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Prediction of rowing performance from anthropometric and metabolic variables in lightweight and heavyweight male rowers

Master Thesis

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Mäestu J, Jürimäe J, Jürimäe T (2000) Prediction of rowing performance from aerobic and anaerobic components in lightweight rowers. *Acta Academiae Olympiquae Estoniae* 8: 86-95.

Mäestu J, Jürimäe J (2000) Anthropometrical and physiological factors of rowing performance: a review. *Acta Kinesiologiae Universitatis Tartuensis* 5: 130-150.

Abstracts

Jürimäe J, Jürimäe T, Mäestu J, Pihl E (2000) Aerobic metabolism, anaerobic metabolism and rowing performance on single sculls. *Medicine and Science in Sports and Exercise* 32(5): S335.

Mäestu J, Jürimäe J, Jürimäe T, Pihl E (2000) Influence of resting levels of anabolic and catabolic hormones and anthropometric variables on the 2000 metre rowing performance in single sculls. *The Proceedings of the Modern Olympic Sport: International Scientific Congress.* Kyiv, Ukraine. P. 65.

Jürimäe J, Mäestu J, Jürimäe T (2000) Interrelations between selected anthropometric and metabolic characteristics in lightweight rowers. *5th Annual Congress of the European College of Sport Science*. Jyväskylä, Finland. P. 366.

Jürimäe J, Jürimäe T, Mäestu J, Pihl E (2000) Prediction of 2000-m rowing performance on single sculls from metabolic and anthropometric variables. *Journal of Sports Sciences* 18(7): 514-515.

Mäestu J, Jürimäe J, Jürimäe T, Pihl E. Antropomeetriliste ja funktsionaalsete näitajate kasutamine võistlustulemuse hindamisel kergekaalu ja raskekaalu sõudjatel. Teadus,sport ja meditsiin. Konverentsi kogumik, 2000, lk: 60.

Populaarteaduslikud väljaanded

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Mäestu J, Jürimäe J. Sõudetreeningu organiseerimise erinevad aspektid. Eesti sõudja 2001, 1: 17 – 19.

1 INTRODUCTION

A typical rowing competition takes place over a 2000 metre course and lasts about 6 – 7 minutes depending on the boat type. A rower has to perform about 250 strokes during this time. Rowing demands a high level of strength and endurance. A large body mass is involved in rowing and body size and body mass are undoubtedly performance related factors (Shephard 1998; Steinacker 1993). Rowing is divided into two categories – sculling (rowers use two oars) and sweep (rowers use one oar) rowing. Differences in anthropometric and metabolic characteristics have been observed between those groups. Rowing competitors are also divided in two categories – lightweight and heavyweight rowers. In lightweight rowing, the maximal body mass of a male rower may reach 72.5 kg and the average of a crew 70.0 kg in male rowers.

The performance of a crew can be measured by their 2000 metre rowing race time. However, it is very difficult to assess physiological parameters during on-water rowing, because of the possible wind and current (Jensen 1994; Shephard 1998). Graven et al. (1993) analysed the rowing stroke on a Concept II (Morrisville, USA) rowing ergometer and concluded that it provides a close approximation to the movements of the rowing stroke and allowes accurate measurements of the physiological changes produced during rowing. Although rowing on an ergometer does not require the same skills as on-water rowing, it has been observed that the ergometer simulates the biomechanical and metabolic demands of on-water rowing (Lamb 1989; Mahony et al. 1999; Rodriguez et al. 1990). Therefore, rowing ergometers are commonly used to measure individual physiological performance variables and training changes (Bouckaert et al. 1983; Hahn et al. 1988).

The 2000 metre time trial on a rowing ergometer has widely been used to assess rowing performance (Cosgrove et al. 1999; Russell et al. 1998; Womack et al. 1996). However, research has demonstrated that 2000 metre rowing ergometer race is significantly faster, and therefore more intensive than 2000 metre on-water rowing race (Jürimäe et al. 1999b). Accordingly, 2000 metre rowing ergometer time trial may not exaclty reflect the metabolic effort of on-water rowing. 2500 metre time trial on a rowing ergometer has been used to assess rowing performance (Kramer et al.

1994; Messonnier et al. 1997). In this experiment, a 2500 metre rowing ergometer race was used to assess rowing performance in male lightweight and heavyweight sculling rowers.

The development of models based on laboratory data, by which performance in everyday skills can be predicted, is of enduring intrest and has practical importance for talent identification and for the development and assessment of activity-specific training programmes. In addition, performance prediction modelling has a contribution to make to understanding the physiological characteristics of a given activity (Russell et al. 1998). Performancce prediction models have successfully been developed for running (Morgan et al. 1989), cycling (Craig et al. 1993) and junior sweep rowing (Russell et al. 1998). To our knowledge, no studies have carried out to develop performance prediction models for lightweight and heavyweight sculling rowers. In this experiment performance prediction models were developed for male lightweight and heavyweight sculling rowers using different anthropometric and metabolic variables.

2 REVIEW OF LITERATURE

2.1 Anthropometrical parameters

In rowing, which is a strength-endurance type of sport, body size and body mass are undoubtedly performance related factors (Bourgois et al. 1998; Shephard 1998). A rower has to develop more than 200 times a stroke with a peak force of 800 to more than 1000 Newton (Table 1) (Steinacker 1993). Maximal strength and strength endurance are therefore basic components of their year round training program (Bourgois et al. 1998; Steinacker et al. 1998). Both components are related to body size and body mass (Figure 1) (Bourgois et al. 1998).

Table 1. Peak force, peak power and power per stroke during 2000 metre rowing race in the single scull.

	Time (s, min)	Peak force (N)	Peak power (W)	Power per stroke (W)
Start spurt	0 – 10	1000 – 1500	2500 – 3000	800 – 1200
Start phase	10 – 60	600 – 800	1400 – 2800	700 – 1000
Race	1 – 5	500 – 700	1000 – 1600	600 – 900
Final spurt	5 – 6	600 - 700	1300 - 1800	750 – 1000

Rowing is a weight-supported sport (Shephard 1998). Nevertheless, the resistance to forward movement of the boat is approximately proportional to the 2/3rd power of the weight of the vessel and its crew members (Secher 1990). Except in competitions with the lightweight categorie, it is advantageous to recruit rowers with a massive body build, thereby ensuring that a high proportion of the total mass transported is active muscle, rather than the “dead-weight” of the cox and the vessel itself (Shephard 1998; Steinacker 1993).

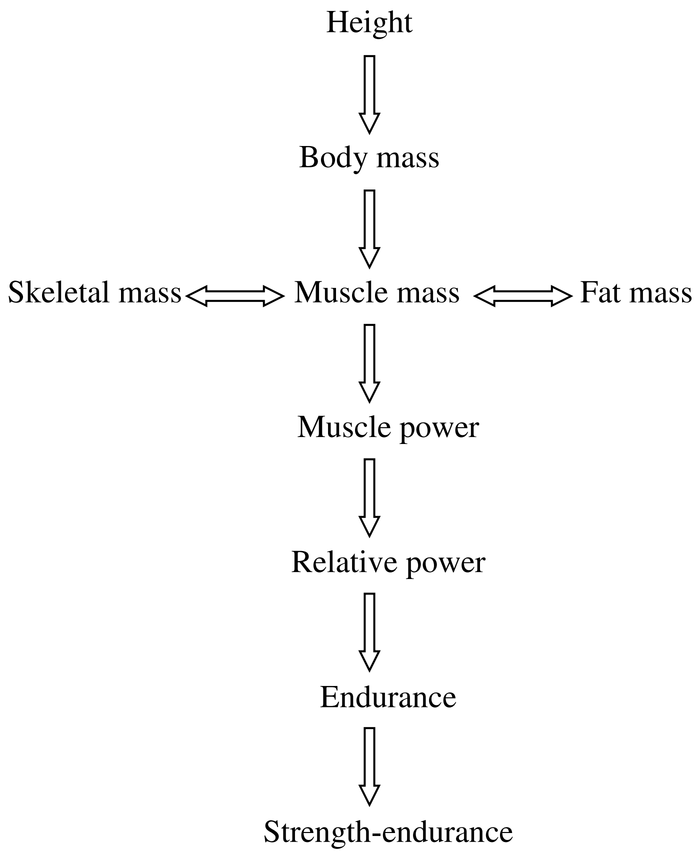

Figure 1. Relationships between anthropometrical parameters and strength-endurance in rowers.

The anthropometric profiles of rowers have extensively been studied (Table 2). It is an advantage for the rower to be tall (Secher 1993; Shephard 1998). Usually, elite rowers are more than 190 cm tall and weigh 90 – 95 kg (Secher 1993). Long arms are particulary helpful in giving extra leverage (Shephard 1998). Ideally, the body mass of rowers should contain a high proportion of muscle mass (Bourgois et al. 1998; Jürimäe et al. 1999a; Shephard 1998). For example, muscle mass of Estonian national level heavyweight rowes was found to be 49.5 kg, which corresponded to 62.3% of their body mass (Jürimäe et al. 1999a). Bourgois et al. (1998) found that the muscle mass of 168 male junior rowing world championship competitors was 50.2 kg and 62.4% of the whole body mass. A large muscle mass does not penalize rowers, whose body mass is supported in the boat (Cosgrove et al. 1999). Significant correlations between muscle mass and 2000 metre rowing ergometer time trial ($r \geq -0.85$) have been found (Cosgrove et al. 1999; Jürimäe et al. 1999a). Furthermore, Jürimäe et al. (1999a) reported a significant relationship between muscle mass and 2000 metre rowing performance time on single sculls in male rowers ($r = -0.64$). The percentage of body fat seems to have been decreasing in recent years (Shephard 1998). Carter (1982) found means of 7.8% in men participating in the 1976 Montreal Olympics and McKensie et al. (1982) reported a mean of 9.6% for the Canadian 1980 Olympic team. Hagerman et al. (1983) found no changes for body composition parameters between in-season and off-season among 1984 USA Los Angeles Olympic team. However, lightweight rowers tend to reduce their body fat% for competition season. For example, Morris et al. (1996) reported that male lightweight rowers reduced their body fat% from 10.0% to 7.8% while no changes in fat-free mass were observed.

Table 2. The anthropometric parameters of male rowers.

	Height (cm)	Body mass (kg)	Body mass index (kg.m^{-2})	Body fat %	Author
Heavyweight					
Sculling rowers in 1997 Junior World Championships (n = 168)	186.5±6.3	80.4±6.9	23.1±1.6	11.5±2.2	Bourgois et al. (1998)
Sweep rowers in 1997 Junior World Championships (n = 214)	188.2±5.3	83.6±7.5	23.6±1.8	11.8±2.6	Bourgois et al. (1998)
All rowers in 1997 Junior World Championships (n =382)	187.4±5.8	82.2±7.4	23.4±1.7	-	Bourgois et al. (1998)
World champions and Olympic winners (n = 2)	197	99	25.5	-	Larsson et al. (1980)
Participants of 1968 Olympic Games (n=85)	185.1	82.6	24.2	-	De Garay et al. (1974)
Participants of 1976 Olympic Games (n=65)	191.3	90.0	24.7	-	Carter et al. (1982)
Dutch national team 1988 (n = 18)	190.0	79.3	22.0	-	Rienks et al. (1991)

Table 2. (continued) The anthropometric parameters of male rowers.

