DISSERTATIONES KINESIOLOGIAE UNIVERSITATIS TARTUENSIS
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PERFORMANCE, MOOD STATE AND SELECTED HORMONAL PARAMETERS DURING THE ROWING SEASON IN ELITE MALE ROWERS

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LIST OF ORIGINAL PUBLICATIONS

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1 INTRODUCTION

Rowing is a strength-endurance type of sport and competition performance depends on different factors such as aerobic and anaerobic power, physical power, rowing technique and race tactics. Accordingly, 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 (Mäestu et al., 2005). Specifically, a typical rowing competition takes place on a 2,000 metre course and lasts for 5–7 minutes depending on the boat class and the performance capacity of an athlete. During the competition race, muscle contraction is relatively slow and about 32–40 duty cycles per minute are used. Maximal power per stroke may be as high as 1,200 W and average power per stroke is about 450–550 W (Steinacker, 1993). During competition, a rower depends mostly on his/her aerobic metabolism because energy stores and glycolysis are limited to cover the energy demand only for approximately 1.5–2.0 minutes (Mäestu et al., 2005; Steinacker, 1993). Aerobic power can be defined as the maximal oxygen consumption (VO_{2max}) as estimated during a performance that lasts from two to 10 minutes (Jensen, 1994). According to Roth et al. (1983), the energy of the 2,000 metre rowing race was provided 67% aerobically and 33% anaerobically, 21% alactic and 12% lactic. Maximal anaerobic alactic and aerobic power have been reported to characterize rowing performance best on a 2,000 metre course on single sculls (Jürimäe et al., 1999).

The training of successful rowers has to be built up on the focus of aerobic training with the proper relation with specific strength and anaerobic training. However, endurance training is the mainstay of success in rowing (Mäestu et al., 2005). For the 2,000 metre rowing 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 (Hagerman and Staron, 1983). The specific rowing training of the international rower has to be approximately 70% of the whole training time. A dose-response relationship has been demonstrated between training and performance in athletes (Bannister et al., 1997). For rowers, it has been found that the trained kilometers on water are positively related to the success in championships (Steinacker et al., 1998). Prolonged extensive rowing on water makes up the largest part of training programmes in rowers (Steinacker et al., 1998) and the risk of overtraining increases with daily training time and in particular with monotonic training (Jürimäe et al., 2002). Rowing training should be organized in periods of stressful heavy training to induce sufficient training response followed by a period of lower load to allow recovery and an increase in performance (Jürimäe et al., 2003; Steinacker et al., 2000). When training stimulus becomes excessive with insufficient recovery between training sessions, the athlete may become overtrained (Mujika et al., 1996; Mäestu et al., 2003). Optimal performance is only achieved when athletes optimally balance training stress with adequate recovery (Mäestu et al. 2005;

Urhausen and Kinderman, 2002). The main feature of the overtraining syndrome is a graded decrease in performance resulting from an imbalance between anabolic and catabolic hormones (Urhausen et al., 1995). In addition, the mood state of an athlete seems to be closely related to the actual performance (Mäestu et al., 2005, 2006). To date, all measured blood biochemical and pscyhometric parameters have either shown inconsistent trends, or there are too few studies to make definite conclusions. Furthermore, most of the studies on training monitoring in rowers have investigated only one microcycle and the following recovery period and to date there appears to be no single marker of training monitoring and possible overtraining in rowers (Mäestu et al., 2005). Accordingly, the aim of the present dissertation was to integrate the hormonal and psychological approaches of training monitoring during the course of the preparatory as well as the competition period in elite male rowers preparing for the Olympic Games; and to investigate possible relationships between training volume, basal hormone levels and perceived mood state in elite male rowers.

2 REVIEW OF LITERATURE

2.1 Training organization in rowing

Athletes and coaches are motivated to apply maximal tolerable training loads in an effort to break previous performance barriers. Even a small (1%) increase in performance capacity improves the results in competition (Hopkins et al., 1999). Rowing training is mainly focused on improving aerobic capacity with the proper relationship of anaerobic and strength training (Mäestu et al., 2005; Steinacker, 1993). For the international class rower, the goals of the annual training cycle are to enhance all relevant aspects of physical capacity, engrain technical mastery, and then enable the athlete to mobilize these capacities and deliver maximal performances during international championship regattas (Fiskerstrand and Seiler, 2004; Steinacker et al., 1998). While athletes maintain a high level of physical fitness throughout the year, the high training volume exposure during the winter preparatory period and early summer is at the threshold of what is tolerable (Mäestu et al., 2005; Steinacker, 1993). Performance capacity is usually depressed during the overreaching phases to facilitate the supercompensation effect prior to key competitions through effective tapering (Mäestu et al., 2005). It has to be taken into account that the performance improvement has continued over the last decade, despite the fact that no meaningful equipment changes have occurred since 1992. For example, in the 2002 World Championships, all-time world best performance times were achieved in nine of 24 events. These developments suggest that the physical capacity of the rowers continues to improve (Fiskerstrand and Seiler, 2004). However, experimental studies recreating the training loads and time frames relevant for international class endurance athletes, including rowers, are almost absent from scientific literature.

Endurance training (training at blood lactate concentration below anaerobic threshold of 4 mmol/l) is the mainstay of success in rowing (Mäestu et al., 2005; Nielsen et al., 1993; Secher, 1993; Steinacker, 1993). During the preparatory period, which usually starts in October, the extensive aerobic endurance training may amount up to 90% of the total training time (Nielsen et al., 2002). Furthermore, it appears that during the preparatory period, rowers should deemphasize resistance training at low velocities and emphasize power development at higher velocities (Bell et al., 1991). It is necessary to train more specifically for the types and velocities of movements used in the rowing technique and at speed necessary to mimic the competitive pace (Hagerman, 2000). The main period for the developing strength-endurance is from January to March (Nielsen et al., 1993). It is interesting to note that over the last three decades, the maximal aerobic capacity of international medal winners in rowing appears to have increased by more than 10%, based on the data from 28 international rowing medal winners from Norway collected between 1970 and

2000 (Fiskerstrand and Seiler, 2004). This has lead to VO_{2max} value in heavyweight rowers of 6.5 to 7.0 l/min (or 72–78 ml/min/kg) at a body mass of over 90 kg (Fiskerstrand and Seiler, 2004). During the same time, annual training volume has increased by about 20%, with most of the increase occurring during the preparatory period. International Norwegian medal winners in rowing currently train between 1,100 and 1,200 hours/year (Fiskerstrand and Seiler, 2004). In fact, Roth (1979) reported training volumes over 1,000 hours/year already in the 1960s and 1970s among German rowers.

The training organization trends during the preparatory period in rowers (Mäestu et al., 2005) are consistent with available data collected on athletes from other endurance sports such as marathon running (Billat et al., 2001), cross-country skiing (Downing et al., 2003; Nilsson et al., 2004; Seiler and Kjerland, 2006; Verges et al., 2004) and cycling (Filaire et al., 2004; Schumaker and Mueller, 2002), suggesting a polarized pattern of training organization. Large increases in basic endurance training at intensities clearly below the first lactate turn point of 2 mmol/l have been utilized together with training at intensities requiring 90–95% of VO_{2max}, most often in the form of long interval bouts lasting 4–8 minutes and relatively little training volume is performed at the intensity of the anaerobic threshold of 4 mmol/l (Fiskerstrand and Seiler, 2004). For example, Hartman and Mader (1990) reported the data of extensive endurance training collected on national team members of West Germany during preparatory period. More than 90% of the training performed by these international level athletes was performed at an intensity below the first lactate turn point of 2 mmol/l and 7% was performed at an intensity of 2 to 4 mmol/l (Hartman and Mader, 1990). Assuming similar active muscle mass, the athletes here training at 65% of their VO_{2max} would have about the same muscular oxidative flux as an untrained person performing at or near VO_{2max} (Hood et al., 2000). Many authors claim that endurance training is only effective if it is done at a lactate concentration between 2.5 and 3.5 mmol/l (Lormes et al., 1988; Steinacker, 1988; Urhausen et al., 1986) or 4 mmol/l (Billat 2001; Fritsch, 1981; Hirsch, 1977;). About 75% of the training sessions in endurance athletes is performed with essentially the entire session below the first ventilatory threshold (≤2.0 mmol/l blood lactate) (Seiler and Kjerland, 2006). The result of most intensity checks made in the field shows that coaches generally assume that long distance training should be made at a lactate concentration of about 3 mmol/l or just under 4 mmol/l (Hartmann et al., 1990).

The competition period usually starts in April and culminates for elite rowers in late August or early September with the World Championships (Nielsen et al., 2002; Mäestu et al., 2005; Slater et al., 2005). During the competition period, aerobic training is still the most important amounting to about 70% of the total training volume (Mäestu et al., 2005; Nielsen et al., 1993). Nielsen et al. (1993) have suggested that the remaining 25% of the training during the competitive period is aerobic-anaerobic (blood lactate concentration from 4 to 8 mmol/l) and the rest is purely anaerobic (blood lactate concentration above 8 mmol/l). Hartman and Mader (1990) reported that the percentage of training volume performed at an intensity eliciting <2 mmol/l blood lactate concentration continued to account for nearly 75% of total training sessions compared to only 18% of training sessions performed at intensities between 2 and 4 mmol/l in West German international level rowers during competitive period. Intense endurance training above the anaerobic training of 4 mmol/l may be important for the improvement of VO_{2max} during the competitive season, but should not amount to higher than 10% of the total training volume (Lormes et al., 1988; Steinacker, 1993).

The training of successful rowers is characterized by extensive as well as intensive endurance training with up to 70–80% of the total training time spent on the water (Mäestu et al., 2005; Secher, 1993; Steinacker, 1993). However, the amount of time of specific on-water rowing training should increase together with the qualification of the rower. Altenburg (1997) has suggested that 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. While strength training is approximately 20% for an 18-year-old and 16% for an adult athlete, general conditioning training is in the range of 26–33% (Altenburg, 1997). It is important to increase specific rowing training with increased training experience (Mäestu et al., 2005; Secher, 1993; Steinacker, 1993).

During the last 30 years, long-distance training volume (i.e., running, cross-country skiing, ergometer rowing, on-water rowing) has increased in each decade in successful Norwegian rowers (Fiskerstrand and Seiler, 2004). Furthermore, strength-endurance training, using movements such as squats performed at approximately 50% of one repetition maximum (1RM) for up to 50 repetitions in one set, has increasingly been used in the 1980s and 1990s. The increase in training volume from 924 (range from 600 to 1,020) hours/year during the 1970s to 1128 (range from 1,104 to 1,200) hours/year in the 1990s in international Norwegian medal winners has mainly been due to increases in long-distance endurance training and strength-endurance training. During the competition period, long-distance training in the boat has increasingly been emphasized from the 1970s to 1990s. In contrast, the absolute and relative volume of boat training at race pace and/or above race pace intensities has been reduced, from about 23 hours/month of race pace or over-speed training in the 1970s to less than 7 hours/month during the 1990s (Fiskerstrand and Seiler, 2004).

In rowing, the problem with studying the specific training effects is the complexity of the goals of training because different capacities (aerobic, anaerobic, power, strength, technical skills, tactical skills) have to be improved (Mäestu et al., 2005; Secher, 1993; Steinacker et al., 1998). This may cause timing problems because several capacities cannot be developed simultaneously and/or problems with monitoring the process of different training effects (Mäestu et al., 2005). For successful rowers, one of the most important tasks is the maintenance of strength gains while training to enhance aerobic endurance capacities simultaneously (Bell et al., 1993). It has been suggested that a sequence of resistance training prior to endurance training should be preferred (Bell et al., 1991). In addition, almost all rowers also use unspecific and cross training to increase training tolerance and to avoid possible overtraining (Mäestu et al., 2005). The main advantage of cross training appears to be the fact that it decreases the monotony of training while simultaneously maintaining the physical capacity of rowers (Secher, 1993).

In conclusion, endurance training is the mainstay in rowing. The specific training of the international level rower has to be approximately 70% of the total training time. The optimal training organization for maximal performance appears to be a polarized model of training with about 75% of training performed well below the anaerobic threshold of 4 mmol/l and 15–20% well above that intensity.

2.2 Training monitoring in rowing

The purpose of athletic training is to improve performance. A dose-response relationship has been demonstrated between training and performance (Bannister et al., 1997). However, the evaluation of the overall state of an athlete and appointing appropriate training load without leading the athlete to the overtraining syndrome is already one of the most complicated tasks in coaching sciences (Hooper et al., 1999; Mäestu et al., 2005). For rowers, it has been found that the trained kilometers are positively related to the success in championships (Steinacker, 1993). Prolonged extensive rowing on-water makes up the largest part of training programmes in rowers (Mäestu et al., 2005; Steinacker et al., 1998) and the risk of overtraining increases with daily training time and particular monotonic training (Fry et al., 1992; Lehmann et al., 1997; Urhausen and Kindermann, 2002). To date, different performance (Ingham et al., 2002; Jürimäe et al., 2000), blood biochemical (Jürimäe et al., 2001; Mäestu et al., 2003; Simsch et al., 2002) and psychological (Hooper et al., 1999; Jürimäe et al., 2002; Kellmann and Günther, 2001; Mäestu et al., 2006) parameters have been used to monitor training in rowers. However, it has been suggested by Steinacker et al. (2000) that the evaluation of the influence of training should be performed in a multi-level approach using the measurements of performance as well as biological and psychological indices. The main purposes of rowing training monitoring are (Altenburg, 1997; Nielsen et al., 1998):

1. The analysis of the physical capacity of athletes to assess the development of athletes. This is necessary for developing a specific training programmes for rowers;

2. The diagnosis of the performance and trainability of athletes. This is necessary for the boat selection especially in larger boats such as fours and eights; and
3. The evaluation of the volume and intensity of specific training sessions and recovery periods between training sessions in athletes. This is necessary for optimizing the training process and minimizing the risk of overtraining in rowers.

