauenstein K. Neuroimmunomodulation via limbic structures-the neuroanatomy of psychoimmunology. Prog Neurobiol 1997; 51: 193-222
145. Brüning JC, Gautam D, Burks DJ, et al. Role of brain insulin receptor in control of body weight and reproduction. Science 2000; 289: 2122-5
146. Withers DJ. Insulin receptor substrate proteins and neuroendocrine function. Biochem Soc Trans 2001; 29: 5252-9
147. Ahima RS, Kelly J, Elmquist JK, et al. Distinct physiologic and neuronal responses to decreased leptin and mild hyperleptinemia. Endocrinology 1999; 140: 4923-31
148. Hackney AC, Sinning WE, Bruot BC. Hypothalamic-pituitary-testicular axis function in endurance trained males. Int J Sports Med 1990; 11: 298-303
149. Steinacker JM, Lehmann M. Clinical findings and mechanisms of stress and recovery in athletes. In: Kellmann M, editor. Enhancing recovery. Champaign (IL): Human Kinetics, 2002: 103-21
150. Lehmann M, Mann H, Gastmann U, et al. Unaccustomed high-mileage vs intensity training-related changes in performance and serum amino acid levels. Int J Sports Med 1996; 17: 187-92
151. Barron JL, Noakes TD, Lewy W, et al. Hypothalamic dysfunction in overtrained athletes. J Clin Endocrinol Metab 1985; 60: 803-6
152. Naessens G, Levevre J, Priessens M. Practical and clinical relevance of urinary basal noradrenaline excretion in the followup of training processes in semiprofessional football players [abstract]. Conference on Overtraining in Sports; 1996; Memphis (TN)
153. Janke W, Wolfgramm J. Biopsychologie von Stress und emotionalen Reaktionen: Ansätze interdisziplinärer Kooperation von Psychologie, Biologie und Medizin. In: Debus G, Erdmann G, Kallus KW, editors. Biopsychologie von Stress und emotionalen Reaktionen. Göttingen: Hogrefe, 1995: 293-349

Correspondence and offprints: Assoc. Prof. *Jaak Jürimäe*, Institute of Sport Pedagogy and Coaching Sciences, University of Tartu, 18 Ülikooli St, Tartu, 50090, Estonia.
E-mail: jaakj@ut.ee