	Height (cm)	Body mass (kg)	Body mass index ($kg.m^{-2}$)	Body fat%	Author
International level German rowers (n = 28)	194	89	23.6	-	Hagerman et al. (1990)
International level German rowers (n = 9)	187.2±4.9	81.1±6.3	23.2±5.6	-	Beneke (1995)
International level French rowers (n = 12)	182.0±5.0	77.0±7.0	23.2±6.0	-	Messonnier et al.(1997)
National level Estonian rowers (n = 10)	186.2±1.7	79.3±7.3	22.8±1.0	10.5±2.3	Jürimäe et al. (1999b)
National level Danish rowers (n = 139)	183.5±2.7	74.8±4.1	22.3±4.3	11.8±2.6	Jensen (1994)
Lightweight					
USA olympic team (n = 12)	183.0±3.0	72.2±1.4	21.5±2.1	-	Hagerman et al. (1983)
Participants of 1985 world championships (n = 144)	180.7	70.3	21.7	-	Rodriguez (1986)
National level Australian rowers (n = 18)	180.5±2.7	69.8±1.6	21.5±2.1	7.8±0.8	Morris et al. (1996)
National level Danish rowers (n = 68)	183.0±4.5	74.5±3.0	22.5±3.8	11.1±1.9	Jensen (1994)

In the men, the world champions were 10.0% taller and 27.2% heavier than the general Canadian population (Secher 1990). Hirata (1979) also pointed out that gold medal winners were consistently taller and heavier than the average for national champions. In the case of single sculls, the respective differences were a substantial 0.12 metre and 9.6 kg. Hahn (1990) suggested that more successful rowers are tall, heavy and possess a low skinfold reading. Malina (1994) noted that promising rowers were already taller than the general population during childhood and they maintained their relative advantage throughout adolescence.The most able young rowers could be distinguished by their height, skeletal robustness and muscular development (Piotrowski et al. 1992). Carter (1982) suggested that the body dimensions of national level contestants were increasing by about 0.02 metre and 5.0 kg per decade.

Comparing different boat classes, Hirata (1979) found that sweep rowers were consistently taller and heavier than sculling rowers, the difference amounting to some 0.02 metre and 3.8 kg for men. In competitions where a cow was carried, there were further small increases in the height and body mass of the successful rowers, 0.03 metre and 5.0 kg in the case of male pairs (Hirata 1979). Bourgois et al. (2000) investigated the participants of the 1997 Junior World Championships and found that the limbs of sweep rowers were taller than the limbs of sculling rowers. Sweep rowers had also bigger girths than scullers, but no differences were found in skinfold thicknesses (Bourgois et al. 2000). Furthermore, no differences were found in bone diametres between sweep and sculling rowers (Bourgois et al. 2000). In addition significant differences in anthropometrical parameters were also observed between finalists and non-finalists (Table 3) (Bourgois et al. 2000). The finalists were reported to be taller, heavier and presented larger girth values in comparison with non-finalists (Bourgois et al. 2000).

Table 3. Differences for male junior rowers participating in 1997 Junior World Championships by performance: finalists and non-finalists. All parameters are significantly higher in finalists (p<0.01).

	Finalists (n = 144)	Non-finalists (n = 222)
Body mass (kg)	84.8±7.1	80.6±7.0
Height (cm)	189.3±5.0	186.3±6.1
Sitting height (kg)	97.6±2.9	96.2±3.3
Leg length (cm)	91.6±3.5	90.1±4.0
Arm length (cm)	83.7±3.0	82.4±3.4
Thigh girth (cm)	58.7±3.4	57.5±3.2
Calf girth (cm)	38.1±1.9	37.5±1.9
Forearm girth (cm)	29.1±1.2	28.2±1.3

The anthropometric characteristics of lightweight rowers differ radically from those of their heavier peers (Mahler et al. 1984; Shephard 1998). In male competitors, de Rose et al. (1989) found no significant differences in anthropometric characteristics between lightweight rowers and untrained student controls. The advantage of heavyweight rowers over lightweight rowers in smaller distances (up to 500 metres) has been calculated to be about 4.0% which is reduced to 2.5% on the 2000 metre distance and remains about the same as the distance gets longer (Steinacker 1993).

In summary, rowers are tall and have relatively high muscle mass. Sweep rowers are usually taller and heavier and have longer limbs than the scullers. In recent years, the height and body mass of rowers has increased, while the percentage of body fat has decreased.

2.2 Physiological aspects of rowing

Rowers are strong, reflecting their large body dimensions, but their maximal muscle strength is not correlated in any simple way to their rowing strength (Secher 1993). Their body mass is supported while seated in the boat (Cosgrave et al. 1999; Steinacker 1993). Rowing is a sport in which about 70% of the whole body muscle mass is involved (Shephard 1998; Steinacker et al. 1998). They are unique in their ability to develop a strength with the use of both legs which corresponds to the sum of strength of the right and left legs (Secher 1993).

Corresponding to the relative low duty cycle (approximately 36 strokes per minute), the strength of rowers is more pronounced at low contraction velocities (Secher 1993; Shephard 1998). For the muscles engaged in rowing, the percentage of slow-twich oxidative muscle fibers is approximately 70% (Secher 1993; Steinacker 1993). Differences were also found between the structure of muscles in highly and less qualified rowers, although they have trained similary with respect to time and volume (Steinacker 1988). In internationally successful competitive rowers, slow-twich oxidative muscle fiber content has been reported to be as high as 85%, with few fast-twitch glycolytic fibers in the *vastus lateralis* muscle (Roth et al. 1983; Steinacker 1993). Muscle hypertrophy is also evident in rowers (Secher 1993; Shephard 1998; Steinacker 1993). Hypertrophy is found not only in fast-twich glycolytic and oxidative-glycolytic muscle fibers, but also in slow-twich oxidative muscle fibers (Howald 1982). The hypertrophy is more evident in internationally successful rowers (Roth 1991). Muscle hypertrophy as a result of training is primaly caused by the volume expansion of single fibers (Roth et al. 1983; Steinacker 1993). The muscle structure also depends on the biomechanical requirements of different boat seats (Roth et al. 1983).

The lungs of rowers reflect their large body dimensions. Rowers have large vital capacities with a highest recorded value of 9.1 litres, and the better rowers tend to have relatively large values of their vital capacity (Secher 1993). As with other types of exercise, ventilation increases during ergometer (Mickelson et al. 1982) and on-water (Secher 1983) rowing in proportion to the increase in oxygen consumption to a certain point, after which a more marked increase takes place (Secher 1993). The highest recorded value has reported to be 243.0 $l.min^{-1}$ (Secher 1993). Hagerman et al. (1978) found the highest ventilation value of 221.0 litres in 310 competitive rowers, while maximal ventilation averaged 200.0 $l.min^{-1}$ in world championships winners (n = 14) (Secher 1983). For a given oxygen consumption, ventilation is low in trained rowers (Secher 1983).

The position of the body and the use of respiratory muscles in rowing may limit ventilation and thereby reduce maximal aerobic power relative to that achieved in cycling or treadmill running (Smith et al. 1994). The results of different investigations have showed that ventilation at a given maximal oxygen consumption during intense submaximal rowing exercise (higher than 75% of maximal oxygen consumption) is not significantly lower compared with that in cycling and treadmill running, which would suggest that submaximal rowing does not restrict ventilation (Smith et al. 1994). At maximal effort, maximal oxygen consumption and ventilation for rowing are less than those for the other types of exercise, although the differences are not statistically different in elite rowers (Smith et al. 1994). These data are consistent with a ventilatory limitation to maximal performance in rowing that may have been partly overcome by training in elite rowers. Alternatively, a lower maximal ventilation in rowing might have been an effect rather than a cause of a lower rate of muscle activation in rowing (Smith et al. 1994). Szal et al. (1989) found that breathing rates are higher for a given intensity of submaximal effort during rowing than during cycling.

Hyperventilation during rowing is more marked than during cycling and is associated with a higher breathing frequency (Szal et al. 1989). A high breathing frequency during rowing in trained rowers reflects that respiration is coupled to the rowing stroke (Mahler et al. 1991). Furthermore, inspiration is relatively short during the drive phase of the stroke (Secher 1993). As elite rowers make two inspirations during one drive cycle (Mahler et al. 1985), then less qualified rowers are able to make only 1.48 inspirations during one drive cycle (Steinacker, 1993). Therefore, some changes in breathing frequency take place as the qualification gets better in rowers.

In summary, elite rowers have more slow-twich oxidative muscle fibers in their working muscles than less qualified rowers. As rowing is very intensive, rowers present high vital capacity and ventilation values in comparison with other sportlers.

2.2.1 Aerobic power

During competition, a rower depends mainly 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 (Steinacker 1993). Aerobic power can be defined as the maximal oxygen consumption as estimated during a performance that lasts two to 10 minutes (Jensen 1994). Aerobic and anaerobic energy contributions on a 2000 metre rowing race in different studies are presented in Table 4. According to Roth et al. (1983), the energy of the 2000 metre race was provided 67% aerobically and 33% anaerobically, 21% alactic and 12 % lactic. While Secher et al. (1982) found that the aerobic energy contribution may be up to 86%.

Table 4. Mean contribution of aerobic and anaerobic energy during rowing in different studies using elite heavyweight male rowers.

Studies	n	Aerobic contribution %	Anaerobic contribution %
Russell et al. (1998)	19	84	16
Droghetti et al. (1991)	19	80	20
Hagerman et al. (1978)	310	70	30
Hartmann (1987)	17	82	18
Mickelson et al. (1982)	25	72	28
Roth et al. (1983)	10	67	33
Secher et al. (1982)	7	70 – 86	14 – 30
Messonnier et al. (1997)	13	86	14

Maximal oxygen consumpton of rowers has extensively been studied (Table 5). Values for maximal oxygen consumption have increased over the years from approximately 3.4 $l.min.^{-1}$ (Secher 1993). In world class rowers, maximal oxygen consumption reaches 6.0 – 6.6 $l.min^{-1}$ (DiPrampero et al. 1977; Shephard 1998; Steinacker 1993). According to Secher (1993), maximal oxygen consumption values may approach an average of 6.4 to 6.6 $l.min.^{-1}$ in heavyweight rowers. While maximal oxygen consumption is often large in rowers, this finding reflects mainly their large body dimensions (Secher 1993). The relative oxygen consumption is relatively low in rowers compared to other endurance athletes because of their high body mass (Hagermann 1984; Secher et al. 1983; Steinacker 1993) and those with the highest value expressed in litres per minute will tend to show the lowest relative value (Jensen et al. 1984). Only in some, mainly in lightweight rowers, relative oxygen consumption reaches 75 ml. $min.^{-1}kg^{-1}$ (Secher et al. 1983; Shephard 1998; Steinacker 1993).

Maximal oxygen consumption is an important predictor of competitional success (Figure 2), although its predictive influence varies in different analyses (Secher et al. 1983; Steinacker 1993). For example, the correlations of r = -0.64 to r = -0.87 between maximal oxygen consumption and on-water rowing performance have been found (Cosgrave et al. 1999; Jürimäe et al. 1999b; Kramer et al. 1994; Secher et al. 1982). Maximal oxygen consumption depends on the content of slow-twich oxidative muscle fibers as well as the level of anaerobic threshold (Shephard 1998; Steinacker 1993).

Maximal oxygen consumption increases with training distance per year, but levels off at training volumes of approximately 5000 – 6000 km per year (Steinacker 1993). Seasonal changes have been described in maximal oxygen consumption. Maximal oxygen consumption may increase 5 – 15 ml. $min.^{-1}$ kg^{-1} during the competitive season (Steinacker 1993). Hagerman et al. (1983) reported maximal oxygen consumption to increase from 5.1 to 6.0 $l.min.^{-1}$ from off-season to in-season

Tabel 5. Maximal oxygen consumption in male rowers.