Numerous investigations have been conducted in an attempt to study possible physiological markers of training stress that might subsequently be used to monitor training and prevent possible overtraining syndrome that may be associated with chronic hard training (Chennaoui et al., 2004; Mäestu et al., 2003, 2006; Kellmann and Günther, 2000; Simsch et al., 2002; Steinacker et al., 2000). When training stimulus becomes excessive with insufficient recovery between training sessions, the athlete may become overtrained (Mujika et al., 1996; Mäestu et al., 2003). Optimal performance is only achieved when athletes optimally balance training stress with adequate recovery (Meeusen et al., 2004; Volek et al., 2004). The main feature of the overtraining syndrome is a decrease in performance resulting from an imbalance between anabolic and catabolic hormones, and dysfunctions within the hypothalamus-pituitary-adrenocortical axis (Chennaoui et al., 2004; Petibois et al., 2003; Urhausen et al., 1995). Recently, in addition to clinical findings, the level of perceived recovery-stress state appears to well reflect the state of an athlete (Jürimäe et al., 2002; Kellmann and Kallus, 1999, 2001; Mäestu et al., 2006). It has to be considered that excessive fatigue at first leads to the state of overreaching, which is characterised by transient underperformance and is reversible within a short-term recovery period in one to two weeks and is followed by supercompensation (Kellmann and Kallus, 1999). This appears to be a regular part of athletic training. However, when overreaching is too profound or is extended for too long, the overtraining syndrome may occur, in which the restoration of performance capacity may take from several weeks to months (Kellmann and Kallus, 1999). The possibility to use different performance, blood biochemical and psychometric parameters in training monitoring in rowers has been summarized in Table 1.

The accurate analysis and assessment of various performance parameters within the training context is an important process for coaches and sport scientists to include as an integral aspect of the training programme of a rower (Mäestu et al., 2005). A key aspect to consider regarding a performance test is the extent to which it is actually correlated with rowing performance (Smith, 2000). Changes in performance capacity can be assessed during different tests in a rowing boat (Coen et al., 2003; Jürimäe et al., 2001) or on the rowing ergometers (Ingham et al., 2002; Messonnier et al., 1997). Maximum rowing performance during a standardized *2*- (Jensen, 1994; Vermulst et al., 1991),

Table 1. Summary of the proposed parameters in training monitoring (compiled from Mäestu et al., 2005; Urhausen and Kindermann, 2002).

Parameter	Testing	Suitability
Sports-specific performance	Maximal „all-out" test	Golden standard; regular testing may be problematic in rowing training.
Ergometer performance	Anaerobic threshold, maximal power, maximal oxygen consumption	Does not diagnose overtraining syndrome, but targets other training errors.
Mood state profile	At rest	Very sensitive, but may be manipulated when not properly used.
Subjective complaints	At rest, after exercise	"Heavy legs": very common; „Sleep disordes": less common; may be manipulated when not properly used.
Borg-scale	Exercise	Rather small changes in rowing training.
Heart rate	At rest, during exercise	May indicate other problems (e.g., infection). Rather small changes in rowing training.
Lactate	Submaximal exercise, maximal exercise	Does not diagnose overtraining syndrome, but excludes other training errors. Typical change in rowing training.
Creatine kinase	At rest, after exercise	Increase may indicate muscular overuse or prolonged carbohydrate depletion.
Testosterone	At rest, after exercise	Large increase may indicate high physiological strain.
Growth hormone	At rest, after exercise	Large increase may indicate high physiological strain.
Cortisol	At rest, after exercise	Large increase may indicate high physiological strain. A decrease measured at rest indicates the late sign of overtraining syndrome.

6- (Hagerman et al., 1978), and *7*- (Snegovskaya and Viru, 1993) *minute, 500* (Smith, 2000; Hagerman, 2000), *2,000* (Jürimäe et al., 1999; Russell et al., 1998; Schabort et al., 1999; Womack et al., 1996), *2,500* (Jürimäe et al., 2000; Messonnier et al., 1997) and *6,000* (Hagerman, 2000; Jürimäe et al., 2005) *metre* all-out tests have been used to evaluate the performance capacity of rowers. In contrast, Steinacker et al. (1998) argued that maximal performance over most oftenly used standardized 2,000 metre or 6-minute all-out test is subject to motivation of the rower tested. They raised a question that a more reliable test such as fast ramp test could be used for measuring rowing performance, because they fit into a training programme more easily (Steinacker et al., 1998). However, the experience in our laboratory has demonstrated that 1 minute of maximal rowing ergometer test has no relationship with changes in rowing ergometer performance over 2,000 metre distance after heavy training periods (Mäestu et al., 2005).

Many researchers have evaluated 2,000 metre performance predictive parameters for rowers including stepwise incremental test to exhaustion for the determination of the oxygen consumption and blood lactate response to exercise (Cosgrove et al., 1999; Ingham et al., 2002; Jürimäe et al., 2000; Perkins and Pivarnik, 2003; Riechman et al., 2002; Womack et al., 1996). All these studies have reported either VO_{2max} (in l/min) or maximal aerobic power (in W) to be an important parameter in predicting performance over a 2,000 metre rowing ergometer distance. While maximal blood lactate concentration obtained during the incremental test to exhaustion shows the production of the anaerobic glycolytic energy pathway (Hartmann et al., 1988; Jürimäe et al., 2000; Shephard, 1998). However, together with the increasing maximal aerobic power, which also increases the level of the intensity at anaerobic threshold, maximal blood lactate concentration decreases due to the lesser amount of energy production through anaerobic glycolytic pathway (Beneke, 2003; Hagerman, 2000; Shephard, 1998; Steinacker, 1993). This demonstrates that anaerobic threshold is an important parameter in rowing training monitoring (Bourgois and Vrijens, 1998; Messonnier et al., 1997; Shephard, 1998; Steinacker, 1993). Anaerobic threshold is the workload that can be performed by the oxidative metabolism and at which blood lactate production and release are balanced during continuous exercise (Hautala et al., 2004; Kindermann et al., 1979; Tokmakidis et al., 1998). To determine anaerobic threshold, numerous concepts and definitions have been presented (Mäestu et al., 2005a). Steinacker (1993), and Wolf and Roth (1987) have reported that the power that elicits a blood lactate concentration of 4 mmol/l is the most predictive parameter of rowing performance in trained rowers, especially in small boats, such as singles and doubles. In successful rowers, the anaerobic threshold of 4 mmol/l is in the range of 75–85% of their maximal aerobic power (Mäestu et al., 2005; Secher, 1993; Steinacker, 1993). In another study, Jürimäe et al. (2001) using 21 male national standard rowers found that the anaerobic threshold value of 3.7 $mmol.l^{-1}$ determined by the LT_{LOG} method (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]) represented the 2,000 metre all-out rowing ergometer performance best. Furthermore, as power at a blood lactate level of 4 mmol/l has not been found to represent a steady-state workload in rowing (Beneke, 1995; Bourgois and Vrijens, 1998), anaerobic threshold determined by the LT_{LOG} method may be a better indicator for selecting training intensities without the accumulation of blood lactate (Jürimäe et al., 2001*)*. The heart rates (HR) at anaerobic threshold determined during the laboratory testing are valid for monitoring on-water training in rowers (Bourdin et al., 2004; Jürimäe et al., 2005)

It has to be considered that performance capacity is depressed during the phases of heavy training stress in rowers to facilitate a supercompensation effect (Mäestu et al., 2005). Specifically, repeated high training volume may facilitate long-term endocrine adaptations (Kjaer, 1998) and greater capacity for sympathetic mobilization following supercompensation training periods and tapering for major races (Fiskerstrand and Seiler, 2004). In accordance with this, the acute responses of the hormones of hypothalamus-pituitary-adrenocortical axis during exercise stress are related to the intensity and duration of specific exercise stimulus as well as to the physical condition of these athletes (Hoogeveen and Zonderland, 1996; Jürimäe and Jürimäe, 2001; Mäestu et al., 2003). The assessment of these circulating hormone concentrations during prolonged training has also received considerable attention due to its implications for general adaptive mechanisms and for physical conditioning (Mäestu et al., 2003; Urhausen and Kindermann, 2002; Vervoorn et al., 1991). Hormonal mechanisms most assuredly help to mediate short-term homeostatic control and long-term adaptations to training in athletes (Häkkinen et al., 1988; Mäestu et al., 2003; Vervoorn et al., 1991). For example, growth hormone and cortisol exert an essential role both in short-term (control of utilization 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 (Urhausen and Kindermann, 2002).

Many investigations have studied the effects of different kind of prolonged training on the hormones of the hypothalamus-pituitary-adrenocortical axis (Chennaoui et al., 2004; Ferguson et al., 2004; Grego et al., 2004; Mero et al., 1990; Vervoorn et al., 1991). Prolonged high volume endurance training regimen causes an increase and a decrease in the fasting levels of cortisol and testosterone, respectively (Kivlighan et al., 2005; Vervoorn et al., 1991). In addition, resting cortisol levels have also been reported to remain relatively unchanged after prolonged endurance training in male athletes (Mackinnon et al., 1997; Mäestu et al., 2003). In another study, a further improvement of performance capacity was associated with increased growth hormone and cortisol levels (Snegovskaya and Viru, 1993). The results of these studies suggest that prolonged training may have a variable influence on the hormones of the hypothalamus-pituitary-adrenocortical axis and it has to be considered that there is still no valid single hormone marker that would help us to prevent overtraining.

Previously, it has been stated that a condition of overstrain may exist in an athlete if at least one of the following criteria are fulfilled: 1) free testosterone/cortisol ratio lower than 0.35×10^{-3}; and/or 2) a decrease in the free testosterone/cortisol ratio of ≥30% (Adlercreutz et al., 1986; Härkonen et al., 1984). In rowers, no relationships were observed between the free testosterone/cortisol ratio and ergometer rowing performance parameters in international level male rowers during a rowing season (Vervoorn et al., 1991). Furthermore, Vervoorn et al. (1991) 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. It appears that the free testosterone/cortisol ratio seems to be more useful as an indicator for a status of insufficient time to recover from training (Vervoorn et al., 1991).

It has been suggested that basal cortisol levels may be used as a marker of heavy training stress in athletes as basal cortisol levels represent the endpoint of the hypothalamus-pituitary-adrenocortical axis (Barron et al., 1985; Hackney, 1999). Increased basal levels of cortisol have been linked to normal stress response to heavy training, while a decrease in basal cortisol has been used as a late sign of overtraining (Salvador et al., 2003; Urhausen and Kindermann, 2002). In addition to the hormonal values, the amount of psychologically related stress seems to reflect well the clinical state of athletes (Jürimäe et al., 2002; Kellmann and Kallus, 1999; Mäestu et al., 2006). Furthermore, variation in cortisol has been linked to changes in mood, sleep quality, and recovery activities (Barron et al., 1985; Jürimäe et al., 2002). These findings suggest that training monitoring in elite athletes should involve valid hormonal as well as psychological indices to assess adaptation to certain training load.

To date, the most common psychometric instruments used in athletes to monitor their performance and training are (Mäestu et al., 2005): 1) the one-item Borg ratio scale (Borg, 1998), which was developed to subjectively measure the intensity of the exercise; 2) the Profile of Mood States (POMS) (Hooper et al., 1999; McNair et al., 1992), which measures only current stress; and 3) the Recovery-Stress Questionnaire for Athletes (RESTQ-Sport) (Kellmann and Kallus, 2001), which allows measuring both subjectively perceived stress and recovery. A highly consistent relationship between the Borg ratio scale perceptions of exertion on a rowing ergometer and HR has been reported in rowers (Marriot and Lamb, 1996). However, a close analysis of ratings of perceived exertion reveals only minor changes in overtrained athletes (Urhausen and Kindermann, 2002). Furthermore, it is difficult to interpret what causes the change of the scale after standardized exercise test and proper intervention is complicated (Kellmann, 2002). Consequently, the Borg ratio scale is not suitable for monitoring training in highly trained rowers (Mäestu et al., 2005). Many studies have reported that mood state (e.g., motivation and striving for success) seems to be closely related to the actual performance of athletes (Kellmann and Kallus, 1999; Morgan et al., 1987; Mäestu et al., 2005, 2006). However, it has to be stated that five of the six scales of POMS measure the negative (*Tension, Anger, Fatigue, Depression* and *Confusion*) and one positive (*Vigour*) mood characteristics (McNair et al., 1992). Furthermore, Berger and Motl (2000) suggested that a decrease in a negative mood state may not necessarily indicate mood benefits. According to Mäestu et al. (2005), when using POMS as the psychometric tool to monitor the mood states of rowers, the main focus is on stress-related behaviour and it might not be appropriate to evaluate the recovery of rowers.

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 better performance (Kellmann and Kallus, 2001). Recovery and stress should be treated using a multi-level approach and 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 (Kellmann and Günther, 2000). The RESTQ-Sport has been reported as one of the few questionnaires that allows measuring the complexities of stress and recovery (Kellmann and Kallus, 2001). This questionnaire has been successfully used for monitoring changes in stress and recovery over different training periods for rowers (Jürimäe et al., 2002; Kellmann and Günther, 2000; Mäestu et al., 2006). For example, using elite rowers during their preparation for Olympic Games, Kellmann and Günther (2000) found that alterations in training load were reflected by changes in specific stress and recovery subscales of the questionnaire. In addition, a close relationship between the recovery-stress state and performance results has been found in swimmers (Kellmann et al., 1996).

In summary, there is no single marker of training monitoring and possible overtraining in rowers. However, the main principle of testing the athlete is minimum testing and maximum reliable information. The closer link between a parameter tested and a specific performance, the more value the testing has (Mäestu et al., 2005). Furthermore, more longitudinal studies with elite rowers are needed to find out more specific markers of training monitoring. The following chapter gives a short overview of the longitudinal studies reported in rowers.

2.3 Longitudinal training studies in monitoring of rowing training

There are not very many longitudinal studies that deal with training monitoring of rowers (Table 2). These studies can be grouped in three major groups: 1) studies that last no longer than one week; 2) studies that are 3–8 weeks in duration; and 3) studies that are 6–12 months in duration. 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 and drawing more definite conclusions more difficult. In addition, a recent study by Fiskerstrand and Seiler (2004) reported the changes in training and performance of elite Norwegian rowers, medal winners in World Championships over the last 30 years. These kinds of studies are very rare in scientific literature. The

Table 2. Longitudinal studies in rowing training.

	Author (s)	**Year**	**Group (n)**	**Training status**	**Study period**	**Performance**	**Blood parameters**	**Mood state**	**Additional information**
I	Jürimäe et al.	2004	21 M	Competitive	6 days	2000m ergo	Testosterone, cortisol	RESTQ-Sport	Training load
	Kokalas et al.	2004	6 M	Well-trained	5 days	P_{max}, AT	Cortisol, testosterone, growth hormone, creatine kinase		Strength tests, training load
II	Urhausen et al.	1987	6 M 3 W	Well-trained	7 weeks		Testosterone, FTCR, cortisol, urea		Training load
	Fischer et al.	1992	36 M	Elite	23 days		Urea, creatine kinase		Training load
	Steinacker et al.	1993	35 M	Elite	26 days	AT	FTCR, testosterone, urea, creatine kinase, cortisol		Training load
	Kellmann and Günther	1999	6 F 5 M	Elite	3 weeks	Competition	Lactate	RESTQ-Sport	Anthropometry
	Kellmann and Günther	2000	9 M 2 F	Elite	3 weeks			RESTQ-Sport	Training load

Table 2 continued. Longitudinal studies in rowing training.

	Author (s)	Year	Group (n)	Training status	Study period	Performance	Blood parameters	Mood state	Additional information
	Smith	2000	10 M 8 F	Elite	4 weeks	P_{max}	Lactate		Training load
	Steinacker et al.	2000	10 M	Elite	5 weeks	P_{max}, AT	Cortisol, testosterone, aldosterone, luteinaizing hormone, growth hormone, insulin	RESTQ-Sport	Training load
	Kellmann et al.	2001	54 M	Competitive	6 weeks		Lactate, creatine kinase,	RESTQ-Sport; POMS	Training load
	Simsch et al.	2002	5 M	Well-trained	6 weeks	P_{max}, VO_{2max}	Leptin, cortisol, TSH		Training load
	Liu et al.	2003	6 M	Well-trained	8 weeks	2000m ergo, VO_{2max}	Lactate		Training load, muscle biopsy
	Mäestu et al.	2003	12 M	Well-trained	6 weeks	2000m ergo	Cortisol, testosterone, growth hormone, leptin		Training load
	Ebben et al.	2004	26 F	Competitive	8 weeks	2000m ergo, VO_{2max},			Training load

Table 2 continued. Longitudinal studies in rowing training.

	Author (s)	**Year**	**Group (n)**	**Training status**	**Study period**	**Performance**	**Blood parameters**	**Mood state**	**Additional information**
III	Vermulst et al.	1991	6 F	Elite	9 months	P_{max}, AT			Training load
	Vervoorn et al.	1991	6 M	Elite	35 weeks	P_{max}, VO_{2max}	Lactate, testosterone, cortisol		Training load
	Snegovskaya and Viru	1993	30 M	Well-trained	20 months	Competition	Cortisol, growth hormone		
	Pearson et al.	1995	8 M	Well-trained		Competition	Adrenaline, cortisol, noradrenaline		Training load
	Baylor and Hackney	2003	17 F	Competitive	20 weeks		fT3, fT4, TSH, leptin		Training load
	Petibois et al.	2003	13 M	Well-trained	47 weeks	VO_{2max}	Glucose, lactate, urea		Training load
	Desgorces et al.	2004	11 M	Competitive	8 months	VO_{2max}	Leptin, insulin		Anthropometry, training load
	Petibois et al.	2004	20 M	Well-trained	47 weeks	P_{max}, 2000m ergo	Glucose, lactate, triglycerides, glycerol, insulin, leptin		Anthropometry

F-female; M-male; P_{max}-maximal aerobic power; AT-anaerobic threshold; $VO2_{max}$-maximal oxygen consumption; 2000m ergo-maximal 2000 metre rowing ergometer performance; TSH-thyroid stimulating hormone; FTCR-free testosterone: cortisol ratio; fT3-free triothyronine; fT4-free thyroxine; RESTQ-Sport-Recovery-Stress Questionnaire for Athletes; POMS-Profile of Mood States.

one week studies in rowers usually investigate the response of training load on specific performance and blood parameters in rowers (Jürimäe et al., 2002; Kokolas et al., 2004). However, this very short time period does not allow to make any conclusions about the pattern and sensitivity of different measured parameters that could be suitable for training monitoring in rowing. The studies that have monitored rowing training up to 8 weeks (i.e., two mesocycles) assess only the training response to specific endurance and/or strength training period (Mäestu et al., 2003; Simsch et al., 2002) and measurements are performed only before and after a specific training period (Liu et al., 2003; Simsch et al., 2002). In addition, studies that are performed to monitor the whole season of training in rowers have measured different parameters after every 5 weeks (Vermulst et al., 1991; Vervoorn et al., 1991) or the interval between two sampling times was even five months (Snegovskaya and Viru, 1993). These prolonged studies on training monitoring have been mostly performed during preparatory period. In addition, there are some studies that have monitored the competition period in rowers (Kellmann and Günther, 2000; Kellmann and Kallus, 1999; Steinacker et al., 2000). However, these studies have focused more on psychometric measurements. There are also very few studies (Jürimäe et al., 2004; Mäestu et al., 2003; Steinacker et al., 2000) that have measured performance, blood biochemical and psychometric parameters at the same time to allow the multi-level assessment of training status in rowers (Mäestu et al., 2005; Steinacker et al., 2000).

In conclusion, there is a lack of studies in elite male rowers that monitor the athletes throughout the whole rowing season using different performance, blood biochemical and psychometric parameters simultaneously. Further studies are still needed in elite athletes.

3 AIM AND PURPOSES OF THE STUDY

The general aim of the present investigation was to further evaluate specific markers that could be used for monitoring performance and training in elite male rowing during the rowing season.

According to the general aim the specific purposes of the investigation were to:

1. determine the specific body composition, physical performance and psychological factors contributing to 2,000-m maximal sculling performance in elite male rowers;
2. investigate the response of perceived recovery-stress state and selected blood biochemical parameters to training stress during the course of the preparatory period in elite male rowers;
3. investigate the response of perceived recovery-stress state and selected blood biochemical parameters during World Cup races before major competitions in elite male rowers;
4. investigate possible relationships between training volume, perceived recovery-stress state and hormone levels in elite male rowers.

4 MATERIAL AND METHODS

4.1 Subjects

In total, 11 elite male rowers, members of and candidates for the Estonian National Team participated in this investigation (Table 3). The rowers were informed of the possible risks involved in the experiments before providing their written consent to participate in the experiment as approved by the Medical Ethics Committee of the University of Tartu. All rowers had long and regular endurance training experience (7.4±3.8 years) and they were competing at national and/or international level.

Table 3. Physical characteristics of the subjects.

Sub-ject	Age (years)	Training experience (years)	Height (cm)	Body mass (kg)	Fat free mass (kg)	Fat mass (kg)	Body fat %
1	17	4.0	194	90.8	81.4	9.4	10.4
2	18	4.0	189	88.7	78.6	10.1	11.4
3	19	4.0	186	93.9	81.3	12.6	13.4
4	21	6.0	185	92.1	79.8	12.3	13.3
5	18	4.0	194	86.3	77.3	9.0	10.4
6	18	4.0	197	88.7	79.3	9.4	10.6
7	25	9.0	197	93.4	82.0	11.5	12.3
8	24	12.0	198	104.2	89.7	14.5	14.0
9	21	11.0	190	82.8	73.9	8.9	10.7
10	26	14.0	197	95.2	82.9	12.4	13.0
11	22	9.0	198	97.0	84.1	10.5	12.0
Mean ±SD	20.8±3.1	7.4±3.8	193.2±4.9	91.7±6.0	80.6±4.3	11.0±2.1	12.0±1.6

4.2 Experimental design

Study I

Ten elite male rowers (20.7±3.3 yrs; 192.7±4.9 cm; 91.6±5.8 kg) took part in this study. Measurements were made before the preparatory period (i.e., in October) and were also meant to be the first qualification event for the Estonian National Team. At first, the rowers performed 2,000 metre competition on single sculls. The air temperature was about +5°C and it was not windy. Heart rate was recorded continuously during the distance and stored at 5 s intervals by heart rate monitor Polar Vantage NV (Kempele, Finland). This was followed by two testing sessions on consecutive days under similar conditions one week later. At the first measurement session, each subject completed body composition assessment (by dual energy X-ray absorptiometry; Lunar Corporation, Madison, WI, USA), filled in the RESTQ-Sport questionnaire and competed on 500-m rowing ergometer (Concept II, Morrisville, VT, USA) distance. The second measurement session consisted of maximal strength tests (Concept II, Morrisville, VT, USA) followed by a performance test on a 6,000-m rowing ergometer distance.

Study II

Eleven elite male rowers (20.8±3.1 yrs; 193.2±4.9 cm; 91.7±6.0 kg) took part in this study. The subjects were tested on seven occasions over the six month training season (from November to April): at the beginning of the preparatory period and after every four weeks during the 24-week preparatory period before the competition period. In these testing sessions, body composition (by bioelectrical impedance method), perceived recovery-stress state and fasting blood biochemical parameters were evaluated after a resting day (Jürimäe et al., 2003; Mäestu et al., 2003).

Maximal oxygen consumption and aerobic capacity were determined twice, before and after the 24-week training period. Estimation of training volume (hours per week) was obtained after calculation from individual training diaries kept by the rowers (Desgorces et al., 2004; Fiskerstrand and Seiler, 2004; Mäestu et al., 2003; Vervoorn et al., 1991). During the 24-week preparatory period, training was mainly organized as low-intensity prolonged training sessions. On-water rowing training was mainly performed on single sculls. In March, from Week 16 to Week 20, rowers were in training camp in Spain, where training load was increased while intensity remained relatively unchanged. The mean weekly training time consisted of about 90% low-intensity extensive training, where the intensity was below anaerobic threshold of 4 mmol/l (between 2 and 4 mmol/l). This kind of training included on-water rowing, ergometer rowing, running and/or swimming. In addition, this kind of training also incorporated some strength-endurance training, where the load was about 50% of 1RM with 50–100 repetitions performed. The athletes monitored the training intensity by using heart rate monitor (Polar Vantage NV, Polar Electro, Kempele, Finland). Leg press, arm press and arm pull were mainly used during the sessions. Another 10% of mean weekly training time was resistance training to maintain muscle strength. During resistance training, the load was about 75% of 1RM, 8–12 repetitions per set with four sets for each exercise. Again, leg press, bench press and bench pull were the dominating exercises.

Study III

The participants were six elite rowers preparing for major competitions and representing Estonia in double sculls (23.0±1.4 yrs; 198.0±0.0 cm; 97.1±6.4 kg) and quadruple sculls (21.5±2.5 yrs; 189.5±5.4 cm; 90.9±4.8 kg). The subjects were training regularly and had been doing so for the last 10.5±2.1 (double scullers) and 7.5±3.1 (quadruple scullers) years, respectively. They took part in three World Cup competitions, which were held in June and July with a three week training period between competitions. The rowers were preparing for major competitions held at the end of August. All subjects completed the RESTQ-Sport questionnaire two days before preliminaries of each World Cup competition. In addition, a 10-ml fasting blood sample was obtained from an anticubital vein with the subject in the upright position at the same time and the cortisol concentration was analyzed. The competition results were obtained from 2,000 metre races and were computed as a percent of finishing time behind the winning boat. The results were also recorded as a percent of time loss behind the World Best Times for a specific boat category (see Fédération Internationale des Sociétés d'Aviron: www.fisa.org). This was done for comparison because competition results in rowing also depend on weather conditions.

4.3 Body composition assessment

The height (Martin metal anthropometer) and body mass (A&D Instruments Ltd, UK) of the participants were measured to the nearest 0.1 cm and 0.05 kg, respectively. Body composition was measured using bioelectrical impedance analysis (Multiscan 5000; Bodystat Ltd; UK) and analyzed for fat (FM) and fat free (FFM) mass using Segal et al. (1988) body composition prediction equation for male subjects with an assumed body fat % of less than 20%. This methodology has been found to be accurate in Estonian athletes (Sudi et al., 2001). Body composition was also measured using dual-energy X-ray absorptiometry (DXA). Scans of the whole body were performed on each of the subjects using a Lunar DPX-IQ scanner (Lunar Corporation, Madison, WI, USA, software version 3.6) and analyzed for FM and FFM values. In addition, arm and leg muscle mass were obtained from DXA scans. The DXA measurements were made in the bone density laboratory of Tartu University Hospital and the measurements were made by an experienced technician.

4.4 Physical performance assessment

Maximal arm pull, arm press and leg press were assessed on a Concept II Dyno strength training device (Concept II, Morrisville, VT, USA). The participants were fully familiarized with the use of this apparatus and were using these exercises during their everyday training. Each subject had three attempts for each exercise separated by at least three minutes and best performance of three attempts was used as a parameter of this maximal strength exercise. Maximal 500-m, maximal 6,000-m ergometer performance and a progressive ergometer test to exhaustion were assessed on a wind-resistance-braked rowing ergometer (Concept II, Morrisville, VT, USA). The rowers were also fully familiarized with the use of this apparatus. Power and stroke frequency were delivered continuously by the computer display of the rowing ergometer. Heart rate was recorded continuously during the rowing ergometer tests and stored at 5 s intervals by the heart rate monitor Polar Vantage NV (Kempele, Finland). A progressive test to exhaustion was performed to determine maximal oxygen consumption (VO_{2max}; $VO_{2max/kg}$) and aerobic capacity (P_{max}) values. Oxygen consumption and carbon dioxide production were continuously measured during the test using a portable open circuit system (MetaMax I, Cortex, Germany). The analyzer was calibrated before the test with gases of known concentration. Athletes performed an initial work rate of 150 W with increments of 50 W every three minutes until fatigue.

4.5 The perceived recovery-stress state

The perceived recovery-stress state was assessed using the RESTQ-Sport questionnaire (Kellmann and Kallus, 2001). The RESTQ-Sport was developed to measure the frequency of current stress along with the frequency of recovery-associated activities (Kellmann and Kallus, 2001). The specific characteristics of the RESTQ-Sport are that it allows systematic and direct measurement of appraised events, states, and activities regarding their frequency while simultaneously considering stress and recovery processes (Kellmann and Kallus, 2001). The estimation of the reliability of the Estonian version of the RESTQ-Sport, the translation from the English version (Kellmann and Kallus, 2001), was satisfactory (Cronbach alpha ranging from 0.71 to 0.94).