Subjects	$l.min.^{-1}$	$ml.min.^{-1}kg^{-1}$	Study
Heavyweight			
Winners of international regattas (n = 14)	5.8	63.0	Secher et al. (1983)
Participants of international regattas (n = 13)	5.5	67.0	Secher et al. (1983)
USA olympic team (n = 14)	6.0	69.1	Hagerman et al. (1983)
International Italian and Danish rowers (n = 18)	5.7±0.4	-	Jensen et al. (1993)
International German rowers (n = 310)	5.9	67.6	Hagerman et al. (1978)
International English rowers (n = 13)	5.7±0.1	-	Doherty et al. (1999)
International Polish rowers (n = 168)	5.2±0.4	60.5±3.2	Klusiewicz et al. (1997)
International level French rowers (n = 13)	4.9±0.3	64.8±5.5	Messonnier et al. (1997)
National level German rowers (n = 13)	4.6±0.6	59.8±8.1	Urhausen et al. (1993)
National level English rowers (n = 25)	4.7±0.4	-	Lakomy et al. (1992)
National level Finnish rowers (n = 25)	5.1±0.4	-	Peltonen et al. (1992)
National level Estonian rowers (n = 10)	4.9±0.6	61.6±5.6	Jürimäe et al. (1999b)
National level Scottish rowers (n = 13)	4.5±0.4	-	Gosgrove et al. (1999)

Tabel 5. Maximal oxygen consumption in male rowers (continued).

Subjects	$l.min.^{-1}$	$ml.min.^{-1}kg^{-1}$	Study
National level USA rowers (n = 10)	4.6±1.5	-	Womack et al. (1996)
National level Swedish rowers (n = 10)	5.1	-	Larsson et al. (1980)
Lightweight			
German lightweight team (n = 10)	5.1	72.0	Secher et al. (1983)
Danish lightweight team (n = 68)	5.2±0.1	-	Jensen (1994)
International Irish lightweight rowers (n = 10)	5.6±0.3	-	Mahony et al. (1999)
Juniors			
English juniors (n = 9)	4.5±0.1	-	Doherty et al. (1999)
Polish juniors (n = 8)	4.9±0.4	58.7±5.1	Faff et al. (1993)
Australian juniors (n =19)	4.6±1.5	-	Russell et al. (1998)
Belgian juniors (n = 10)	4.1±0.4	-	Bourgois et al. (1998)

Figure 2. Maximal oxygen consumption of a crew and its placing in an international regatta.

among USA 1984 Olympic rowing team, while maximal heart rate showed no statistically significant changes. Pronounced decreses in maximal oxygen consumption of highly trained rowers take place if during off-season the distance rowed is reduced below approximately 100 km per week (Steinacker 1993).

However, although research has consistently demonstrated that success in rowing is associated with a high peak VO_{2max} (Cosgrove et al. 1999; Jürimäe et al. 1999a), peak VO_{2max} alone is not a good predictor of rowing performance when rowers of similar endurance ability are compared (Steinacker 1993). It has been suggested that the submaximal endurance capacity measured at the power which elicits a blood lactate level of 4.0 $mmol.l^{-1}$ has been reported to be the most predictive parameter for competition performance in trained rowers, especially in small boats such as singles and doubles (Beneke 1995; Jürimäe et al. 1999; Secher 1993; Shephard 1998; Steinacker 1993; Wolf and Roth 1987). Other investigations have demonstrated that rowers with high absolute maximal oxygen consumption at a blood lactate concentration of 4.0 mmol.l^{-1} perform better in six or seven minute maximal tests than rowers with low maximal oxygen consumption at the same level of blood lactate concentration (Steinacker 1993). In highly trained rowers, the power at a blood lactate level of 4.0 mmol.l^{-1} corresponds to approximately 80 – 85% of maximum performance (Steinacker 1993). The maximal oxygen consumption at the power of 4.0 mmol.l^{-1} blood lactate has been reported to be approximately 85% of maximal oxygen consumption (Steinacker 1993).

Nowadays, the blood lactate response to exercise is commonly accepted as a tool for performance assessment and training prescription (Steinacker 1993; Tokmakidis et al. 1998). The blood lactate response has been investigated thoroughly and described using variety of terms and definitions (Bishop et al. 1998; Tokmakidis et al. 1998). The anaerobic threshold has been one of the most commonly used terms for describing the blood lactate response. Anaerobic threshold can be defined as the workload that can be performed by the oxidative metabolism and at which blood lactate production and release are balanced during continuous exercise (Bishop et al. 1998; Kindermann et al. 1979; Steinacker 1993; Tokmakidis et al. 1998).

To determine anaerobic threshold, numerous concepts and definitions have been published in the last decades. A number of methods are based on the observation that blood lactate levels change suddenly at some critical work rate and thus reflect a threshold phenomenon (Brooks 1985). For example, some authors consider the anaerobic threshold to be the work rate at which the lactate concentration first begins to increase above the resting level (Yoshida et al. 1987), whereas others have suggested an increase of 1.0 mmol.l^{-1} above baseline during incremental exercise (Coyle et al. 1983). To overcome the disadvantage of visual, subjective determination of anaerobic threshold, lactate parameters may also be identified by using various curve fitting procedures such as log-log transformation, where log (lactate) is plotted against the log (power output) (Beaver et al. 1985), the D_{MAX}, method identified as the point on the regression curve that yielded the maximal perpendicular distance to the strait line formed by the two end data points (Cheng et al. 1992), or a modified D_{MAX} method (D_{MOD}), described by the point on the polynomal regression curve that yielded the maximal perpendicular distance to the strait line formed by final lactate point and the point where the first increase in blood lactate concentration above the resting level and the final lactate point during an incremental exercise (Bishop et al. 1998) (see p. 32). Other investigations have proposed a fixed lactate level to define and detect anaerobic threshold. For example, values of 2.0 $mmol.l^{-1}$ (LaFontaine et al. 1981), 3.0 $mmol.l^{-1}$ (Föhrenbach et al. 1987) and 4.0 $mmol.l^{-1}$ (Kindermann et al. 1979) have been proposed. However, although a number of competing models exist to fit blood lactate concentration data during incremental ecercise, there has been little comparison between different concepts in rowers.

Muscular structure plays also an important role in submaximal performance (Steinacker 1993). With a higher percentage of slow-twich muscle fibers, rowers are able to perform with more power per stroke at a blood lactate concentration of 4.0 $mmol.l^{-1}$ (Steinacker 1993). However, specific endurance training increases the work rate per stroke at a given blood lactate level, without changing the slow-twich muscle fiber content mainly due to higher oxidative capacities of fast-twich muscle fibers (Howald 1988). As rowing training increases the oxidative capacity of both slow-twich and fast-twich muscle fibers, the maximal oxygen consumption of highly trained rowers with different slow-twich muscle fiber content may not be different (Howald 1988; Steinacker 1993).

In summary, the maximal oxygen consumption of rowers is high among other endurance athletes and significant changes in maximal oxygen consumption take place during a year round training. The relative oxygen consumption in rowers is lower due to high body mass in heavyweight rowers but higher in lightweight rowers. Submaximal endurance capacity appears to be a significant predictor af rowing performance, unfortunately, little research has been completed in this area in rowers.

2.2.3 Anaerobic power

Roth et al. (1983) calculated from metabolic and bioptic measurements in tank rowing that the energy for the simulated rowing race of seven minutes was provided 67% aerobically and 33% anaerobically, 21% alactic and 12% lactic. However, anaerobic power explains only 10 – 20% of the performance in competition in trained rowers (Steinacker 1993; Wolf and Roth 1987). One reason could be that all trained rowers have a highly developed strength due to the hypertrophy of slow-twich and fast-twich muscle fibers as well as increased muscle mass (Steinacker 1993). The reported energy contribution from the anaerobic energy system suggests that it would significantly influence 2000 metre rowing performance (Russell et al. 1998). Anaerobic power is a physiological factor dominating the performance during the start and the finish of the rowing race (Secher et al. 1982; Steinacker 1993). Lower glycolytic capacities may be of negative effect at the start acceleration and the final spurt in the rowing race (Steinacker et al. 1998).

The lactate concentration in blood shows the power of the anaerobic energy process. Average team values of 15.0 mmol.l^{-1} have been measured after national regattas and 17.0 mmol.l^{-1} after international regattas (Vaage 1986). For example, lactate concentration after 2000 metre single scull race was found to be 16.0±2.4 mmol.l^{-1} in Estonian national level rowers (Jürimäe et al. 1999b). These values reflect that rowers have extremely large anaerobic capacities (Jürimäe et al. 1999b; Secher 1993). Bangsbo et al. (1993) suggested that the anaerobic energy production during intense exercise is related to the muscle mass involved.

Anaerobic power can be estimated as the total power performed during a modified Wingate test (Koutedakis et al. 1986) or the maximal oxygen deficit method, i.e. the difference between the estimated total oxygen requirement and the oxygen consumption established during an “all-out” performance lasting from two to six minutes (Medbø et al. 1988). The accumulated oxygen deficit was 36% higher during maximal rowing compared to running (Bangsbo et al. 1993). Taking the different stroke frequences into account, the maximal oxygen deficit has been calculated to be 95 ml.min.$^{-1}$kg^{-1} for rowers (Droghetti et al. 1991), or close to the 97 ml.min.$^{-1}$kg^{-1} found by Szögy et al. (1974) and thus substantially higher than the 64 ml.min.$^{-1}$kg^{-1} in runners as reported by Bangsbo et al. (1993). Russell et al (1998) found accumulated oxygen deficit in 19 junior male sweep rowers to be 2.1±1.4 $l.min.^{-1}$. While the total oxygen debt for 310 competitive rowers during six minute “all-out” rowing ergometer test averaged 13.4 litres (Hagerman et al. 1978). The validity of this method of measuring anaerobic power is supported by a close relationship with the anaerobic energy produced in a single muscle group (Bangsbo et al. 1990). The oxygen deficit appears not to be related to blood lactate during submaximal exercise, muscle enzyme activity, number of muscle cappillaries, percent of slow-twich muscle fibers and/or muscle buffer capacity (Bangsbo et al. 1990).

It is well established that the central and peripheral adaptations in rowers in response to exercise training result in an increase in maximal oxygen consumption as well as in a concomittant shift of the blood lactate versus work rate curve to the right, i.e. towards higher absolute and relative work rates (Koutedakis et al. 1985; Messonnier et al. 1997). The shift of the lactate curve towards higher relative work rate shows a possible dissociation between the underlying phenomena that lead to the shift and those involved in the concomittant increase in the aerobic capacity. The shift indicates that the magnitude of the adaptive metabolic processes inducing the changes in lactate is proportionally greater than the corresponding changes in oxygen consumption (Koutedakis et al. 1985; Messonnier et al. 1997; Steinacker 1993). Under these conditions, differences may subsist in lactate kinetics parameters among highly trained rowers with approximately the same oxygen consumption and working at the same relative work rate (Messonier et al. 1997; Steinacker 1993).