Data were also pooled to obtain an overall average score and an estimation of the standard deviation (Kellmann and Kallus, 1999). Based on these data, a score was computed that possibly reflects the recovery-stress state for rowers (Kellmann and Kallus, 1999). The scores of stress-related scales were summed and divided by the number of scales representing the Standardized Stress. The same procedure was used for the recovery-oriented scales resulting in a Standardized Recovery. The Standardized Stress as well as the Standardized

Recovery were converted to standardized values by subtracting the global sample mean and dividing the difference by the standard deviation (Kellmann and Kallus, 1999). In this way, a standardized recovery and stress score could be obtained on a common scale, which allowed computing a difference between stress and recovery (Standardized RESTQ-Index). The factor analysis (Kellmann and Kallus, 2001) of the Estonian version of this questionnaire also demonstrated one stress-related and one recovery-related factor for the general as well as for the sport-specific parts of the RESTQ-Sport scales. 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 three 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 (e.g., social activities, vacation, sauna, etc.) (Kellmann and Kallus, 2001).

4.6 Blood analysis

A 10-ml blood sample was obtained from an anticubital vein with the participant in the upright position. The plasma was separated and frozen at –20 °C for later analysis. Cortisol, testosterone and growth hormone were analysed in duplicate on Immunolite 2000 (DPC, Los Angeles, USA). The inter- and intra-assay coefficients of variation were smaller than 5%. Creatine kinase activity was measured by means of photometric method using a commercial kit (Boehringer Mannheim, Germany).

4.7 Statistical analysis

Descriptive statistics (mean ± standard deviation [SD]) for each of the dependent variables were determined. Pearson Product Moment Correlation coefficients were used to determine the strength of the relationship between each of the dependent variables and competition time for single sculls. An alpha level was set to 0.05. Multiple linear regression analysis was used to predict the 2,000-m competition result as independent variable and different body composition, physical performance and mood state parameters showing significant correlations with competition time for single sculls as dependent variables. Friedman analyses of variance by ranks were used to examine changes in dependent variables over preparatory period. The Wilcoxon matched-pairs signed-ranks test was used where post-hoc analysis was relevant. Kendall Rank Correlation coefficients were used to evaluate associations among different variables of interest measured during the preparatory period. Changes in dependent variables during the World Cup competitions were assessed using effect sizes (ES) for rowers of double and quadruple sculls separately (Cohen, 1969). The magnitudes of ESs from <0.25, 0.25–0.50, 0.50–1.0, and >1.0 are categorized as trivial, small, medium and large differences for highly trained athletes, respectively (Rhea, 2004). However, given the small sample sizes, the computed differences in the measured variables between World Cup races are only descriptive. Thus, they are presented for the elite rowers in Estonia in an exploratory way to direct later research as further evaluation is required with larger samples.

5 RESULTS

5.1 Body composition, physical performance and psychological factors contributing to 2,000-m maximal sculling in elite male rowers (Study I)

Mean (±SD) body composition, physical performance, mood state parameters and 2,000-m maximal sculling time are presented in Table 4. Maximal and mean HR values during the 2,000-m time trial for single sculls were 190.7±3.5 and 182.9±5.1 beats/min, respectively. Significant relationships were observed between the 2,000-m maximal sculling time and body mass, arm muscle mass, arm pull, leg press, 6,000-m ergometer time, Standardized Stress and Standardized Recovery values (Table 4). Multiple regression equations in Table 5 demonstrate that the prediction model using physical performance variables predicts performance time of 2,000-m distance on single sculls best (R=0.86), followed by the equations comprising body composition (R=0.71) and mood state (R=0.56) variables.

Table 4. Body composition, physical performance, mood state and correlations with 2,000-m single sculling time in elite rowers.

Variable	Mean ± SD	Range	Correlation with 2,000-m time
Height (cm)	192.7±4.9	185.0–198.0	–0.42
Body mass (kg)	91.6±5.8	82.8–104.2	–0.63*
Body fat %	10.6±1.9	7.3–13.4	–0.54
Fat mass (kg)	9.3±2.2	6.4–13.8	–0.48
Fat free mass (kg)	82.3±4.0	76.1–90.2	–0.45
Arm muscle mass (kg)	8.6±1.1	6.6–10.3	–0.65*
Leg muscle mass (kg)	27.8±1.5	25.1–29.9	–0.46
Arm pull (kg)	114.5±20.9	84.0–144.0	–0.63*
Arm press (kg)	102.1±15.2	79.0–120.0	–0.41
Leg press (kg)	244.4±21.5	214.0–277.0	–0.62*
500-m ergometer (s)	80.3±2.1	75.7–82.4	0.40
6,000-m ergometer (s)	1 200.8±29.9	1 147.3–1247.7	0.79*
Standardized stress	2.3±0.8	1.4–3.6	0.63*
Standardized recovery	2.5±0.7	1.4–4.0	–0.65*
2,000-m sculling (s)	437.8±7.5	424.7–445.3	–

* Statistically significant; p<0.05.

Table 5. Multiple regression equations, adjusted R and standard error of the estimate (SEE) for the body composition, physical performance and mood state categories.

Category	**Multiple regression equation**	**R** **SEE**
Body composition	Time(s) = 480.852 – 0.217 x Body mass(kg) – 3.330 x Arm muscle mass(kg)	0.71 5.97 s
Physical performance	Time(s) = 281.207 + 0.156 x 6,000-m ergometer(s) – 0.096 x Leg press(kg) –0.060 x Arm pull(kg)	0.86 4.71 s
Mood state	Time(s) = 440.171 – 3.469 x Recovery + 2.805 x Stress	0.56 7.07 s

5.2 Psychological and hormonal responses to preparatory period in elite male rowers (Study II)

The evolution of body composition during the study period is presented in Table 6. In comparison with the first measurement value (Week 0), body mass and FFM values were not changed ($p>0.05$) over the training period. Body fat % and FM values demonstrated a significant decrease ($p<0.05$) after the 8 and 12 training weeks compared to the first measurement session, respectively. Significant increases ($p<0.05$) in VO_{2max} (from 6.2±0.5 to 6.4±0.6 l/min), $VO_{2max/kg}$ (from 67.6±3.0 to 69.2±3.1 ml/min/kg) and P_{max} (from 442.8±40.5 to 465.9±26.2 W) were observed as a result of the 24-week training period.

During the relative rest period before preparatory period, the overall mean weekly training volume averaged 90 min per day and was significantly lower ($p<0.05$) compared to the mean weekly training volume during the preparatory period. At the beginning of the preparatory period, the mean value of training volume was about 128 min/day (Figure 1). With regard to this initial value, there was a significant increase ($p<0.05$) after Week 8 to Week 20 (Week 8: ≈129 min/day; Week 12: ≈135 min/day; Week 16: ≈146 min/day; Week 20: ≈167 min/day). At the end of the study (Week 24), the mean training volume was about 116 min/day. The Standardized RESTQ-Index did not change significantly over the 24-week preparatory period in elite rowers. Standardized

Table 6. Body compositional parameters of elite rowers during the preparatory period.

Week	Body mass (kg)	Fat free mass (kg)	Fat mass (kg)	Body fat (%)
0	91.7±6.0	80.6±4.3	11.0±2.1	12.0±1.6
4	92.1±5.8	81.2±4.1	10.9±2.0	11.7±1.5
8	92.2±5.7	81.5±4.5	10.7±1.7	11.6±1.3#
12	93.3±5.5	82.3±3.9*	10.4±1.9#	11.2±1.5*#
16	93.7±5.0	82.4±3.9	10.9±1.6*	11.6±1.3*
20	92.4±4.8*	81.8±3.7	10.6±1.5	11.4±1.3#
24	92.2±6.3	81.8±4.2	10.4±1.9#	11.3±1.4#

* Significantly different from previous measurement week; $p<0.05$.
# Significantly different from Week 0; $p<0.05$.

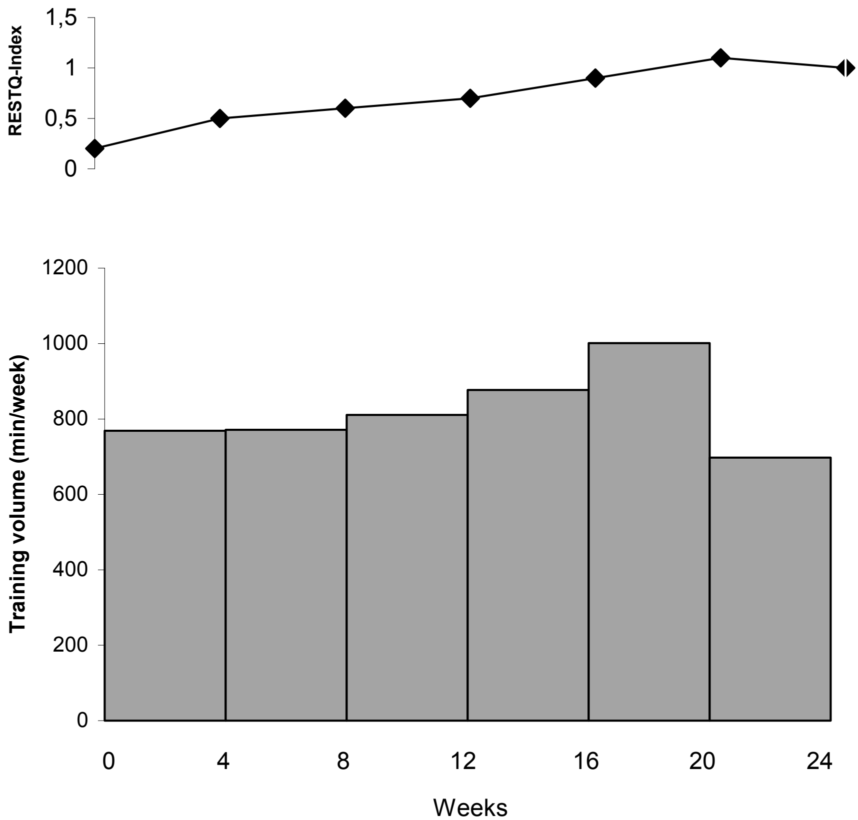

Figure 1. Mean weekly training volume and RESTQ-Index values in elite rowers during the preparatory period.

Stress score significantly changed after Week 12 compared to the pretraining score (Figure 2). While Standardized Recovery score was also significantly higher from Week 20 in comparison with pretraining value. When comparing the fasting cortisol concentrations with the first measurement, Weeks 12 and 20 show significant increases (Table 7). Fasting testosterone concentration demonstrated a significant increase after Weeks 4, 8 and 20 compared to the initial measurement (Week 0). Fasting growth hormone concentration did not change throughout the 24-week training period. Creatine kinase activity was significantly increased after the first four week training period and remained elevated until the end of the 20th week of training. After 24 weeks, all measured blood biochemical parameters were not different ($p>0.05$) from the values of the first measurement session.

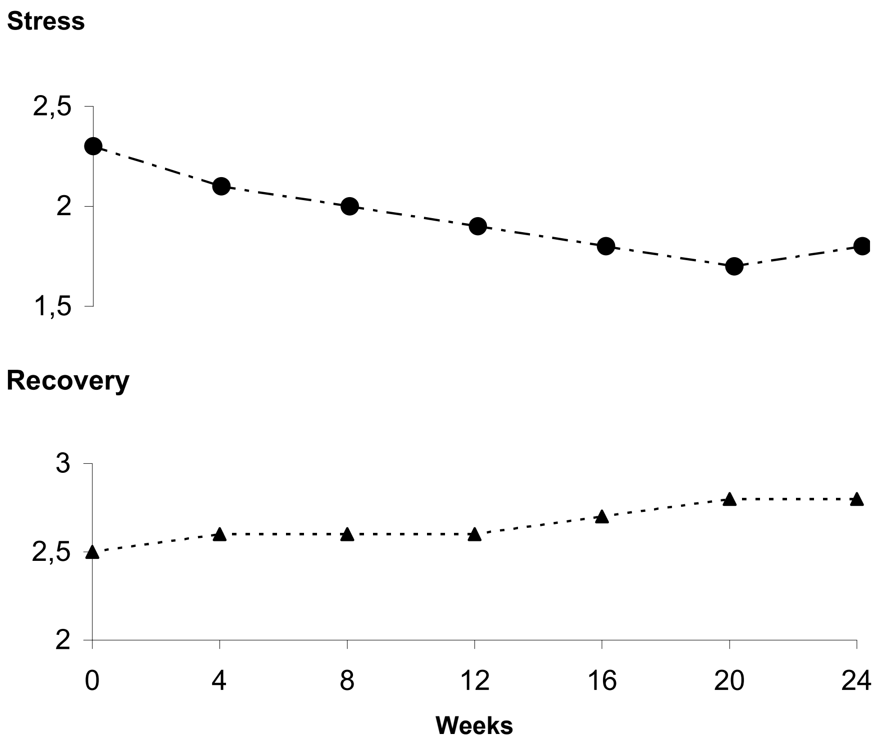

Figure 2. Mean Standardized Stress and Standardized Recovery scores in elite rowers during the preparatory period.

Table 7. Blood biochemical parameters of elite rowers during the study period.

Week	Cortisol (nmol/l)	Testosterone (nmol/l)	Growth hormone (µIU/ml)	Creatine kinase (U/l)
0	393.9±145.6	19.2±6.1	0.9±0.8	269.6±128.8
4	474.6±115.1	26.0±4.2*#	0.9±0.7	359.7±190.1*#
8	446.9±67.9*	22.7±8.8#	2.4±3.5	469.0±180.3#
12	495.8±111.5#	25.3±7.2	1.9±3.0	484.9±218.4#
16	489.1±101.3	23.9±6.0	2.0±2.8	430.5±204.2#
20	560.7±78.2#	29.8±8.0*#	0.9±1.0	406.1±235.6#
24	336.6±73.3*	18.9±5.4*	0.9±1.8	285.4±100.1*

* Significantly different from previous measurement week; $p<0.05$.
# Significantly different from Week 0; $p<0.05$.

Significant relationships were observed between mean weekly training volume, and fasting cortisol (r=0.42; p=0.010) and testosterone (r=0.53; p=0.001) values. Standardized Stress score was significantly related to fasting cortisol (r=0.38; p=0.002) and growth hormone (r=0.28; p=0.021) values, while Standardized Recovery was significantly related to fasting creatine kinase activity only (r=–0.25; p=0.045). In addition, RESTQ-Index was significantly related to fasting creatine kinase activity (r=–0.30; p=0.015), cortisol (r=0.32; p=0.009), growth hormone (r=0.42; p=0.001) and testosterone (r=0.35; p=0.004) values.

5.3 Psychological and hormonal responses during World Cup races before major competitions in elite male rowers (Study III)

The time taken to row the 2,000-m distance and the competition results for double scullers were best during the World Cup 1, followed by the World Cup 2 and World Cup 3 competitions, respectively (Table 8). The same pattern was observed when we computed the percent time loss from the winners. Our rowers achieved competition times longer by 3.1%, 4.8% and 9.6% for results of the winning boats of World Cup 1, World Cup 2 and World Cup 3, respectively. When we compared these times with the World Best Times, the results were worse by 3.3% (World Cup 1), 15.6% (World Cup 2) and 8.3% (World Cup 3). Resting cortisol level showed a large increase before World Cup 2 (by 44.4%; ES=1.6) and remained elevated before World Cup 3 (by 43.5%; ES=1.5) compared to the value obtained before World Cup 1. There was a trivial decrease in the Standardized Stress score from World Cup 1 to World Cup 2 (by 5.6%; ES=0.1), while a moderate increase in the Standardized

Table 8. Performance results, means and standard deviations for cortisol and standardized recovery-stress questionnaire scores in rowers.

	World Cup 1	**World Cup 2**	**World Cup 3**
Double scullers (n=2)			
Cortisol (nmol/l)	281.5±142.1	506.0±67.9*	498.5±98.3*
Standardized Stress	1.9±1.0	1.8±0.4	2.1±0.3
Standardized Recovery	2.7±0.2	2.3±0.1*	2.2±0.4*
RESTQ-Index	0.9±1.1	0.5±0.5	0.1±0.1*
Quadruple scullers (n=4)			
Cortisol (nmol/l)	248.5±64.4	424.3±140.8*	495.8±47.7*
Standardized Stress	1.4±1.1	1.7±1.0	2.0±1.5
Standardized Recovery	2.9±1.4	2.8±1.7	2.9±1.8
RESTQ-Index	1.5±1.8	1.1±2.3	0.8±3.0

* Large difference from World Cup 1, Effect Size >1.0.

Stress score occurred before World Cup 3 (by 14.3%; ES=0.8) compared to the previous values. Standardized Recovery worsened largely before World Cup 2 (by 17.4%; ES=2.0) and World Cup 3 (by 22.7%; ES=2.5) compared to the value obtained before World Cup 1. There was a small decrease in the Standardized RESTQ-Index between World Cup 1 and World Cup 2 (by 44.4%; ES=0.4) and a further moderate decrease in this index occurred between World Cup 2 and World Cup 3 (by 80%; ES=0.8).

Quadruple scullers demonstrated best time in World Cup 1 (+2.9% from the winning boat time), followed by World Cup 3 (+5.7% from the winning boat time) and World Cup 2 (+9.4% from the winning boat time) (Table 9). When we compared these times with World Best Times, the results were worse by 3.4% (World Cup 1), 9.6% (World Cup 2) and 5.7% (World Cup 3). Resting cortisol levels indicated a large increase between World Cup 1 and World Cup 2 (by 70.7%; ES=2.7), and a further moderate increase in this value occurred between World Cup 2 and World Cup 3 (by 16.9%; ES=0.5). Similarly, the Standardized Stress score increased from World Cup 1 to World Cup 2 (by 21.4%; ES=0.3), and from World Cup 2 to World Cup 3 (by 17.6%; ES=0.3). No changes were monitored in Standardized Recovery value during the three World Cup competitions (ES<0.1). Standardized RESTQ-Index worsened from World Cup 1 to World Cup 2 (by 26.7%; ES=0.2), and from World Cup 2 to World Cup 3 (by 27.3%; ES=0.1).

6 DISCUSSION

6.1 Body composition, physical performance and psychological factors contributing to 2,000-m maximal sculling in elite male rowers (Study I)

The 2,000-m distance in rowing places considerable stress upon the systems of aerobic and anaerobic metabolism (Mäestu et al., 2005; Steinacker, 1993). Competition success in rowing also depends on the specific mood state (Kellmann and Günther, 2000; Steinacker et al., 2000) and body composition (Ingham et al., 2002; Jürimäe et al., 2000) parameters. Furthermore, different boat classes may demand different physical and functional characteristics from athletes. For example, the power at the anaerobic threshold of 4 mmol/l has been reported to be the best single physiological determinant in small boats, such as singles and doubles (Steinacker, 1993; Wolf and Roth, 1987), while others have reported that maximal aerobic power (P_{max}) is the best determinant of 2,000 metre rowing performance (Ingham et al., 2002; Jürimäe et al., 2000). This demonstrates that there is not a single parameter that could be used to evaluate rowers of different performance levels and different boat classes. Therefore, the present investigation was undertaken to find possible markers of sculling performance in a relatively homogeneous group of elite scullers. In addition to widely used different body composition and physical performance characteristics, we also assessed the athletes' mood state using an easily administered questionnaire. The results of the present study demonstrated that body mass and arm muscle mass from measured body composition, 6,000 metre ergometer performance, maximal leg press and maximal arm pull from measured physical performance, and the level of stress and recovery from measured psychological parameters determine the 2,000 metre sculling time in a group of elite scullers. In addition to training monitoring, all these parameters could also be used in the selection process for different sculling boat classes as well as different seating for these boats.

The strongest correlate of sculling performance was the 6,000 metre ergometer time ($r=0.79$; $p<0.05$). In accordance with this, maximal aerobic capacity has been reported to be a predictor of competitive success in rowing (Hagerman, 2000; Ingham et al., 2002; Steinacker et al., 1998). Numerous studies have also suggested that VO_{2max} is closely related to rowing performance (Cosgrove et al., 1999; Ingham et al., 2002; Jürimäe et al., 2000; Steinacker, 1993; Womack et al., 1996). However, it has been suggested that while the indices of maximal oxygen consumption may not correlate well with performance (Morgan et al., 1989), peak power or velocity is a very accurate correlate of performance (Steinacker, 1993; Womack et al., 1996). Furthermore, changes in maximal oxygen consumption may often be smaller in year-round training than changes in maximal aerobic capacity (Steinacker, 1993; Womack et al., 1996). Accordingly, the 6,000-m ergometer test was chosen to reflect maximal aerobic metabolism in the scullers of this study.

An interesting finding of this study was that the measure of anaerobic glycolytic capacity, 500 metre ergometer time was not related ($r=0.40$; $p>0.05$) to sculling performance, while maximal arm pull ($r=-0.63$; $p<0.05$) and leg press ($r=-0.62$; $p<0.05$) strength values were related to sculling performance. These findings indicate that the glycolytic capacity of highly trained rowers is less important in comparison with maximal strength values. In accordance with these findings, maximal anaerobic alactic power has been reported to characterize rowing performance on the 2,000-m course in a heterogeneous group of competitive rowers (Jürimäe et al., 1999). Alactic anaerobic power has been reported to be an important part of energy supply during the starting and finishing phases of the 2,000 metre competition race (Steinacker, 1993). Thus, it can be suggested that scullers need great muscular strength for the acceleration of the boat during the start and final spurt phases in addition to the high oxidative capacity to maintain the speed during a 2,000 metre race.

Body composition analysis using a sophisticated method of DXA revealed that arm muscle mass ($r=-0.65$; $p<0.05$) was a strong predictor of sculling performance in addition to other previously reported body mass values (Jürimäe et al., 2000; Russell et al., 1998). This indicates that the development of upper body muscles may have higher importance in scullers than sweep rowers. To date, more attention has been paid on the development of leg muscles and leg muscle strength in rowers (Cosgrove et al., 1999; Jürimäe et al., 2000). In this study, similarly to maximal leg press strength, maximal arm pull was also significantly related ($r=-0.63$; $p<0.05$) to sculling performance in elite scullers. Taken together, the results of the present study indicate that upper body may have more importance in elite sculling than sweep rowing.

An important implication of this study is that the results of RESTQ-Sport questionnaire were highly related to 2,000-m sculling performance time (see Tables 4 and 5). This demonstrates that the results of the questionnaire reflect well the performance capacity of elite scullers. Using this questionnaire, athletes and coaches could become aware of the importance of daily activities, how these events are related to stress and recovery and about their impact on performance in sport (Kellmann and Kallus, 1999, 2001). The advantage of RESTQ-Sport is that it takes recovery activities also into account, i.e., how athletes behave outside training sessions and what recovery activities they prefer and use. It has to be considered that most international teams undertake very large amounts of low-intensity high-volume training in preparation for major competitions (Fiskerstrand and Seiler, 2004; Mäestu et al., 2005, 2006; Steinacker et al., 1998) and the use of this questionnaire allows us to relatively easily monitor the state of athletes. Another important implication of the questionnaire is that it allows to select athletes with similar personal state before competitions to one crew in case a substitute is needed.

The results of present study indicate that although the prediction model using physical performance (i.e., aerobic capacity and maximal strength; R=0.86) values predicts 2,000-m sculling time best in elite sculling, body composition (i.e., body mass and arm muscle mass; R=0.71) and mood state (i.e., recovery and stress; R=0.56) are also important categories in elite sculling. This demonstrates that training monitoring and crew selection is a complex and not easy task in elite sculling. The specificity of different boat classes and competition level is well demonstrated by the results of Russell et al. (1998) study, who found that anthropometric parameters (R=0.78) best predict rowing performance in elite schoolboy sweep rowers. While previous studies have demonstrated the importance of different anthropometric and physiological characteristics in prediction of 2,000 metre rowing performance (Ingham et al., 2002; Jürimäe et al., 2000; Russell et al., 1998), the present study also demonstrated the importance of mood state parameters in prediction of 2,000 metre rowing performance.

In summary, the results of the present study indicate that specific body composition, physical performance and mood state parameters determine the 2,000 metre sculling performance in elite athletes. It appears that arm muscle mass and maximal arm muscle strength in addition to maximal aerobic capacity are most important characteristics in the studied group of elite scullers. In addition to specific anthropometric and physiologic characteristics, the evaluation of mood state in athletes has an important implication in training monitoring and crew selection.

6.2 Psychological and hormonal responses to preparatory period in elite male rowers (Study II)

It has been suggested that prolonged high volume low-intensity training periods may facilitate long-term endocrine adaptations (Kjaer, 1998; Mäestu et al., 2005) and a greater capacity for sympathetic mobilization following low volume training periods and tapering for major competitions (Fiskerstrand and Seiler, 2004). The major problem for elite rowing training monitoring could be that the limit between adaptation and intolerance to high volume training load cannot be accurately determined. A 24-week heavy training period in our study resulted in significant improvements of all measured aerobic capacity values (e.g., VO_{2max}: from 6.2±0.5 to 6.4±0.6 l/min), indicating that the main aim of the preparatory training period was successfully achieved (Mäestu et al., 2005; Steinacker, 1993). The aerobic capacity values were comparable with other results obtained from successful international level male rowers (Petibois et al., 2003; Secher, 1993). Similarly, all measured body compositional parameters were at the same level with other international level male rowers (Petibois et al., 2003; Shephard, 1998). However, average training volume during this period was somewhat lower compared to elite Norwegian rowers who have won medals in international championships (Fiskerstrand and Seiler, 2004). This could be explained by the fact that rowers in our study were relatively young (20±3 years), while Norwegian rowers won their first championship medal at the age of 24±2 years. It has to be considered that the athletes of our study had just achieved international level and were not able to train at a very high training volume. However, two rowers were fourth and four rowers ninth in the championships that followed the preparatory period. This indicates that our rowers have a potential to increase the training volume and win medals in further championships.

In association with the improved aerobic capacity parameters at the end of the preparatory period, changes in circulating anabolic (testosterone and growth hormone) and catabolic (cortisol) hormone concentrations as well as in the activity of creatine kinase in blood were tracked several times throughout the 24-week training period. Though within the normal range reported in the literature (i.e., 10.4–41.6 nmol/l) (Young, 1998), basal serum testosterone concentrations were considered somewhat low before (19.2±6.1 nmol/l) and after (18.9±5.4 nmol/l) the 24-week training period in elite rowers indicating that athletes in this study had similar basal testosterone values with other endurance athletes (Chennaoui et al., 2004; Daly et al., 2005; Mäestu et al., 2003). However, basal testosterone concentrations were significantly elevated after Weeks 4, 8 and 20 (see Table 7), showing a high anabolic profile of our athletes following hard endurance training sessions. Furthermore, basal testosterone was significantly related to mean weekly training volume ($r=0.42$; $p=0.010$). Although basal testosterone remained within normal recognized values, circulating values were considered high for the predominance of the preparatory period indicating a positive anabolic adaptation (Kokolas et al., 2004; Kraemer et al., 2004) to endurance training as also demonstrated by improved aerobic capacity values. This does not necessary mean muscle hypertrophy as also indicated by no significant changes in FFM values throughout the study period (see Table 6), but may mediate increased expression of aerobic enzymes and/or adaptation in other processes, such as erythropoiesis (Kokolas et al., 2004).

In similar fashion to the trends observed for basal testosterone, initial (393.9±145.6 nmol/l) and Week 24 (336.6±73.3 nmol/l) cortisol concentrations were considered somewhat lower compared to the normal resting range of 138–635 nmol/l (Young, 1998) but similar to the values obtained from other endurance athletes (Chennaoui et al., 2004; Daly et al., 2005; Mäestu et al., 2003). Basal cortisol concentrations were also elevated for the predominance of preparatory period indicating also a high catabolic environment of our athletes. Similarly to basal testosterone, basal cortisol was also significantly related to the mean training volume ($r=0.53$; $p=0.001$). It has to be considered that activation of catabolic processes is an essential tool for adaptation in a high stress situation (Kraemer et al., 2004; Petibois et al., 2003). Furthermore, high basal cortisol levels suggest a high activity of the adaptation process, whereas a suppression from baseline levels is an indicator of significant reduction in the adaptation reserves of the organism (i.e., overtraining syndrome) (Mäestu et al., 2005; Urhausen et al., 1995; Urhausen and Kindermann, 2002).