Despite the importance of the lactate performance curve and the anaerobic threshold, this concept has some limitations (Steinacker 1993). In successful rowers of comparable competitional level, the anaerobic threshold of 4.0 $mmol.l^{-1}$, maximum lactate and maximal oxygen consumption may be very different (Figure 3) (Steinacker 1988). A lower anaerobic threshold of 4.0 $mmol.l^{-1}$ may be compensated to some degree by higher lactate formation, by increased lactate tolerance, and also by higher work efficiency (Steinacker 1993). Maximum lactate decreases with higher anaerobic threshold oh 4.0 $mmol.l^{-1}$ due to higher oxidative metabolic capacity (Secher 1993; Steinacker 1993). Since lactate concentration is the dynamic resultant of both lactate appearance and disappearance, a shift in 4.0 mmol.l^{-1} blood lactate concentration can be a result of a change in one or both of these processes (Messonnier et al. 1997). However, the measurement of 4.0 mmol.l^{-1} blood lactate concentration alone gives no information on any of these parameters in rowers (Messonnier et al. 1997; Steinacker 1993).

Figure 3. Lactate concentration (La) ands relative oxygen consumption ($VO_{2max/kg}$) in an incremental ergometer test in two rowers.

Rower 1 (□): anaerobic threshold 280 W; 6-min test: max.power 365 W, lactate 19.2 mmol.l^{-1};

Rower 2 (■): anaerobic threshold 335 W: 6-min test: max power 370 W, lactate 13.2 mmol.l^{-1}.

Peak lactate levels should always be determined on well-rested and well-nourished competitors, since values may be influenced by both recent exercise and glycogen depletion (Shephard 1998). The peak lactate concentrations appear to be substantially higher in male competitors, both adults and juniors (typically 11.0 – 19.0 mmol.l^{-1} and occasionally as high as 25.0 mmol.l^{-1}) than in females (8.6 – 10.5 mmol.l^{-1} (Shephard 1998). The main explanation is likely to be that men have larger muscle mass relative to blood volume than women (Shephard 1998; Steinacker 1993). The peak lactate concentrations reached by male competitors are inversely related to the proportion of slow-twich muscle fibers in the active muscle groups (Steinacker 1993).

Anaerobic power can be measured on a rowing ergometer. The anaerobic alactic power has been measured by five maximal strokes and anaerobic lactic power by 40 second maximal work (Jürimäe et al. 1999b; Steinacker 1993). However, anaerobic tests have not been sensitive enough to detect changes with training (Lormes et al. 1990; Steinacker 1993). Although, strength and anaerobic capacity are important in rowing, they should not be increased above a “critical” value (Lormes et al. 1990).

In summary, anaerobic power explains about 10 – 30% of the performance in rowing competition and is high in trained rowers. Average blood lactate values have been reported to be 15.0 – 17.0 mmol.l^{-1} after 2000 metre distance. Maximum blood lactate decreases with higher anaerobic threshold due to the higher oxidative metabolic capacity.

3 PURPOSE

According to the review of the literature, rowing performance is determined by several anthropometric and metabolic factors. However, limited information is available on the relationships between different anthropometric parameters, metabolic variables and rowing performance in male lightweight and heavyweight sculling rowers. The aim of this study was to examine the possible contribution of different anthropometric and metabolic indices to rowing ergometer performance in male lightweight and heavyweight sculling rowers.

The purposes of this study were to:

1. measure different anthropometric and metabolic variables in male sculling rowers;
2. compare various methods and criteria used to identify anaerobic threshold in male sculling rowers and find the best indicator of rowing performance from identified different concepts of anaerobic threshold;
3. develop performance prediction models to predict rowing performance in lightweight male sculling rowers using different anthropometric and metabolic variables; and
4. develop performance prediction models to predict rowing performance in heavyweight male sculling rowers using different anthropometric and metabolic variables.

4 METHODS

4.1 Subjects

21 male experienced sculling rowers including eight lightweight rowers volunteered to participate in this study. The subjects were training regulary and had being doing so for the last 5.0±1.9 years. The rowers were fully familiarized with the laboratory procedures and possible risks before providing their written consent to participate in the experiment. Each rower was tested on three separate occasions over a three week period with at least three days between the tests. The rowers were asked not to participate in any physical activity in the 24 hours before testing and to abstain eating for three hours before testing.

4.2 Anthropometrics

The height (Martin metal anthropometer) and body mass (A&D Instruments Ltd., UK) of the subjects were measured to the nearest 0.1 cm and 0.05 kg, respectively, and body mass index (BMI, $kg.m^{-2}$) was calculated. In total eight skinfolds (*biceps, triceps, subscapular, abdominal, supraspinale, front-thigh, medial-calf and suprailiac*), three girths (*forearm, thigh and calf*) and four breadths *(ankle, wrist, humerus and femur*) were measured. Three series of anthropometric measurements were taken by a trained anthropometrist who had previously shown test-retest reliability of $r > 0.90$. The Centurion Kit instrumentation was used (Rosscraft, Surrey, BC, Canada). The skinfold thicknesses were measured using Holtain (Crymmych, UK) skinfold calipers.

Sum of six skinfolds (SUM6SF) was calculated using *triceps, subscapular, abdominal, supraspinale, front-thigh* and *medial-calf* skinfolds (Drinkwater and Mazza 1994).

Body density was calculated according to Durnin and Womersley (1974):

Body density = $1.1610 - 0.0632\log\sum 4$;

where $\sum 4$ is the sum of four skinfolds (*biceps, triceps, subscapular and suprailiac*).

The percent of body fat was calculated using the equation of Siri (1956):

% body fat = [(4.95/body density) – 4.5] x 100.

Muscle mass was calculated according to Martin et al. (1990):

Estimated muscle mass (kg) = [Height (cm) x 0.0553 x CMTG^2 + 0.0987 x FG^2 + 0.03331 x CCG^2) – 2445] / 1000,

where CMTG is *mid-thigh* girth (cm) corrected for *front thigh* skinfold thickness (FTSF, mm)

$\text{CMTG} = \text{MTG} - \prod \times \text{FTSF} / 10; \prod = 3.1416;$

FG is uncorrected forearm girth (cm);

CCG is calf girth (cm) corrected for *medial calf* skinfold thickness (MCSF, mm)

$\text{CCG} = \text{CG} - \prod \times \text{MCSF} / 10.$

Percent of muscle mass was calculated as estimated muscle mass divided by body mass times 100.

Skeletal mass was calculated according to Martin (1991):

Estimated skeletal mass (kg) = 0.00006 x height (cm) x (FEMRB + HUMRB + + WRSTB + ANKLB)^2,

where FEMRB is femur breadth (cm);

HUMRB is humerus breadth (cm);

WRSTB is wrist breadth (cm);

ANKLB is ankle breadth in (cm).

The cross-sectional area of thigh (CSA-thigh) was estimated according to Hawes (1996):

CSA-thigh $(cm^2) = \prod [(C / 2\prod) - (SF / 2)]^2$,

where C is girth measure (cm);

SF is *front-thigh* skinfold (cm).

4.3 Testing procedures

All exercise tests were performed on a wind resistance braked rowing ergometer (Concept II, Morrisville, USA). The rowers were fully familiarized with this kind of apparatus. Power and stroke frequency were delivered continuously by the computer display of the rowing ergometer. Heart rate (HR) was measured continuously and stored at 5 second intervals during all exercise tests by sporttester Polar Vantage NV (Kempele, Finland).

At the **first measurement session**, a progressive incremental exercise test to maximal intensity was performed (Jürimäe et al. 1999b; Messonnier et al. 1997; Womack et al. 1996). This was carried out for the determination of maximal oxygen consumption (VO_{2max}) (in $l.min.^{-1}$ and $ml.min.^{-1}kg^{-1}$), maximal aerobic power, defined as the mechanical power where VO_{2max} is reached (Pa_{max} in W) and the different indices of anaerobic threshold for each subject. The test started at 150 W and power output was increased in every three minutes by 50 W until volitional exhaustion. Stroke rate during the test varied from 18 to 38 stroks per minute. Capillary blood samples (20 μl) for enzymatic determination of blood lactate concentrations (Lange Germany) (Greiling and Gressner 1987) were taken from the fingertips during a 30 second rest interval at the end of each intensity (Jürimäe et al. 1999b; Messonnier et al. 1997; Womack et al. 1996). Expired gas was sampled continuously for the measurement of VO_{2max} (TrueMax 2400 Metabolic Measurement System, Parvo Medics, USA). The analyzers were calibrated prior to the test using commercial gases of known concentration. To establish that VO_{2max} is reached, the following criteria were used: attainment of a plateau in VO_2 with increasing work rate or, when this plateau was not observed, a respiratory exchange ratio exceeding 1.1, an end exercise blood lactate concentration higher than 9.0 $mmol.l^{-1}$ and a theoretical maximal HR (Messonnier et al. 1997).

Different indices of anaerobic threshold were calculated using the following criteria (Figure 4): 1) LT, the power output preceding the first increase in blood lactate concentration above the resting level during an incremental exercise test (Yoshida et al. 1987); 2) LT_1, the power output preceding a blood lactate increase by 1 $mmol.l^{-1}$ or more (Coyle et al. 1983); 3) LT_{LOG}, the power output at which blood lactate concentration begins to increase when the log (blood lactate) is plotted against the log (power output) (Beaver et al. 1985); 4) LT_D, the threshold calculated by the D_{MAX} method, identified as the point on the regression curve that yielded the maximal perpendicular distance to the strait line formed by the two end data points (Cheng et al. 1992); and 5) LT_{MOD}, a modified LT_D described by the point on the polynomal regression curve that yielded the maximal perpendicular distance to the strait line formed by the LT and final lactate point (Bishop et al. 1998). In addition, the workloads at the fixed blood lactate levels of 2.0 (LaFontaine et al. 1981), 3.0 (Föhrenbach et al. 1987) and 4.0 (Kindermann et al. 1979) $mmol.l^{-1}$ were assessed by linear interpolation from the lactate versus workload curve (P2, P3 and P4, respectively).

At the **second measurement session**, the subjects were asked to cover a 2500 metre distance on a rowing ergometer in as least time as possible (Jensen 1994; Kramer et al. 1994; Messonnier et al. 1997). The measurement started with 10 minutes warm-up exercise at 40 – 45% Pa_{max}. Capillary blood samples for enzymatic blood lactate analyzes were taken from the fingertips three and five minutes after the exercise (Lange, Germany) (Greiling and Gressner 1987). Two parameters were considered to represent the rowing performance: the time (T_{2500} in sec) and the average workload (P_{2500} in W) (Jensen 1994; Messonnier et al. 1997).

The **third measurement session** consisted of five (anaerobic alactic power) and 20 (anaerobic lactic power) maximal strokes on a rowing ergometer. This session

Figure 4. Different concepts of determining anaerobic threshold.

started with 10 minutes warm-up exercise at 40 – 50% of Pa_{max}. After two minutes rest, five maximal strokes test was performed and the maximal work rate (P5 in W) was recorded. After 10 minutes rest, 20 maximal strokes test was performed and the mean work rate (P20 in W) of this test was recorded. Capillary blood samples for enzymatic blood lactate analyzes were taken from the fingertips three and five minutes after the 20 maximal strokes test (Lange, Germany) (Greiling and Gressner, 1987).

4.4 Statistical methods

Descriptive statistics (mean ± standard deviation [SD] for each of the dependant variables were determined. Differences between the measured parameters of lightweight and heavyweight rowers were estimated with indipendent t-tests. A one way analysis of variance was used to test for differences between the blood lactate levels of different concepts of anaerobic threshold. The Scheffe method was used where post-hoc analysis was required.