Although basal growth hormone concentrations were not significantly changed, they demonstrated a trend to increase during the course of the preparatory period (see Table 7). These stress hormone data further confirm the information obtained from basal testosterone and cortisol levels and suggest high resources of adaptivity of our athletes. In addition, it appears that basal growth hormone is a less sensitive marker of training stress compared to other stress hormones of the hypothalamus-pituitary-adrenocortical axis in typical elite rowing training during the preparatory period. In view of these adapted stress hormonal responses, it could be argued that athletes in our study could have used more of their adaptation reserves before signs of overreaching syndrome occurred. This was further confirmed by the results of creatine kinase activity, which demonstrated a significant increase after Week 4 and was returned to the pretraining value only after Week 24 (see Table 7). It is well known that the value of creatine kinase activity is considered to be a marker of the mechanical-muscular strain of training because of muscle cell leakage or damage, and the morning levels represent mainly the creatine kinase release during the previous days (Urhausen and Kindermann, 2002). The normalization of the creatine kinase activity demonstrates reduced muscle stress (Hartman and Mester, 2000). While creatine kinase activity was measured highest after Week 12 (484.9±218.4 U/l), creatine kinase activity values were not very high throughout the 24-week study period suggesting that the muscular system adapted well to such training loads (Hartman and Mester, 2000). Conspicuously elevated values in elite athletes have been reported to occur when creatine kinase activity reaches 1,000 U/l and more (Hartman and Mester, 2000). The hormonal results of this tracking study over the preparatory period in elite rowers suggest that rowers adapted well to high endurance training load and no overreaching syndrome could have been detected at any measurement point.

In accordance with hormonal values, simultaneously assessed perceived recovery-stress state also demonstrated that rowers did not use all their adaptation resources during the preparatory period but adopted positively to training stress (see Figures 1 and 2). The RESTQ-Sport allows the assessment of subjective stress and recovery during the all year-round training and preparing for major competitions in different athletes (Kellmann and Günther, 2000; Kellmann and Kallus, 1999). It has been suggested that the Standardized RESTQ-Index could be used as an athletes' resource measure taking into account perceived stress- and recovery-associated aspects at the same time (Kellmann and Kallus, 1999; Mäestu et al., 2005, 2006). In our study, the RESTQ-Index did not change significantly over the 24-week training period. This would suggest that the training volume during the preparatory period did not seriously affect the psychological resources of adaptivity in our rowers.

However, the RESTQ-Index demonstrated a dose-response relationship with rapid and heavy increases in training volume in previous overreaching study in highly trained male rowers (Mäestu et al., 2006). According to the results of these studies, it could be speculated that the RESTQ-Index can be used to detect the overreaching and/or overtraining syndrome in elite rowing training. However, when Standardized Stress and Standardized Recovery scores were presented separately (see Figure 2), it showed that Standardized Stress (after Week 12) and Standardized Recovery (after Week 20) scores even improved during the course of the preparatory period in elite rowers. This could be explained by the fact that when our rowers started to train hard and especially at a training camp, they did not have to deal with everyday problems and they had more time for recovery. This demonstrates that the current psychological adaptation state of an athlete appears to be very complex. Adequate recovery periods during phases of heavy training allow the adaptation of the athlete to physical stress and prevent overtraining (Mäestu et al., 2006; Raglin, 1993).

The interesting finding of our study was that significant relationships were found between basal cortisol and Standardized Stress ($r=0.38$; $p=0.002$) and RESTQ-Index ($r=-0.32$; $p=0.009$) scores. In addition, basal testosterone ($r=-0.35$; $p=0.004$) and growth hormone ($r=-0.42$; $p=0.001$) were related to the RESTQ-Index. These close relations between hormonal and psychometric response are very intriguing from a multi-level approach of training monitoring. The hypothalamus has an important role in integrating different stress influences and the answers from the hypothalamus are expressed via the endocrine system, the autonomic nervous system and the behaviour (Barron et al., 1985). Changes in basal cortisol levels reflect the metabolic stress as the endpoint of the hypothalamus-pituitary-adrenocortical axis (Barron et al., 1985; Hackney, 1999). Accordingly, changes in basal cortisol have been identified as metabolical signs of changes in psychological adaptation resources (Barron et al., 1985; Weidenfeld et al., 1990). Currently, it is mainly a subject of speculation how the hypothalamus senses metabolic dysbalance (Barron et al., 1985; Weidenfeld et al., 1990). Similarly, the Standardized Recovery score was related to creatine kinase activity ($r=-0.30$; $p=0.015$), which has been measured as an essential indicator for the determination of muscular stress (Hartman and Mester, 2000). This further confirms the need for a multi-level approach of training monitoring in elite rowers.

In summary, fasting testosterone and cortisol appear to be more sensitive to changes in training volume in typical elite rowing training during the preparatory period. Increases in these stress hormone concentrations represent positive adaptation to current training load. Significant relationships between hormonal and perceived recovery-stress state suggest that metabolic and psychological changes should be carefully monitored to avoid unfavourable outcome on the training status in elite rowers. According to the results of the present study, the studied rowers can increase their training volume to a certain extent without the appearance of the overtraining syndrome.

6.3 Psychological and hormonal responses during World Cup races before major competitions in elite male rowers (Study III)

The purpose of the present investigation was to examine the expected influence of the perceived recovery-stress state on performance for international competition in highly trained male rowers competing in two boat classes. Double scullers were more experienced, while rowers in quadruple sculls for the first time took part in international competitions. Generally, the performance of double scullers in three World Cup series met their expectations, while the performance in quadruple scullers was as expected in the first two World Cup competitions. Rowers in both boat classes continued training with a relatively high load during this period. Previously, we have shown a dose-response relationship between high training load and subjective assessments of stress and recovery (Jürimäe et al., 2002). In this study, the decrease in the RESTQ-Index from World Cup 1 to World Cup 3 was accompanied by the increased loss for winning boat time in double sculls (World Cup 1: +3.1%; World Cup 2: +4.8%; World Cup 3: +9.6%). In another study, Kellmann et al. (1996) found a close relationship between the recovery-stress state and performance in the competition of swimmers.

Largely increased cortisol values before World Cup 2 (see Table 9) also showed a high metabolic stress in rowers of both boat classes (Jürimäe et al., 2002; Mäestu et al., 2005). While the fasting cortisol values in more experienced double scullers remained almost at the same level between World Cup 2 and World Cup 3, the fasting cortisol level in quadruple scullers increased further between World Cup 2 and World Cup 3 (by 16.9%; ES=0.5). These stress hormones suggest that more experienced rowers coped better with high training and competition stress. This was also confirmed by the fact that the Standardized Stress score did not change from World Cup 1 to World Cup 2 and a moderate increase occurred only before World Cup 3 (by 14.3%; ES=0.8) in double scullers. For quadruple scullers there was a constant increase in the Standardized Stress value form World Cup 1 to World Cup 3. This suggests that rowers in quadruple sculls were more stressed, both metabolically and psychologically, as the Standardized Recovery value remained almost unchanged during the three World Cup competitions. According to these results, it can be speculated that the training and competition load for the rowers performing in quadruple sculls might have been too hard for them to cope with, since they finished in the 10th place in World Cup 3 competitions. Probably, they were in an overreaching state (i.e., Jürimäe et al., 2002) before World Cup 3, which was reflected by increases in perceived stress and catabolic stress hormone concentration.

Another interesting finding of the present study was the decrease in the RESTQ-Index in quadruple scullers accompanied by a large increase in the

Standardized Stress score. The RESTQ-Index worsened in double scullers because recovery activities were inadequate as indicated by a large decrease in the Standardized Recovery score between World Cup 1 and World Cup 3 (see Table 9). This suggests that double scullers coped with training and competition stress better than quadruple scullers, and their relative loss to the winning boat in World Cup 3 was accompanied by inadequate recovery between training sessions and competition races. Athletes should be aware of the importance of recovery in the training process (Kellmann and Günther, 2000; Kellmann and Kallus, 1999). Adequate recovery periods during phases of heavy training and competitions allow the adaptation of the athletes to stress and prevent overtraining (Mäestu et al., 2006; Raglin, 1993). The knowledge of the importance of active recovery gives an athlete more responsibility for his own activities.

These different results of our study in double and quadruple scullers indicate the importance of assessing perceived stress and recovery at the same time. The advantage of using the RESTQ-Sport questionnaire is the detailed picture of the rowers` state provided. Concrete solutions to potential problems can be derived only from the up-to-date recovery-stress profile (Kellmann and Kallus, 2001). This profile can be used to derive specific intervention strategies. The present results also showed athletes and coaches the importance of daily activities on their mood state and how these activities are related to their performance in international competitions. Similarly to this study, studies of German rowers suggest that before important competitions athletes become more sensitive about certain activities and perceive their environment differently, although the coaches' view did not change (Kellmann and Kallus, 1999).

In summary, through the utilization of the RESTQ-Sport questionnaire, athletes and coaches can be informed of the importance of daily activities during training and how these activities are related to recovery-stress state in athletes. These results indicated that the recovery-stress state reflects the performance in international competitions. While the RESTQ-Index could be used as an athletes' resource measure, Standardized Stress and Standardized Recovery scores reflect an athletes'extent of stress and recovery separately.

7 CONCLUSIONS

1. Specific body composition, physical performance and mood state parameters determine the 2,000 metre sculling performance in elite male scullers. Arm muscle mass, maximal arm muscle strength and maximal aerobic capacity are important characteristics of rowing performance in elite male scullers.
2. Fasting testosterone and cortisol concentrations together with the perceived recovery-stress state are sensitive to changes in training volume and represent a positive adaptation to current training load during the preparatory period of elite male scullers.
3. The perceived recovery-stress state influences the performance of elite male scullers in international competitions. While RESTQ-Index could be used as an athletes' resource measure, Standardized Stress and Standardized Recovery scores reflect athletes' extent of stress and recovery separately.
4. Significant relationships between stress hormone concentrations and perceived recovery-stress state suggest that metabolic and psychological changes should be monitored together to avoid unfavourable outcome on the training status of elite male scullers.

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SUMMARY IN ESTONIAN

Sõudjate aastase treeningutsükli kompleksne hindamine kasutades erinevaid psühholoogilisi, funktsionaalseid ja vere biokeemilisi markereid

Sissejuhatus

2000 meetri võistlusdistantsi läbimisele kulutavad sõudjad tavaliselt 5–7 minutit, olenevalt paadiklassist ja ilmastikuoludest. Võistluste ajal töötavad maksimaalselt nii sõudjate aeroobsed kui ka anaeroobsed energiatootmismehhanismid. On teada, et treeningul läbitud kilomeetrid on sõudjatel usutavas seoses võistlustulemusega, kuid seoses sellega võib sportlasel esineda ka üleväsimust ja ületreeningu ohtu. Ettevalmistusperioodil iseloomustab sõudjate treeningut madal intensiivsus ja suur maht, võistlusperioodil aga siiski suurem intensiivsus ja väiksem maht. Tänapäeval kasutatakse treeningu monitooringus erinevaid funktsionaalseid teste ning mitmesuguseid vere biokeemilisi ja psühholoogilisi parameetreid. Mitmed uuringud on näidanud, et kõige paremini saab diagnoosida sportlase seisundit uurides treeningu mõju kompleksselt, sest üksikute parameetrite hindamine ei pruugi anda objektiivset pilti sportlase üldisest seisundist.

Käesoleva uurimistöö eesmärgiks oli välja selgitada, millised vere biokeemilised, psühholoogilised ja funktsionaalsed markerid sobivad sõudjate aastase treeningtsükli kompleksseks hindamiseks.

Uurimustöö ülesanded:

1. Määrata Eesti tippsõudjate 2000m võistlustulemust iseloomustavad spetsiifilised keha koostise, funktsionaalsete võimete ja subjektiivse enesetunde näitajad;
2. uurida treeningukoormuse mõju Eesti tippsõudjate subjektiivsel enesetundel ja vere biokeemilistele näitajatele ettevalmistusperioodil;
3. uurida treeningukoormuse mõju Eesti tippsõudjate subjektiivsele enesetundele ja võistlustulemusele maailmakarika etappidel;
4. uurida võimalikke seoseid Eesti tippsõudjate treeningumahu, subjektiivse enesetunde ja hommikuse puhkeoleku vere biokeemiliste näitajatel vahel.

Uuritavad ja metoodika

Uuritavateks oli 11 Eesti sõudekoondise meessõudjat, kellest 6 sportlast osalesid tiitlivõistlustel. Sportlased treenisid etteantud treeninguplaanide alusel.

Sportlastel määrati enne ettevalmistusperioodi:

- keha koostise parameetrid, kasutades DXA meetodit.
- 2000 meetri sõudmise tulemus ühestel paatidel
- 6000 meetri sõudmise tulemus sõudeergomeetritel
- 500 meetri sõudmise tulemus sõudeergomeetril.
- sõudmisspetsiifiline maksimaalne jalgade ja käte jõud aparaadil Concept II Dyno strength training device.
- maksimaalne hapniku tarbimine (VO2max) sõudeergomeetril kasvavate koormustega suutlikkuseni.

Ettevalmistusperioodi (24 nädalat) jooksul määrati sportlastel iga 4 nädala tagant peale puhkepäeva hommikul enne söömist:

- antropomeetrilised näitajad (pikkus, kehamass).
- keha koostise parameetrid kasutades BIA meetodit
- subjektiivne enesetunne RESTQ-Sport enesehinnangu küsimustiku abil
- hommikused puhkeoleku vere biokeemilised parameetrid (kortisool, testosteroon, kasvuhormoon ja kreatiinkinaasi aktiivsus)
- treeningu maht ja iseloom.

Võistlusperioodil maailmakarikavõistluse etapil määrati sportlastel:

- subjektiivne enesetunne RESTQ-Sport enesehinnangu küsimustiku abil
- hommikused puhkeoleku vere biokeemilised parameetrid (kortisool)
- treeningu maht ja iseloom
- võistlustulemus (koht, aeg, kaotus võitjale ja kaotus maailma parimale ajale)

Järeldused

1. Spetsiifilised keha koostise, funktsionaalsed ja subjektiivse enesetunde näitajad iseloomustavad paarisaeruliste paatide sõudjate võistlustulemust. Käe lihasmass, käe maksimaalne jõud ja maksimaalne aeroobne võimsus on olulised parameetrid iseloomustamaks võistlustulemust.
2. Hommikused testosterooni, kortisooli ja subjektiivse enesetunde näitajad iseloomustavad treeningumahu muutusi tippsõudjate ettevalmistusperioodi ajal.
3. Subjektiivse enesetunde näitajad on seotud tippsõudjate võistlustulemusega rahvusvahelistel võistlustel. RESTQ-indeksit võib kasutada sportlaste valmisoleku hindamisel, kuid standardiseeritud stressi- ja taastumise näitajad iseloomustavad täpsemalt taastumise ja stressi vahekorda.
4. Statistiliselt usutavad seosed vere stressihormoonide sisalduse ja subjektiivse enesetunde küsimustiku (RESTQ-Sport) vahel näitavad, et tänapäeva tippsõudjate treeningu monitooringus tuleb kasutada kompleksselt nii vere biokeemiliste näitajate määramist kui ka subjektiivse enesetunde hindamist.

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PUBLICATIONS

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HORMONAL AND PSYCHOLOGICAL ADAPTATION IN ELITE MALE ROWERS DURING PROLONGED TRAINING

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ABSTRACT

In this study, we examined possible hormonal and psychological changes in elite male rowers during 24-week preparation period. Eleven elite male rowers were tested on seven occasions over the six month training season. Fasting testosterone, growth hormone, cortisol and creatine kinase activity, and perceived recovery-stress state were evaluated after a resting day. Maximal oxygen consumption was determined before and after the training period. Training was mainly organized as low-intensity prolonged training sessions. Significant increases in VO_{2max} (from 6.2±0.5 to 6.4±0.6 l/min) were observed as a result of training. The overall perceived recovery-stress index did not change during the preparation period. Standardized recovery and stress scores separately changed during the course of training in comparison with pretraining value. When basal hormone concentrations were compared with the first measurement, significant changes in testosterone and cortisol values were observed together with changes in mean weekly training volume. Basal testosterone ($r=0.416$; $p=0.010$) and cortisol ($r=0.527$; $p=0.001$) were related to mean weekly training volume. Basal growth hormone did not change during the training. Changes in creatine kinase activity demonstrated similar pattern with changes in mean weekly training volume. The overall perceived recovery-stress index was related to testosterone, cortisol, growth hormone, and creatine kinase activity values ($r>0.299$; $p<0.015$). Our findings indicate that testosterone and cortisol are more sensitive to changes in training volume in elite rowing training. Increases in these stress hormone concentrations represent positive adaptation to current training load. Significant relationships between hormonal and perceived recovery-stress state suggest that metabolic and psychological changes should be carefully monitored to avoid unfavourable outcome on the training status in elite rowers.

INTRODUCTION

Numerous investigations have been conducted in an attempt to study possible physiological markers of training stress that might subsequently be used to monitor training and prevent possible overtraining syndrome that may be associated with chronic hard training (Mäestu *et al.*, 2003; Chennaoui *et al.*, 2004). When training stimulus becomes excessive with insufficient recovery between training sessions, the athlete may become overtrained (Mujika *et al.*, 1996; Mäestu *et al.*, 2003). Optimal performance is only achieved when athletes optimally balance training stress with adequate recovery (Mäestu *et al.*, 2003). The main feature of overtraining syndrome is a decrease in performance resulting from an imbalance between anabolic and catabolic hormones, hypothalamus-pituitary dysfunction and a possible imbalance in amino acids (Urhausen *et al.*, 1995; Petibois *et al.*, 2003; Chennaoui *et al.*, 2004). Recently, in addition to clinical findings, the level of perceived recovery-stress state appears to well reflect the state of an athlete (Kellmann and Kallus, 1999, 2001; Jürimäe *et al.*, 2002).

Many investigations have studied the effects of different kind of prolonged training has on the hormones of the hypothalamus-pituitary-adrenocortical axis (Vervoorn *et al.*, 1991; Chennaoui *et al.*, 2004). Prolonged heavy endurance training regimen causes an increase and a decrease in the fasting levels of cortisol and testosterone, respectively (Vervoorn *et al.*, 1991). In addition, resting cortisol levels have also been reported to remain relatively unchanged after prolonged endurance training in male athletes (Mackinnon *et al.*, 1997; Mäestu *et al.*, 2003). In another study, a further improvement of performance capacity was associated with increased growth hormone and cortisol levels (Snegovskaya and Viru, 1993). The results of these studies suggest that prolonged training may have a variable influence on the hormones of the hypothalamus-pituitary-adrenocortical axis.

It has been suggested that basal cortisol levels may be used as a marker of training stress in athletes as basal cortisol levels represent the endpoint of the hypothalamus-pituitary-adrenocortical axis (Barron *et al*., 1985; Hackney, 1999). Increased levels of basal cortisol have been linked to normal stress response to heavy training, while a decrease in basal cortisol has been used as a late sign of overtraining (Urhausen and Kindermann, 2002). In addition to the hormonal values, the amount of psychologically related stress seems to reflect well the clinical state of athletes (Kellmann and Kallus, 1999; Jürimäe *et al*., 2002). Furthermore, variation in cortisol has been linked to changes in mood, sleep quality, and recovery activities (Barron *et al*., 1985; Jürimäe *et al*., 2002). These findings suggest that training monitoring in elite athletes should involve a multi-level approach using valid hormonal as well as psychological indices to assess adaptation to certain training load.

The aim of the present investigation was to integrate hormonal and psychological approaches of training monitoring during the course of preparation period in elite rowers; and to investigate possible relationships between training volume, basal hormone levels and perceived recovery-stress state. These hormone and perceived recovery-stress state markers should reflect the variations in the training volume that take place during the 24-week training season in elite male rowers.

METHODS

Participants

Eleven elite male rowers (age 20.2±2.9 years; height: 192.7±4.9 cm), members and candidates for the Estonian National Team, participated in this study. Subjects were in good mental and physical conditions, and were not taking any medication during the study. The rowers were informed about the possible risks involved in the experiments before providing their written consent to participate in the experiment as approved by the Medical Ethics Committee of the University of Tartu. All rowers had a long and regular endurance training experience (7.4±3.8 years) and they were competiting at national or international level. The height (Martin metal anthropometer) and body mass (A&D Instruments Ltd, UK) of the participants were measured to the nearest 0.1 cm and 0.05 kg, respectively. Body composition was measured using bioelectrical impedance analysis (Multiscan 5000; Bodystat Ltd; UK) and analyzed for fat (FM) and fat free (FFM) mass using Segal *et al*. (1988) body composition prediction equation. A progressive test to exhaustion was performed on a rowing ergometer (Concept II, Morrisville, USA) to determine maximal oxygen consumption (VO_{2max}; $VO_{2max/kg}$) and aerobic capacity (Pa_{max}) values (Jürimäe and Jürimäe, 2001).

Experimental design

The subjects were tested on seven occasions over the six month training season (November to April) (Fiskerstrand and Seiler, 2004): at the beginning of the preparation period and after every four weeks during the 24-week preparation period before competition period. In these testing sessions, body composition, perceived recovery-stress state and fasting blood parameters were evaluated after a resting day (Mäestu et al., 2003). While maximal oxygen consumption and aerobic capacity values were determined twice, before and after the 24-week training period. Caloric intake was not measured in this study (Jürimäe and Jürimäe, 2001; Baylor and Hackney, 2003; Jürimäe *et al*., 2003). However, all athletes were instructed by experienced dietician during the whole study period and their daily food intake consisted of a high-carbohydrate diet with the composition remaining stable (Baylor and Hackney, 2003; Jürimäe *et al*., 2003). Estimation of training volume (hours per week) was obtained after calculation from individual training diaries kept by the rowers (Mäestu *et al*., 2003; Desgorces *et al*., 2004; Fiskerstrand and Seiler, 2004). During the 24-week preparation period, training was mainly organized as low-intensity prolonged training sessions (Fiskerstrand and Seiler, 2004). While on-water rowing training was mainly performed on single sculls. In March, from Week 16 to Week 20, rowers were in training camp in Spain, where training load was increased while intensity remained relatively unchanged.

The perceived recovery-stress state

The perceived recovery-stress state was assessed using the Recovery-Stress-Questionnaire for Athletes (RESTQ-Sport) (Kellmann and Kallus, 2001). The RESTQ-Sport was developed to measure the frequency of current stress along with the frequency of recovery-associated activities (Kellmann and Kallus, 2001). The specific characteristics of the RESTQ-Sport are that it allows systematic and direct measurement of appraised events, states, and activities regarding their frequency while simultaneously considering stress and recovery processes (Kellmann and Kallus, 2001). The estimation of the reliability of the Estonian version of the RESTQ-Sport, the translation from the English version (Kellmann and Kallus, 2001), was satisfactory (Cronbach alpha ranging from 0.71 to 0.94). Data were also pooled to obtain an overall average score and an estimation of the standard deviation (Kellmann and Kallus, 1999). Based on these data, a score was computed that possibly reflects the recovery-stress state for rowers (Kellmann and Kallus, 1999). The scores of stress-related scales were summed and divided by the number of scales representing the Standardized Stress. The same procedure was used for the recovery-oriented scales resulting a Standardized Recovery. The Standardized Stress as well as the Standardized Recovery were converted to standardized values by subtracting the global sample mean and dividing the difference by the standard deviation (Kellmann and Kallus, 1999). In this way, a standardized recovery and stress score could be obtained on a common scale, which allowed computing a difference between stress and recovery (Standardized RESTQ-Index). The factor analysis (Kellmann and Kallus, 2001) of the Estonian version of this questionnaire also demonstrated one stress-related and one recovery-related factor for the general as well as for the sport-specific parts of the RESTQ-Sport scales. 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 three 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 recovery activities (e.g. social activities, vacation, sauna, etc.) (Kellmann and Kallus, 2001).

Blood analysis

A 10-ml blood sample was obtained from an anticubital vein with the participant in the upright position. The plasma was separated and frozen at -20^0C for later analysis. Cortisol, testosterone and growth hormone were analysed in duplicate on Immunolite 2000 (DPC, Los Angeles, USA). The inter- and intra-assay coefficients of variation were less than 5%. Creatine kinase activity was measured by means of photometric method using a commercial kit (Boehringer Mannheim, Germany).

STATISTICAL ANALYSIS

Means and standard deviations were determined. Friedman analyses of variance by ranks were used to examine changes. The Wilcoxon matched-pairs signed-ranks test was used where post-hoc analysis was relevant. Kendall rank correlation coefficients were used to evaluate associations among different variables of interest. The level of significance was set at $P<0.05$.

RESULTS

The evolution of body composition during the study period is presented in Table 1. In comparison with the first measurement value (Week 0), body mass and FFM values were not changed over the training period. Body fat% and FM values demonstrated a significant decrease after the 8 and 12 training weeks compared to the first measurement session, respectively. However, body fat% and FM values returned to their pretraining levels after the 24-week training period. Significant increases in VO_{2max} (from 6.2±0.5 to 6.4±0.6 $l.min^{-1}$), $VO_{2max/kg}$ (from 67.6±3.0 to 69.2±3.1 $ml.min.^{-1}kg^{-1}$) and Pa_{max} (from 442.8±40.5 to 465.9±26.2 W) were observed as a result of 24-week training period.

At the beginning of the preparation period, the mean value of training volume was about 128 min per day (Figure 1). With regard to this initial value, there was a significant increase ($P<0.05$) after Week 8 to Week 20 (Week 8: ≈129 $min.day^{-1}$; Week 12: ≈135 $min.day^{-1}$; Week 16: ≈146 $min.day^{-1}$; Week 20: 167 $min.day^{-1}$). At the end of the study (Week 24), the mean training volume was about 116 $min.day^{-1}$. The Standardized RESTQ-Index did not change significantly over the 24-week preparation period in elite rowers. Standardized Stress score significantly changed after Week 12 compared to the pretraining score (Figure 1). While Standardized Recovery score was also significantly higher from Week 20 in comparison with pretraining value. When comparing the fasting cortisol concentrations with the first measurement, Weeks 12 and 20 show significant increases (Table 2). While fasting testosterone concentration demonstrated a significant increase after Weeks 4, 8 and 20 compared to the initial measurement (Week 0). Fasting growth hormone concentration did not change throughout the 24-week training period. Creatine kinase activity was significantly increased after the first four week training period and remained elevated until the end of the 20th week of training. After 24 weeks, all measured blood biochemical parameters were not different ($P>0.05$) from the values of the first measurement session.

Significant relationships were observed between mean weekly training volume, and fasting cortisol ($r=0.416$; $p=0.010$) and testosterone ($r=0.527$; $p=0.001$) values. Standardized Stress score was significantly related to fasting cortisol ($r=0.381$; $p=0.002$) and growth hormone ($r=0.284$; $p=0.021$) values. While Standardized Recovery was significantly related to fasting creatine kinase activity only ($r=-0.248$; $p=0.045$). In addition, RESTQ-Index was significantly related to fasting creatine kinase activity ($r=-0.299$; $p=0.015$), cortisol ($r=0.321$; $p=0.009$), growth hormone ($r=0.417$; $p=0.001$) and testosterone ($r=0.349$; $p=0.004$) values.

DISCUSSION

To achieve better rowing performance time over 2000-m course, aerobic capacity and lean body mass values should be improved using extensive endurance training sessions (Mäestu *et al.*, 2003; Petibois *et al.*, 2003; Fiskerstrand and Seiler, 2004). While elite athletes maintain a high level of fitness throughout the year, the high training volume exposure during the preparation period is at the possible tolerable threshold (Fiskerstrand and Seiler, 2004). As a consequence, this training implies energetic metabolism for endurance exercises, but also protein metabolism for muscular conditioning (Petibois *et al.*, 2003). It has been suggested that this kind of high volume training periods may faciliate long-term endocrine adaptations (Kjaer, 1998) and a greater capacity for sympathetic mobilization following low volume training periods and tapering for major competitions (Fiskerstrand and Seiler, 2004). The major problem for elite rowing training monitoring could be that the limit between adaptation and intolerance to high volume training load may not be accurately determined. Therefore, the aim of the present study was to describe training effects of typical preparation period of elite rowers using percieved recovery-stress state and fasting hormone parameters. A standardized testing session was performed seven times over the 24-week training period to monitor possible changes in these parameters.

A 24-week heavy training period resulted in significant improvements of all measured aerobic capacity values (e.g., VO_{2max}: from 6.2±0.5 to 6.4±0.6 l/min), indicating that the main aim of the preparation training period was successfully achieved (Fiskerstrand and Seiler, 2004). The aerobic capacity values were comparable with other results obtained from successful international level male rowers (Petibois *et al.*, 2003; Fiskerstrand and Seiler, 2004). Similarly, all measured body compositional parameters were at the same level with other international level male rowers (Petibois *et al.*, 2003; Fiskerstrand and Seiler, 2004). However, average training volume during this period was somewhat lower compared to elite Norweigian rowers who have won medals in international championships (Fiskerstrand and Seiler, 2004). This could be explained by the fact that rowers in our study were relatively young (20±3 years), while Norweigian rowers won their first championship medal at the age 24±2 years. It has to be considered that the athletes of our study had just achieved international level and were not able to train at very high training volume. However, two rowers were fourth and four rowers ninth in the championships that followed the preparation period. This indicates that our rowers have a potential to increase training volume and win medals in further championships.