Intercorrelations (Pearson Product Moment Correlations) between the various blood lactate response parameters were calculated. Statistical generality and specificity between blood lactate response parameters were thought to be achieved when the shared variance (r^2) was greater and less than 0.50, respectively (Abernethy and Jürimäe 1996). Forward stepwise multiple regression analysis was performed with a rowing performance time on a 2500 metre rowing ergometer race as independent variable and blood lactate response parameters as dependent variables.

Pearson Product Moment Correlation coefficents were also used to determine the strength and relationship between each of the measured anthropometric and metabolic variables, and a rowing performance time on a 2500 metre rowing ergometer race in lightweight and heavyweight rowers. Forward multiple regression analyses were used to develop performance prediction equations from the anthropometric and metabolic variables to predict the rowing performance time in lightweight and heavyweight rowers. Only these anthropometric and metabolic parameters were entered into forward stepwise multiple regression analyses which demonstrated statistical generality (i.e. $r^2 > 0.50$) with rowing performance. For all tests, the level of significance was set at 0.05.

5 RESULTS.

2500 metre rowing ergometer performance characteristics in lightweight and heavyweight rowers are presented in Table 6. 2500 metre rowing ergometer time was significantly lower and corresponding power significantly higher in heavyweight rowers in comparison with lightweight rowers. No significant differences were observed in the values of maximal and mean HR as well as in the concentrations of lactate in blood following the distance between studied groups.

Table 7 presents mean (±SD) anthropometric parameters of lightweight and heavyweight rowers. There was a large spread in the individual anthropometric characteristics as indicated by large SDs in both studied groups. All measured anthropometric parameters were significantly higher in heavyweight rowers in comparison with lightweight rowers.

Mean (X±SD) blood lactate values recorded during the incremental rowing ergometer test are listed in Table 8. All calculated blood lactate parameters were significantly different from each other ($p<0.05$). All blood lactate response parameters were highly correlated one with another ($r = 0.72$ to $r = 0.98$) and attained statistical generality (i.e. $r^2>0.52$) (Table 9). This demonstrates that selected blood lactate response parameters failed to demonstrate a distinct threshold and many points of the curve provided similar information. All selected LT points were significantly related to the rowing performance (T_{2500}: $r =-0.48$ to $r =-0.61$) (Table 10). Of the selected blood lactate response parameters, LT_{LOG} correlated best with performance parameters (T_{2500}: $r = -0.61$). The forward stepwise multiple regression analysis also indicated that the LT_{LOG} index was selected from the blood lactate response parameters to characterise rowing performance ($R^2 = 0.345$; SEE = 19.1 sec). Accordingly, LT_{LOG} was further used as an index of anaerobic threshold.

Mean (X±SD) metabolic variables of lightweight and heavyweight rowers are presented in Table 11. All measured metabolic variables were significantly higher in heavyweight rowers in comparison with lightweight, except $VO_{2max/kg}$ value.

Table 6. Mean (±SD) 2500 metre rowing ergometer performance characteristics in lightweight and heavyweight rowers.

Variable	Lightweight rowers (n =8)	Heavyweight rowers (n = 13)
Time (sec)	535.9±20.2	500.6±13.5*
Power (W)	286.0±31.5	350.8±29.3*
Max HR (beats.min.$^{-1}$)	190.4±8.0	192.9±4.4
Mean HR (beats.min.$^{-1}$)	180.9±6.9	180.7±5.8
LA 1' (mmol.l^{-1})	18.2±3.6	16.9±1.6
LA 3' (mmol.l^{-1})	17.0±4.2	16.5±2.6
LA peak (mmol.l^{-1})	18.4±3.5	17.7±2.3
Time to LA peak (min)	1.3±0.7	2.5±1.4

HR – heart rate; LA – blood lactate concentration following the test.

* - significantly different from lightweight rowers; $p < 0.05$.

Table 7. Mean (±SD) anthropometric characteristics in lightweight and heavyweight rowers.

Variable	Lightweight rowers (n = 8)	Heavyweight rowers (n = 13)
Height (cm)	182.1±5.8	190.0±5.2*
Body mass (kg)	73.1±3.9	89.0±3.9*
BMI (kg.m^{-2})	22.1±1.3	24.6±1.5*
SUM6SF (mm)	56.8±10.1	68.8±19.2*
% body fat (%)	8.5±1.2	12.0±2.0*
LBM (kg)	67.0±4.1	78.0±3.2*
Muscle mass (kg)	42.6±4.3	53.3±4.2*
Skeletal mass (kg)	10.8±0.9	12.4±4.1*
CSA thigh (cm^2)	226.2±13.4	276.9±22.7*

BMI – body mass index; SUM6SF – the sum of *triceps, subscapular, abdominal, supraspinale, front-thigh* and *medial-calf* skinfolds; LBM – lean body mass; CSA thigh – the cross-sectional area of a thigh.

* - significantly different from lightweight rowers ($p<0.05$)

Table 8. Blood lactate values recorded during the incremental rowing ergometer test in male rowers (n = 21).

Parameter	**Mean±SD**
LT (mmol.l^{-1})	2.5±0.6
LT$_1$ (mmol.l^{-1})	3.2±0.7
LT$_{LOG}$ (mmol.l^{-1})	3.7±0.8
LT$_D$ (mmol.l^{-1})	4.5±1.0
LT$_{MOD}$ (mmol.l^{-1})	5.6±0.9

LT - the power output preceding the first increase in blood lactate concentration above the resting level during an incremental exercise test; LT$_1$ - the power output at which blood lactate increases by 1.0 mmol.l^{-1} or more; LT$_{LOG}$ - the power output at which blood lactate concentration begins to increase when the log (La) is plotted against the log (power output); LT$_D$ - the lactate threshold calculated by the D$_{max}$ method; LT$_{MOD}$ - a modified LT$_D$ method.

Table 9. The intercorrelations between different blood lactate responses to incremental exercise in male rowers (n = 21).

	P2	P3	P4	LT	LT_1	LT_{LOG}	LT_D	LT_{MOD}
P2 (W)	1.00							
P3 (W)	0.98	1.00						
P4 (W)	0.92	0.96	1.00					
LT (W)	0.86	0.88	0.94	1.00				
LT_1 (W)	0.72	0.78	0.88	0.85	1.00			
LT_{LOG} (W)	0.84	0.85	0.93	0.92	0.88	1.00		
LT_D (W)	0.83	0.88	0.92	0.90	0.83	0.88	1.00	
LT_{MOD} (W)	0.86	0.90	0.97	0.96	0.89	0.95	0.95	1.00

P2, P3, P4 – the workloads at the fixed blood lactate levels of 2.0, 3.0 an 4.0 $mmol.l^{-1}$ respectively; LT - the power output preceding the first increase in blood lactate concentration above the resting level during an incremental exercise test; LT_1 - the power output at which blood lactate increases by 1.0 $mmol.l^{-1}$ or more; LT_{LOG} - the power output at which blood lactate concentration begins to increase when the log (La) is plotted against the log (power output); LT_D - the lactate threshold calculated by the D_{max} method; LT_{MOD} - a modified LT_D method.

Table 10. The power at different blood lactate response parameters and correlations with the 2500 metre rowing ergometer time in male rowers (n = 21).

	W (X±SD)	Correlation with T_{2500}
P2 (W)	179.1±46.0	-0.48
P3 (W)	232.8±52.2	-0,49
P4 (W)	270.1±50.9	-0.53
LT (W)	205.6±32.5	-0.53
LT_1 (W)	244.0±36.0	-0.55
LT_{LOG} (W)	270.3±53.2	-0.61
LT_D (W)	275.6±39.1	-0.53
LT_{MOD} (W)	293.8±41.8	-0.58

P2, P3, P4 – the workloads at the fixed blood lactate levels of 2.0, 3.0 an 4.0 mmol.l^{-1} respectively; LT - the power output preceding the first increase in blood lactate concentration above the resting level during an incremental exercise test; LT_1 - the power output at which blood lactate increases by 1.0 mmol.l^{-1} or more; LT_{LOG} - the power output at which blood lactate concentration begins to increase when the log (La) is plotted against the log (power output); LT_D - the lactate threshold calculated by the D_{max} method; LT_{MOD} - a modified LT_D method.

Table 11. Mean (±SD) metabolic variables in lightweight and heavyweight rowers

Variable	Lightweight rowers (n = 8)	Heavyweight rowers (n = 13)
P5 (W)	591.5±74.9	795.7±132,0*
P20 (W)	506.2±61.6	697.8±113.0*
AT (W)	218.3±28.0	285.3±48.4*
Pa $_{max}$ (W)	308.6±37.5	399.4±53.8*
VO_{2max} ($l.min.^{-1}$)	4.3±0.6	5.2±0.5*
$VO_{2max./kg}$$^{-1}$($ml.min.^{-1}kg^{-1}$)	58.7±7.7	58.9±4.5

P5 – five maximal strokes on a rowing ergometer; P20 – 20 maximal strokes on a rowing ergometer; AT – anaerobic threshold, determined by LT_{LOG} method – the power output at which blood lactate concentration begins to increase when log (lactate) is plotted against the log (power output); Pa_{max} – maximal aerobic power; VO_{2max} – maximal oxygen consumption.

* - significantly different from lightweight rowers

Correlations between 2500 metre rowing ergometer performance time and anthropometrical variables in lightweight and heavyweight rowers are summarised in Tables 12. Significant relationships were found between 2500 metre rowing ergometer performance time and body fat% and LBM in lightweight rowers. In heavyweight rowers, 2500 metre rowing ergometer performance time was significantly related to muscle mass and CSA thigh.

Correlations between 2500 metre rowing ergometer performance time and metabolic variables in lightweight and heavyweight rowers are presented in Table 13. Significant relationships were found between 2500 metre rowing ergometer performance time and P5, P20, Pa_{max}, VO_{2max} and $VO_{2max/kg}$. In heavyweight rowers, 2500 meter rowing ergometer performance time was significantly related to P5, P20, AT, Pa_{max} and VO_{2max}.

Multiple regression equations, adjusted R and standard error of the estimate (SEE) for the individual physiological categories and the overall best predictor multiple regression equations in lightweight and heavyeight rowers are presented in Tables 14 and 15, respectively. The rowing performance time in lightweight rowers could be predicted best when using metabolic parameters only on the combination of anthropometric and metabolic parameters (99.2%). While anthropometric parameters characterized only 51.2% of the rowing performance time in lightweight rowers. In heavyweight rowers the rowing performance time could be predicted best when using the combination of anthropometric and metabolic variables (61.5%). A combination of categories was followed by the regression equations compraising anthropometric (57.5%) and metabolic (57.3%) variables in heavyweight rowers.

Table 12. Correlations between 2500 metre rowing ergometre performance time and anthrpometrical variables in lightweight and heavyweight rowers.

Variable	Lightweight rowers (n = 8)	Heavyweight rowers (n = 13)
Height (cm)	-0.50	-0.21
Body mass (kg)	-0.65	-0.55
BMI ($kg.m^{-2}$)	0.04	-0.28
SUM6SF (mm)	0.55	0.12
% body fat (%)	0.76*	-0.03
LBM (kg)	-0.91*	-0.67
Muscle mass (kg)	-0.67	-0.81*
Skeletal mass (kg)	-0.55	-0.40
CSA thigh (cm^2)	-0.35	-0.88*

BMI – body mass index; SUM6SF – the sum of *triceps, subscapular, abdominal, supraspinale, front-thigh* and *medial-calf* skinfolds; LBM – lean body mass; CSA thigh – the cross-sectional area of a thigh.