In association with improved aerobic capacity parameters at the end of the preparation period, changes in circulating anabolic (testosterone and growth hormone) and catabolic (cortisol) hormone concentrations as well as in the activity of creatine kinase in blood were tracked several times throughout the 24-week training period. Though within the normal range reported in the literature (i.e., 10.4–41.6 nmol.l^{-1}) (Young, 1998), basal serum testosterone concentrations were considered somewhat low before (19.2±6.1 nmol.l^{-1}) and after (18.9±5.4 nmol.l^{-1}) 24-week training period in elite rowers indicating that athletes in this study had similar basal testosterone values with other endurance athletes (Mäestu *et al.*, 2003; Chennaoui *et al.*, 2004; Daly *et al.*, 2005). However, basal testosterone concentrations were significantly elevated after Weeks 4, 8 and 20 (see Table 2), showing a high anabolic profile of our athletes following hard endurance training sessions. Furthermore, basal testosterone was significantly related to mean weekly training volume (r=0.416; P=0.010). Although basal testosterone remained within normal recognized values, circulating values were considered high for the predominance of the preparation period indicating a positive anabolic adaptation (Kokolas *et al.*, 2004; Kraemer *et al.*, 2004) to endurance training as also demonstrated by improved aerobic capacity values. This does not necessary mean muscle hypertrophy as also indicated by no significant changes in FFM values throughout the study period (see Table 1), but may mediate increased expression of aerobic enzymes and/or adaptation in other processes, such as erythropoiesis (Kokolas *et al.*, 2004).

In similar fashion to the trends observed for basal testosterone, initial (393.9±145.6 nmol.l^{-1}) and Week 24 (336.6±73.3 nmol.l^{-1}) cortisol concentrations were considered somewhat lowered compared to the normal resting range of 138–635 nmol.l^{-1} (Young, 1998) but similar to the values obtained from other endurance athletes (Mäestu *et al.*, 2003; Chennaoui *et al.*, 2004; Daly *et al.*, 2005). Basal cortisol concentrations were also elevated for the predominance of preparation period indicating also a high catabolic environment of our athletes (Kokolas *et al.*, 2004; Kraemer *et al.*, 2004). Similarly to basal testosterone, basal cortisol was also significantly related to the mean training volume (r=0.527; P=0.001). It has to be considered that activation of catabolic processes are essential tools for adaptation in the high stress situation (Petibois *et al.*, 2003; Kraemer *et al.*, 2004). Furthermore, high basal cortisol levels suggest a high activity of the adaptation process, whereas a suppression from baseline levels is an indicator of significant reduction in the adaptation reserves of the organism (i.e., overtraining syndrome) (Urhausen *et al.*, 1995; Urhausen and Kindermann, 2002).

Although basal growth hormone concentrations were not significantly changed, they demonstrated a trend to increase during the course of the preparation period (see Table 2). This stress hormone data further confirm the information obtained from basal testosterone and cortisol levels and suggest a high resources of adaptivity of our athletes. In addition, it appears that basal growth hormone is less sensitive marker of training stress compared to other stress hormones of hypothalamus-pituitary-adrenocortical axis in typical elite rowing training during the preparation period. In a view of these adapted stress hormonal responses, it could be argued that athletes in our study could have used more their adaptation reserves before signs of overtraining syndrome could have occurred. This was further confirmed by the results of creatine kinase activity, which demonstrated a significant increase after Week 4 and was returned to the pretraining value only after Week 24 (see Table 2). It is well known that the value of creatine kinase activity is considered to be a marker of the mechanical-muscular strain of training because of muscle cell leakage or damage, and the morning levels represent mainly the creatine kinase release during the previous days (Urhausen and Kindermann, 2002). The normalization of the creatine kinase activity demonstrates a reduced muscle stress (Hartman and Mester, 2000). While creatine kinase activity was measured highest after Week 12 (484.9±218.4 $U.l^{-1}$), creatine kinase activity values were not very high throughout the 24-week study period suggesting that the muscular system adapted well to such training loads (Hartman and Mester, 2000). Conspicuously elevated values in elite athletes have been reported to occur when creatine kinase activity reaches 1000 $U.l^{-1}$ and more (Hartman and Mester, 2000). The hormonal results of this tracking study over the preparation period in elite rowers suggest that rowers adapted well to high endurance training load and no overtraining syndrome could have been detected at any measurement point.

In accordance with hormonal values, simultaneously assessed perceived recovery-stress state also demonstrated that rowers did not use all their adaptation resources during the preparation period but adopted positively to training stress (see Figure 1). The RESTQ-Sport for Athletes questionnaire allows the assessment of subjective stress and recovery during the all year-round training and preparing for major competitions in different athletes (Kellmann and Kallus, 1999; Kelmann and Günther, 2000). It has been suggested that the Standardized RESTQ-Index could be used as an athletes` resource measure taking into account perceived stress- and recovery-associated aspects at the same time (Kellmann and Kallus, 1999; Mäestu *et al*., 2005). In our study, RESTQ-Index did not change significantly over the 24-week training period. This would suggest that the training volume during the preparation period did not affect seriously the psychological resources of adaptivity in our rowers. However, RESTQ-Index demonstrated a dose-response relationship with rapid and heavy increases in training volume in our previous overreaching study in highly trained male rowers (Mäestu *et al*., 2005). According to the results of these studies, it could be speculated that RESTQ-Index can be used to detect overreaching and/or overtraining syndrome in elite rowing training. However, when Standardized Stress and Standardized Recovery scores were presented separately (see Figure 1), it showed that Standardized Stress (after Week 12) and Standardized Recovery (after Week 20) scores even improved during the course of the preparation period in elite rowers. This could be explained by the fact that when our rowers started to train hard and specially at training camp, they did not have to deal with everyday problems and they had more time for various recovery activities. This further demonstrates that the current psychological adaptation state of an athlete appears to be very complex. Adequate recovery periods during phases of heavy training allow the adaptation of the athlete to physical stress and prevents overtraining (Raglin, 1993).

The interesting finding of our study was that significant relationships were found between basal cortisol and Standardized Stress (r=0.381; P=0.002) and RESTQ-Index (r=–0.321; P=0.009) scores. In addition, basal testosterone (r=–0.349; P=0.004) and growth hormone (r=–0.417; P=0.001) were related to RESTQ-Index. These close relations between hormonal and psychometric response are very intriguing from a multi-level approach of training monitoring. The hypothalamus has an important role in integrating different stress influences and the answers from the hypothalamus are expressed via the endocrine system, the autonomic nervous system and the behaviour (Barron *et al.*, 1985). Changes in basal cortisol levels reflect the metabolic stress as the endpoint of the hypothalamus-pituitary-adrenocortical axis (Barron *et al.*, 1985; Hackney, 1999). Accordingly, changes in basal cortisol have been identified as metabolical signs of changes in psychological adaptation resources (Barron *et al.*, 1985; Weidenfeld *et al.*, 1990). Currently, it is mainly a subject of speculation how the hypothalamus senses metabolic dysbalance (Barron *et al.*, 1985; Weidenfeld *et al.*, 1990). Similarly, Standardized Recovery score was related to creatine kinase activity (r=–0.299; P=0.015), which has been measured as an essential indicator for determination of muscular stress (Hartman and Mester, 2000). This further confirms the need for a multi-level approach of training monitoring in elite rowers.

In summary, testosterone and cortisol appears to be more sensitive to changes in training volume in typical elite rowing training during preparation period. Increases in these stress hormone concentrations represent positive adaptation to current training load. Significant relationships between hormonal and perceived recovery-stress state suggest that metabolic and psychological changes should be carefully monitored to avoid unfavourable outcome on the training status in elite rowers.

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Table 1. Body compositional parameters of elite rowers during the study period.

Week	Body mass (kg)	Fat free mass (kg)	Fat mass (kg)	Body fat (%)
0	91.6±5.8	80.6±4.3	11.0±2.1	12.0±1.6
4	92.1±5.8	81.2±4.1	10.9±2.0	11.7±1.5
8	92.1±5.7	81.5±4.5	10.7±1.7	11.6±1.3#
12	93.3±5.5	82.3±3.9*	10.5±1.9#	11.2±1.5*#
16	93.7±5.0	82.4±3.9	10.8±1.6*	11.6±1.3*
20	92.4±4.8*	81.8±3.7	10.6±1.5	11.4±1.3#
24	93.1±5.7	81.8±4.2	11.3±1.9*	12.1±1.4*

* Significantly different from previous measurement week; $p<0.05$.
# Significantly different from Week 0; $p<0.05$.

Table 2. Blood biochemical parameters of elite rowers during the study period.

Week	Cortisol (nmol/l)	Testosterone (nmol/l)	Growth hormone (µlU/ml)	Creatine kinase (U/l)
0	393.9±145.6	19.2±6.1	0.87±0.77	269.6±128.8
4	474.6±115.1	26.0±4.2*#	0.94±0.71	359.7±190.1*#
8	446.9±67.9*	22.7±8.8#	2.42±3.49	469.0±180.3#
12	495.8±111.5#	25.3±7.2	1.93±2.96	484.9±218.4#
16	489.1±101.3	23.9±6.0	1.99±2.83	430.5±204.2#
20	560.7±78.2#	29.8±8.0*#	0.88±0.97	406.1±235.6#
24	336.6±73.3*	18.9±5.4*	0.91±1.80	285.4±100.1*

* Significantly different from previous measurement week; $p<0.05$.
# Significantly different from Week 0; $p<0.05$.

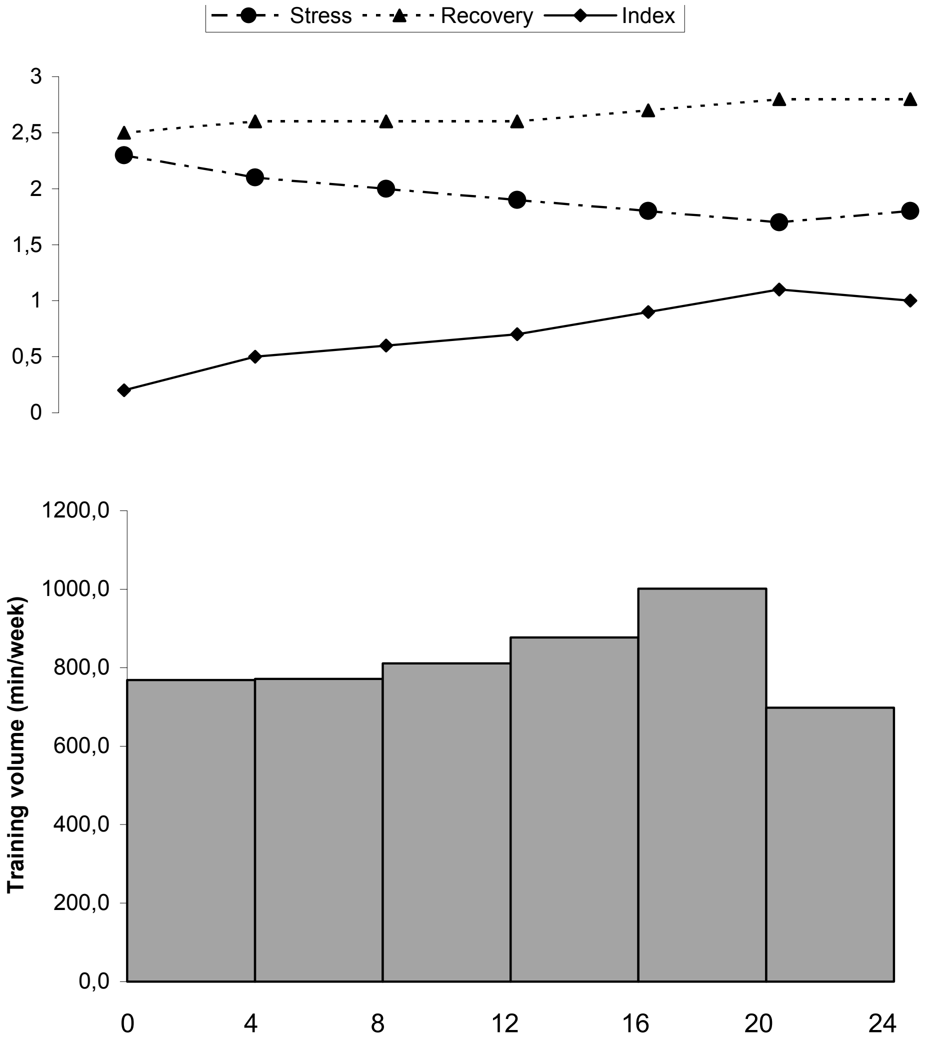

Fig. 1. Mean weekly training volume, RESTQ-Index, Standardized Stress and Standardized Recovery scores of elite rowers during the study period.

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Educational Career

2003–2006	Doctoral study. Faculty of Exercise and Sport Sciences, University of Tartu.
2003	MSc, Faculty of Exercise and Sport Sciences, University of Tartu.
2001–2003	Physical education teacher training, Faculty of Exercise and Sport Sciences, Physical Education Theacher in Gymnasium, University of Tartu
1997–2001	BSc, Faculty of Exercise and Sport Sciences, University of Tartu.
1985–1997	Tartu 3. Secondary School.

Professional Employment

2003–	Researcher at the University of Tartu, Institute of Sport Pedagogy and Coaching Sciences.
2002–2003	Physical education teacher in Tartu Annemõisa school
1998–2003	Rowing trainer in rowing club “Tartu”

Special courses

2005	International summer course for PhD students in Kääriku
2002	ERF rowing coaching level II license
2001	Studing at the University of Graz in Austria (3 months)
1998	ERF rowing coaching level I license

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Töökogemus

2003–	Tartu Ülikool, Spordipedagoogika õppetooli teadur
2002–2003	Tartu Annemõisa Kooli kehalise kasvatuse õpetaja
1998–2003	Sõudmistreener Sõudmise ja aerutamise keskuses “Tartu”

Erialane enesetäiendus

2005	Rahvusvaheline doktorantide suvekursus Käärikul.
2002	Sõudeliidu sõudmistreeneri II astme lintsens
2001	Õpingud Austrias Grazi Ülikoolis (3 kuud)
1998	Sõudeliidu sõudmistreeneri I astme litsens

Peamised uurimisvaldkonnad

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- Treeninguõpetus