* - statistically significant, $p<0.05$

Table 13. Correlations between 2500 metre rowing ergometer performance time and metabolic variables in lightweight and heavyweight rowers.

Variable	Lightweight rowers (n = 8)	Heavyweight rowers (n = 13)
P5 (W)	-0.80*	-0.93*
P20 (W)	-0.98*	-0.91*
AT (W)	-0.06	-0.76*
Pa $_{max}$ (W)	-0.95*	-0.93*
VO$_{2max}$ (l.min.$^{-1}$)	-0.92*	-0.68*
VO$_{2max/kg}$$^{-1}$ (ml.min.$^{-1}$kg^{-1})	-0.83*	-0.07

P5 – five maximal strokes on a rowing ergometer; P20 – 20 maximal strokes on a rowing ergometer; AT – anaerobic threshold, determined by LT$_{LOG}$ method – the power output at which blood lactate concentration begins to increase when log (lactate) is plotted against the log (power output); Pa$_{max}$ – maximal aerobic power; VO$_{2max}$ – maximal oxygen consumption.

* - statistically significant ($p<0.05$)

Table 14. Multiple regression equations, adjusted R and standard error of the estimate (SEE) for the individual physiological categories and the overall best predictor multiple regression equations in lightweght rowers.

Physiological category (variables in equations)	Multiple regression equation	R SEE
Anthropometric		
LBM (kg) %body fat (%)	Time (sec) = 635.137 – 2.393 x LBM (kg) + 7.202 x %body fat (%)	51.2% 14.2 (sec)
Metabolic		
P20 (W) VO_{2max} ($l.min.^{-1}$)	Time (sec) = 701.882 – 0.245 x P20 (W) – 9.766 x VO_{2max} ($l.min.^{-1}$)	99.2% 1.8 (sec)
Combination of categories		
P20 (W) $VO_{2\ max}$ ($l.min.^{-1}$)	Time (sec) = 701.882 – 0.245 x P20 (W) – - 9.766 x VO_{2max} ($l.min.^{-1}$)	99.2% 1.8 (sec)

BMI – body mass index; LBM – lean body mass; P20 – 20 maximal strokes on a rowing ergometer; VO_{2max} – maximal oxygen consumption.

Table 15. Multiple regression equations, adjusted R and standard error of the estimate (SEE) for the individual physiological categories and the overall best predictor multiple regression equations in heavyweight rowers.

Physiological category (variations in equations)	Multiple regression eguation	R SEE
Anthropometric		
Muscle mass (kg) CSA thigh (cm^2)	Time (sec) = 654.331 – 1.767 x muscle mass (kg) – 0.215 x CSA thigh (cm^2)	57.5 % 8.8 sec
Metabolic		
AT (W) P20 (W)	Time (sec) = 565.896 – 0.114 x AT (W) – 0.046 x P20(W)	57.3% 8.8 sec
Combination of categories		
Muscle mass (kg) AT (W)	Time (sec) = 606.695 – 1.359 x muscle mass (kg) – 0.116 x AT (W)	61.5 % 8.4 sec

CSA thigh – the cross-sectional area of a thigh; AT – anaerobic threshold, determined by LT_{LOG} method – power output at which blood lactate concentration begins to increase when log (lactate) is plotted against the log (power output).

6 DISCUSSION

6.1 Rowing performance

The most simple test for rowers to determine rowing performance is to determine the shortest possible time for a given on-water rowing distance, but the result is difficult to reproduce as exernal factors such as wind, waves and current may influence the result (Jensen 1994). Furthermore, a need may exist to evaluate the individual contribution to a boat including as many as eight rowers. An evaluation of physical performance on a rowing ergometer offers a possibility to assess the individual performance of rowers under standardized conditions (Bouckaert et al. 1983; Jensen 1994). In order to simulate a 2000 metre on-water rowing race, performance of six minutes (Faff et al. 1993; Gullstrand 1996; Hagerman et al. 1978; Hartmann and Mader 1993; Mahler et al. 1984) or 2000 metre race (Cosgrove et al. 1999; Jürimäe et al. 1999b; Klusiewicz et al. 1997; Russell et al. 1998; Womack et al. 1996) on a rowing ergometer has often been used. However, it has been demonstrated that these rowing ergometer performance tests are significantly faster and more intensive than 2000 metre race on single sculls (Jensen 1994; Jürimäe et al. 1999b). For example, Jürimäe et al. (1999b) demonstrated that maximal lactate and average heart rate after 2000 metre rowing ergometrer race were significantly higher than after 2000 metre single scull race. Accordingly, 2500 metre rowing ergometer performance would be more appropriate to reflect the metabolic effort of 2000 metre rowing race on single sculls (Jensen 1994). Similarly, in this study, a 2500 metre rowing ergometer race was used to determine rowing performance in male lightweight an heavyweight sculling rowers.

Heavyweight rowers showed significantly shorter 2500 metre rowing ergometer time (500.6±13.5 s) and higher power output (535.9±20.2 W) than lightweight rowers (350.8±29.3 s vs 286.0±31.5 W, respectively). It has been demonstrated that heavyweight rowers have an advantage of 2.5% compared to lightweight rowers on single scull distances over 2000 metres and longer (Steinacker 1993). The average power of international French heavyweight rowers was reported to be 376.0 W (Messonnier et al. 1997), which is higher than the average power in heavyweight rowers of our study. However, Estonian rowers could be classified rather national than international level competitors.

Heart rate and blood lactate values demonstrated no significant differences between heavyweight and lightweight rowers (see Table 6). In their study, Jürimäe et al. (1999b) compared 2000 metre rowing ergometer race to 2000 metre single scull race. They found that the average heart rate during 2000 metre single scull race was 179.9 beats.min.$^{-1}$ (Jürimäe et al. 1999b) which is very similar to average heart rate values obtained during 2500 metre rowing ergometer race in lightweight (180.9 beats.min.$^{-1}$) and in heavyweight (180.7 beats.min.$^{-1}$) rowers of present study. Similarly, average blood lactate values three minutes after 2500 metre rowing ergometer race in lightweight (17.0 mmol.l^{-1}) and in heavyweight (16.5 mmol.l^{-1}) rowers were comparable with the same values obtained after 2000 metre single scull race (16. 0 mmol.l^{-1}) (Jürimäe et al. 1999b). Thus, when 2000 metre single scull race should be simulated in laboratory conditions, a 2500 metre rowing ergometer distance is more appropriate to determine rowing performance in male lightweight and heavyweight rowers.

6.2 Anthropometric parameters

It has been reported that the anthropometrical parameters of lightweight rowers differ radically from those of the heavyweight rowers (Shephard 1998). This was also the case in our study where all measured anthropometrical parameters were significantly higher in heavyweight rowers (see Table 7). It is well known that in rowing body size and body mass are undoubtedly performance related factors (Bourgois et al. 1998; Jürimäe et al. 1999a; Shephard 1998). Ideally, the body mass of rowers should contain a high proportion of muscle mass as rowing involves approximately 70% of the whole body muscle mass (Jürimäe et al. 1999a; Shephard 1998; Steinacker 1993). Heavyweight rowers in our study had relatively high muscle mass (53.3±4.2 kg), which corresponded to 60.1±4.1% of their body mass. The lightweight rowers had significantly lower muscle mass (42.6±4.3 kg) in comparison with heavyweight rowers, while the relative amuont of muscle mass did not differ significantly from the heavyweight rowers (58.3±4.1%). According to the results of present study, it could be argued that the lightweight rowers had also a relatively high muscle mass and the amount of muscle mass plays also an important role in rowing success in lightweight categorie.

Rowing performance time was significantly related to muscle mass (r = -0.81) and CSA thigh (r = -0.88) values in heavyweight rowers In lightweight rowers significant relationships were observed between rowing ergometer performance time and LBM indices (r = -0.91). In accordance with the results of our study, Cosgrove et al. (1999) found that LBM was one of the the best predictors of rowing ergometer performance (r = 0.85; p<0.001). Although the participants in Cosgrove et al. (1999) study were not classified as lightweight rowers, their body mass averaged 73.1 kg. The implication of the importance of high muscle mass in rowing success is that rowers should devote more time on the development of their muscle mass. A large muscle mass does not penalize rowers whose body mass is supported in the boat (Cosgrove et al. 1999; Jürimäe et al. 2000; Shephard 1998). Individuals with a large muscle mass are potentially able to produce a greater force during the rowing stroke (Cosgrove et al. 1999). A rower needs to perform more than 200 strokes with a peak power of 1000 – 1200 Newton during a typical rowing competition in single sculls (Steinacker 1993). A large muscle mass is achieved by the long hours of aerobic training combined with resistance training (Jürimäe et al. 2000; Russell et al. 1998; Steinacker et al. 1998). This type of training also results in a rower with a large aerobic capacity and metabolic efficiency (Jürimäe et al. 2000; Russell et al. 1998; Steinacker et al. 1998) as demonstrated by the high values of aerobic capacity indices in studied lightweight and heavyweight rowers (see Table 11). It is difficult to achieve a high muscle mass values because of the weight limits (72.5 kg) in male lightweight categorie. Thatswhy it is advantageous for a lightweight rower not being very tall and trying to have a low body fat% value. This is in accordance to the results of our study, where a significant correlation was found between 2500 meter rowing performance time and body fat% in lightweight rowers (r = 0.76).

6.3 Metabolic parameters

6.3.1 Blood lactate responses

Despite the widespread use of blood and plasma lactate concentrations in both assessing performance (Farrell et al. 1979; Steinacker 1993; Yoshida et al. 1987) and prescribing training intensities (Coen et al. 1991; Keith et al. 1992; Steinacker 1993), interpretation and application of changes in blood lactate levels have shown considerable variation (Bishop et al. 1998). A number of methods are based on the observation that lactate levels change suddenly at some critical work rate and thus reflect a threshold phenomenon (Brooks 1985).

One purpose of our investigation was to find out which of the blood lactate responses during incremental exercise described in the literature is the best indicator of rowing performance. It has been reported that the lactate response parameters appear to be highly correlated with various types of endurance performance, correlation coefficents varying from $r = 0.61$ up to $r = 0.99$ (Bishop et al. 1998; Föhrenbach et al. 1987; Heck et al. 1985; Jacobs 1986; LaFontaine et al. 1981; Tokmakidis et al. 1998; Yoshida et al. 1987). However, these investigations concerned runners, cyclists or triathletes and the results of these studies can not easily compared with the current study. Rowing is different from other endurance events as rowing is a strength-endurance type of sport and involves approximately 70% of the whole body muscle mass because all extremities and the trunk participate in rowing (Steinacker 1993). It has to be taken into account that during work rate with smaller muscle mass, the metabolic rate per unit of contracting muscle at the same exercise intensity will be greater, resulting in lactate production at a lower maximal oxygen consumption (Jacobs and Sjödin 1985).

To our knowledge, no other study has directly compared different blood lactate response parameters and their relationships with rowing performance in competitive rowers. All anaerobic threshold points selected in this study were highly corelated with each other ($0.72<r<0.98$) and attained statistical generality (i.e. $r^2>0.50$) even when there were many differences among the determined anaerobic threshold points ($p<0.05$). The substantial common variance (i.e. $r^2 = 0.52 - 0.96$) reported among anaerobic threshold indices suggested that all indicies could be used to discriminate between the submaximal aerobic capacity of male competitive rowers. All selected anaerobic threshold points were significantly related to the rowing performance ($r > -0.48$). Of all the calculated blood lactate parameters compared in this study, LT_{LOG} was the most highly correlated with rowing performance ($r = -0.61$).

Steinacker (1993) and Wolf and Roth (1987) have reported that the submaximal aerobic capacity measured as the power which elicits a blood lactate level of 4.0 $mmol.l^{-1}$ is the most predictive parameter of competition performance in trained rowers, especially in small boats such as singles and doubles. However, a power at blood lactate level of 4.0 $mmol.l^{-1}$ has not been reported to represent a steady state workload in rowing (Beneke 1995; Bourgois et al. 1998). Some authors have questioned the physiological significance of a fixed blood lactate value of 4.0 $mmol.l^{-1}$, which does not take into account the inividual kinetics of the lactate concentration curve (Coyle 1995; Stegman et al. 1981). Thus, LT_{LOG} value, which detects the anaerobic threshold with less subjectivity, may be a more appropriate measure of training modality in sculling rowing.

This is in contrast with the results of previous studies, reporting that LT was better correlated than P4 or LT_1 with 12 minute run performance in 19 untrained females (Yoshida et al. 1987), LT was better correlated than P4 in marathon distance in 12 well-trained male runners (Tanaka and Matsura 1984) and LT_D was better correlated than LT_{MOD} or P4 with one hour cycle performance in 24 well-trained female cyclists (Bishop et al. 1998). The results of these studies indicate that there is not one blood lactate parameter that best predicts competition performance in all endurance events. For endurance events of different intensity and duration, different blood lactate parameters may provide a simple method of estimating a pace that does not result in premature fatigue (Bishop et al. 1998).

The substantial common variance (i.e. $r^2 = 0.52 - 0.96$) reported among anaerobic threshold indicies suggested that all indicies could be used to discriminate between the submaximal aerobic capacity of male competitive rowers. However, forward stepwise multiple regression analysis with all blood lactate response curve parameters as independent variables demonstrated that LT_{LOG} value was selected from the blood lactate parameters to detect rowing performance. This value characterised 37.9% of the total variance in 2500 metre rowing ergometer race time. Furthermore, of the all blood lactate response parameters calculated, LT_{LOG} presented the highest correlation with rowing performance (r = -0.61). This indicates that LT_{LOG} is the most effective discriminator among used blood lactate response parameters in the group of competitive male rowers recruited for this investigation. LT_{LOG} should be used as a diagnostic tool for the assessment of training effects and description of training intensities in rowers.

However, it must be taken into account that the disparity of the results of different blood lactate studies may also be partially attributed to the differences in blood sampling methods and/or test protocols (Beneke 1995; Bishop et al. 1998). The choice of blood sampling site (i.e. arterial, venous or capillary) and the choice of blood media analysed (i.e. plasma or whole blood) have been reported to influence the exercise intensity corresponding to a fixed blood lactate concentration but not to significantly alter anaerobic threshold (Bishop et al. 1998). Furthermore, blood lactate concentrations (Fry et al. 1992) and parameters (Heck et al. 1995) have also been reported to be protocol specific. For example, the protocols of Yoshida et al. (1987) and Bishop et al. (1998) used cycle ergometers with 20 and 25 W increments every four and three minutes, respectively. While the protocol of the present study used rowing ergometer with 50 W increments every three minutes and 30 second rest intervals for fingertip blood sampling after every load. Thus, care should be exercised when comparisons are made between different studies using blood lactate parameters.

6.3.2 Aerobic and anaerobic power indicies

High aerobic power is needed to maintain a high speed throughout a rowing race (Shephard 1998; Steinacker 1993). The rowers in both categories in our study had high aerobic power values (see Table 11). These values were similar with previous investigations in terms of VO_{2max}, and Pa_{max} indices in national level lightweight (Burge et al. 1993; Jensen 1994) and heavyweight rowers (Jensen 1994; Messonnier et al. 1997; Womack et al. 1996). Maximal and submaximal aerobic power indices are known to be a good predictors of competition success in rowing (Jürimäe et al.

1999a,b; Messonnier et al. 1997), although their predictive influence varies in different studies (Secher 1993; Steinacker 1993). The important finding was a strong correlation between Pa_{max} and rowing performance in both categories ($r > -0.93$), which was better than VO_{2max} ($r > -0.68$) and AT ($r > -0.06$) (see Table 13). This is in agreement with previous studies with rowers (Jürimäe et al. 1999a, b), cyclists (Bishop et al. 1998), swimmers (Hawley et al. 1992) and runners (Morgan et al. 1986). Morgan et al. (1986) suggested that, while peak VO_2 may not correlate well with performance among endurance trainers, peak power is a very accurate correlate of endurance performance. It has also been reported that changes in VO_{2max} may often be smaller in year-round rowing training than changes in Pa_{max} (Secher 1993; Womack et al. 1996). The high correlations between Pa_{max} and rowing performance could suggest that the time consuming and costly analysis of VO_{2max} and blood lactate analyses may always not be necessary for the evaluation of rowers' performance. However, Pa_{max} is a subject to motivation of the rower tested and it may be not sensitive enough for monitoring a complete rowing season (Steinacker 1993). Furthermore, blood lactate parameters have been suggested as useful for the prescription of training intensities (Cheng et al. 1992; Kindermann et al. 1979; Yoshida et al. 1987). Therefore, although it may be simpler and less expensive to use Pa_{max} for prediction of rowing performance. Blood lactate parameters are useful for assigning training intensities.

It has been reported that although a high VO_{2max} is a good predictor of rowing performance in lightweight and heavyweight rowers, the predictive value of relative VO_{2max} is not significant in heavyweight rowers (Shephard 1998). This was also the case in our study, where the value of $VO_{2max/kg}$ was not significantly related to the 2500 metre rowing ergometer performance time in heavyweight rowers ($r = -0.07$). However, a significant relationship was found between 2500 metre rowing ergometer performance time and relative VO_{2max} in lightweight rowers ($r = -0.83$). The large body mass results in a relatively low $VO_{2max/kg}$ value in heavyweight rowers compared with lightweight rowers. However, a large muscle mass does not penalize rowers, whose body mass is supported in the boat (Cosgrove et al. 1999).

Competitional rowing means not only high aerobic, but also high anaerobic power values (Shephard 1998; Secher 1993; Steinacker 1993). Anaerobic power has been reported to explain approximately 30% of the performance in competition in trained rowers (Roth et al. 1983). In this study anaerobic lactic power was assessed by 20 maximal strokes test on a rowing ergometer. Significant relationships were found between P20 indices and 2500 metre rowing ergometer performance time in lightweight and heavyweight rowers (r = -0.98 and r = –0.74, respectively). Furthermore, lightweight (18.2±3.6 mmol.l^{-1}) and hevyweight (16.9±1.5 mmol.l^{-1}) rowers presented relatively high peak lactate concentrations in blood after 2500 metre race on a rowing ergometer (Table 6). The concentration of blood lactate has been reported to be approximately 15.0 and 17.0 mmol.l^{-1} after national and international regattas, respectively (Vaage 1986). This demonstrates that rowers have extremely large anaerobic lactic power. Although lightweight rowers showed significantly lower P20 values than heavyweight rowers (506.2±61.6 W and 697.8±113.0 W, respectively), the results of our study suggest that anaerobic lactic power has a significant influence on the rowing performance in both studied categories.

The stroke rate in rowing is limited to range from approximately 30 to 40 strokes per minute during maximal exertion. However, the power per stroke may be limited by the strength which can be developed over a certain range of the stroke (Hartmann et al. 1993; Secher 1993; Steinacker 1993). Thus, in the daily routine of rowing diagnostics, five maximal strokes test on a rowing ergometer has been recommended (Jürimäe et al. 1999a, b; Steinacker 1993). In our study, the value of P5 was significantly related to the 2500 metre rowing ergometer performance time in lightweight (r = -0.80) and heavyweight (r = -0.93) rowers. Thus, relatively low contraction velocity during rowing competition is also characterised to some extend by maximal anaerobic alactic power. Anaerobic alactic power has been reported to be an important part of energy contribution during start and finish phases of 2000 metre single scull competition race (Secher 1993; Steinacker 1993).

6.4 Prediction models

Scientists have developed performance prediction models for different sports (Craig et al. 1993; Morgan et al. 1989). Russell et al. (1998) developed a performance prediction model for junior sweep rowers on a rowing ergometer. The use of laboratory-based rowing ergometer tests and prediction models allow coaches and scientists to predict on-water rowing performance. This is in accordance with Lamb (1989) and Rodriguez et al. (1990) studies, who have observed that rowing ergometry replicates the kinematic movement patterns of on-water rowing. To our knowledge, this study was the first one to develop performance prediction models for lightweight and heavyweight sculling rowers using different anthropometric and metabolic variables.

Multiple regression equations in Table 14 demonstrate that the power of prediction was the same (99.2%) when the models included metabolic variables only or a combination of anthropomeetric and metabolic variables to predict performance time in lightweight rowers. Anthropometric variables had much less predictive value (51.2%) in lightweight rowers. As there are weight limits in lightweight categorie (i.e. 72.5 kg in male rowers), it is difficult for lightweight rower to achieve high antropometric values that characterise competitive rowing generally. It is well known that a large body mass is involved in rowing and body size and body mass are undoubtedly performance related factors (see Chapter 6.2). Furthermore, large body mass does not penalize rowers whose body mass is supported in the boat (Cosgrave et al. 1999). Multiple regression equations demonstrate that lightweight rowers depend mainly on maximal aerobic (VO_{2max}) and anaerobic lactic (P20) power to maintain high speed during 2500 metre rowing ergometer distance.

Multiple regression equations in Table 15 demonstrate that the prediction models using the combination of anthropometric and metabolic parameters predicted rowing ergometer performance time best (61.5%), followed by the equations using only anthropometric (57.5%) and metabolic (57.3%) variables in heavyweight rowers. The results suggest that in heavyweight categorie, the specific anthropometric profile plays a more important role in competitional success than in lightweight categorie. In another study, Russell et al. (1998) found that anthropometric variables alone predicted rowing performance best (78.0 %), while metabolic variables alone characterized only 49.0% of rowing performance in male junior rowers. However, the prediction equations in Russell et al. (1998) study were developed specially for sweep rowers. Sweep rowers have been reported to be taller and heavier and are also characterised by a greater muscle development as compared to the sculling rowers (Bourgois et al. 1998). In addition, the rowing performance in Russell et al. (1998) investigation was characterised by 2000 metre rowing ergometer time trial, which is metabolically more intensive than 2500 metre rowing ergometer time-trial and is not suitable to assess 2000 metre single scull race (Jensen 1994; Jürimäe et al. 1999b). This could be the reason why metabolic variables in junior rowers performance had smaller predictive value in Russell et al. (1998) study compared to our study. Heavyweight rowers should devote more time in developing muscle mass compared to lightweight rowers. Thus, a resistance training plays much more important part in a year-round training cycle in heavyweight rowers.

The development of performance prediction models based on laboratory data has a practical importance for talent identification and for the development and assessment of training programmes in rowers. The results of present study suggest that metabolic variables have best predictive value when predicting rowing ergometer performance in national level lightweight sculling rowers, while both anthropometric and metabolic parameters have a high predictive value in national level heavyweight sculling rowers.

7 CONCLUSIONS

1. Lightweight and heavyweight sculling male rowers are very lean athletes with high muscle mass values and both categories are characterized by high aerobic and anaerobic power values
2. Submaximal aerobic power in rowers is best characterized by LT_{LOG} value, – the power output where blood lactate concentration begins to increase when the log (power output) is plotted against the log (lactate);
3. The rowing performance in lightweight rowers is best characterized by metabolic (P20 and VO_{2max}) variables;
4. The rowing performance in heavyweight rowers is best characterized by combination of anthropometric (muscle mass) and metabolic (AT) variables.

8 REFERENCES

1. Abernethy P.J., Jürimäe J. Cross-sectional and longitudinal uses of isoinertial, isometric and isokinetic dynamometry. Med Sci Sports Exerc, 1996, 28: 1180 – 1187.
2. Bangsbo J., Gollnick P.D., Graham T.E., Juel C., Kiens B., Mizuno M., Saltin B. Anaerobic energy production and O_2 deficit-debt relationships during exhaustive exercise in humans. J Appl Physiol, 1990, 422: 539 – 559.
3. Bangsbo J., Petersen A., Michalsik L. Accumulated oxygen deficit during intense exercise and muscle characteristics of elite athletes. Int J Sports Med, 1993, 14: 207 – 213.
4. Beaver W.L., Wasserman B.J., Whipp B.J. Improved detection of lactate threshold during exercise using a log-log transformation. J Appl Physiol, 1985, 59: 1936 – 1940.
5. Beneke R. Anaerobic threshold, individual anaerobic threshold, and maximal lactate steady-state in rowing. Med Sci Sports Exerc, 1995, 27: 863 – 867,
6. Bishop D., Jenkins D.G., Mackinnon L.T. The relationship between plasma lactate parameters, W_{peak} and 1-h cycling performance in women. Med Sci Sports Exerc, 1998, 30: 1270 – 1275.
7. Bouckaert J., Pannier L., Vrijens J. Cardiorespiratory response to bicycle and rowing ergometer exercise in oarsmen. Eur J Appl Physiol, 1983, 51: 51 – 59.
8. Bourgois J., Vrijens J. Metabolic and cardiorespiratory responses in young oarsmen during prolonged exercise tests on a rowing ergometer at power outputs corresponding to two concepts of anaerobic threshold. Eur J Appl Physiol, 1998, 77: 164 – 169.
9. Bourgois J., Claessens A.L., Vrijens J., Philippaerts R., van Renterghem B., Thomis M., Janssens M., Loos R., Lefevre J. Anthropometric characteristics of elite male junior rowers. Br J Sports Med, 2000, 34: 213 – 217.
10. Bourgois J., Claessens A.L., Vrijens J. Hazewinkel athropometric project 1997. Astudy of world class male and female junior rowers. Vlaamse Trainerschool, BLOSO, Brüssels, 1998.
11. Brooks G.A. Anaerobic threshold: review of the concept and directions for future research. Med Sci Sports Exerc, 1985, 17: 22 – 31.

12. Burge C.M., Carey M.F., Payne W.R. Rowing performance, fluid balance and metabolic function following dehydration and rehydration. Med Sci Sports Exerc, 1993, 25: 1358 – 1364.
13. Carter J.E.L. Body composition of athletes. In: Physiol Structure of Olympic Athletes. Part I (ed. J.E.L. Carter). Basel. Karger, 1982: 107 – 116.
14. Carter J.E.L., Ross W.D., Aubury S.P., Hebbelinck M., Borms J. Anthropometry of Montreal olympic athletes. In: Physical structure of Olympic Athletes. Part I, (ed. J.E.L. Carter), Basel, Karger, 1982: 25 – 52.
15. Cheng B., Kuipers A.C., Snyder H.A., Keizer A., Jeukendrup A., Hesslink M. A new approach for the determination of ventilatory and lactate thresholds. Int J Sports Exerc, 1992, 13: 518 – 522.
16. Coen B., Schwarz L., Urhausen A., Kindermann W. Control of training in middle- and long-distance running by means of the individual anaerobic threshold. Int J Sports Med, 1991, 12: 519 – 524.
17. Cosgrave M.J., Wilson J., Watt D., Grant S.F. The relationship between selected physiological variables of rowers and rowing performance as determined by a 2000 m ergometer test. J Sports Sci, 1999, 17: 845 – 852.
18. Coyle E.F., Martin W.H., Ehsani A.A., Hagberg J.M., Bloomfield S.A., Sinacore D.R., Holloszy J.O. Blood lactate threshold in some well-trained ischaemic heart disease patients. J Appl Physiol, 1983, 54: 18 – 23.
19. Coyle E.F. Integration of the physiological factors determining endurance performance ability. Exerc Sport Sci Rev, 1995, 23: 25 – 64.
20. Craig N.P., Norton K.I., Bourdon P.C., Woolford S.M., Stanef T., Squires B., Olds T.S., Conyers R.A., Walsh C.B.V. Aerobic and anaerobic indices contributing to track endurance cycling performance. Eur J Appl Physiol, 1993, 67: 150 – 158.
21. Craven R.P., Kinch R.F.T., Parker D.F., Walter S.J. Stroke analyses using a modified Concept II rowing ergometer. J Appl Physiol, 1993, 449: 133.
22. de Garay A.L., Levine L., Carter J.E.L. Genetic and anthropological studies of Olympic athletes. New York, Academic Press, 1974.
23. de Rose E., Crawford S.M., Kerr D.A., Ward R., Ross W.D. Physique characteristics of Pan-American lightweight rowers. Int J Sports Med, 1989, 10: 292 – 297.

24. DiPrampero P.E., Cerretelli P., Cortili G., Celentano F. Physiological aspects of rowing. J Appl Physiol, 1971, 31: 853 – 857.
25. Doherty M., Hughes M.G., Godfrey R., Warrington G., Hawkins S. A comparison of skeletal physical, physiological and performance parameters in Great Britain senior and junior oarsmen. J Sports Sci, 1999, 17: 12 – 13.
26. Drinkwater D.T., Mazza J.C. Body composition. In: Kinanthropometry in aquatic sports. Astudy of World Class Atheletes. (ed: J.E.L. Carter and T.R. Ackland), Champaign, Illinois: Human Kinetics, 1994: 102 – 137.
27. Droghetti P., Jensen K., Nielsen T.S. The total estimated metabolic cost of rowing. FISA Coach, 1991, 2: 1 – 4.
28. Durnin J.V.G.A., Womersley J. Body fat assessed from total body density and its estimation from skinfold thickness. Br J Nutr, 1974, 32: 77 – 97.
29. Faff J., Biensko A., Jagodinska T., Burkhard K., Borkovski L. Diagnostic value of indices derived from the critical power test in assessing the anaerobic work capacity of rowers. Biol Sport, 1993, 10: 9 – 14.
30. Farrell P.A., Wilmore J.H., Coyle E.F., Billing J.E., Costill D.L. Plasma lactate accumulation and distance runing performance. Med Sci Sports Exerc, 1979, 11: 338 – 344.
31. Fry R.W., Morton A.R., Keast D. Cautions with the use of data from incremental work-rate tests for the prescription of work rates for interval training. Sports Med Training Rehab, 1992, 3: 131 – 145.
32. Föhrenbach R., Mader A., Hollmann W. Determination of endurance capacity and prediction of exercise intensities for training and competition in marathon runners. Int J Sports Med, 1987, 8: 11 – 18.
33. Greiling H., Gressner A.M. Lehrbuch Der Klinichen Chemie und Pathobiochemie. Schattauer, Stuttgart, 1987: 210 – 211.
34. Gullstrand L. Physiological responses to short-duration high-intensity intermittent rowing. Can J Appl Physiol, 1996, 21: 197 – 208.
35. Hagerman F., Connors M., Gault J., Hagerman G. Energy expenditure during simulated rowing. J Appl Physiol, 1978, 45: 87 – 93.

36. Hagerman F., Staron R. Seasonal variables among physiological variables in elite oarsmen. Can J Appl Sports Sci, 1983, 8: 143 – 148.
37. Hagerman F. Applied physiology of rowing. Sports Med, 1984, 1: 303 – 326.
38. Hagerman F., Hagerman M. A comparison of energy output and input amung elite rowers. FISA Coach, 1990, 2: 5 – 8.
39. Hahn A. Identification and selection of talent in Australian rowing. Excel, 1990, 6: 5 – 11.
40. Hahn A.G., Tumility D.M.A., Shackespear P., Rowe P., Telford R. Physiological testing of oarswomen on Gjessing and Concept II rowing ergometers. Exel, 1988, 5: 19 – 25.
41. Hartmann U. Querschnittungen an Leistungsrudern im Flachland und Langsschnittungersuchungen an Elite-rudern in der hähe mittels eines zweistufigen Tests auf einem Gjessing-ruderergometer. Hartnung Görre Verlag. Konstanz, 1987.
42. Hartmann U., Mader A. Modeling Metabolic Conditions in Rowing through Post-Exercise Simulation. FISA Coach, 1993, 4: 1 – 8.
43. Hartmann U., Mader A., Wasser K., Laklauer I. Peak force, velocity and power during five and ten maximal rowing ergometer strokes by world class female and male rowers. Int J Sports Med, 1993: 14: 42 – 45.
44. Hawes M.R. Human body composition. In: Kinanthropometry and Exercise Physiology Laboratoy Manual. Tests, Procedures and Data. E & FN Spon (ed. R. Eston and T. Reilly), London, 1996: 5 – 34.
45. Hawley J.A., Williams M.M., Vickovic M.M., Handcock P.J. Muscle power predicts freestyle swimming performance. Br J Sports Med, 1992, 26: 151- 155.
46. Heck H., Mader A., Hess G., Mücke R., Müller R., Hollmann W. Justification of the 4-mmol/l lactate threshold. Int J Sports Med, 1985, 6: 117 – 130.
47. Hirata K. Selections of Olympic Champions. Tokyo, Hirata Institute, 1979.
48. Howald H. Training-induced morphological and functional changes in skeletal muscle. Int J Sports Med, 1982, 3: 1 – 12.
49. Howald H. Leistungsphysiologiche Grundlagen des Ruderns. In Rudern (ed. J. Steinacker). Berlin, Heidelberg, Springer, 1988: 31 – 38.

50. Jacobs I. Blood Lactate. Implications for training and sports performance. Sports Med, 1986, 3: 10 – 25.
51. Jacobs I., Sjödin B. Relationship of ergometer-specific VO_{2max} and muscle enzymes to blood lactate during submaximal exercise. Br J Sports Med, 1985, 19: 77 – 80.
52. Jensen K. Test procedures for rowing. FISA Coach, 1994, 4: 1 – 6.
53. Jensen K., Nielsen T. High altitude training does not increase maximum oxygen uptake or work capacity at sea level in rowers. Scand J Med Sci Sport, 1993, 3: 56 – 62.
54. Jensen K., Secher N.H., Fiskerstrand A., Christensen N.J., Lund J.O. Influence of body weight on physiologic variables measured during dynamic exercise. Acta Physiol Scand, 1984, 121: 39 – 43.
55. Jürimäe J., Jürimäe T., Pihl E. Changes in the body fluids during endurance rowing training. Annals of NY Acad Sci, 2000, 5: 353 – 358.
56. Jürimäe J., Mäestu J., Jürimäe T., Pihl E. Relationships between anthropometric variables and performance characteristics of elite single scullers. Papers on Anthropology VIII. Tartu University Press. Tartu, 1999a: 32 – 39.
57. Jürimäe J., Mäestu J., Jürimäe T., Pihl E. Relationship between rowing performance and different metabolic parameters in male rowers. Med della Sport, 1999b, 52: 119 – 126.
58. Keith S.P., Jacobs I., McLellan T.M. Adaptions to training at the individual anaerobic threshold. Eur J Appl Physiol, 1992, 65: 316 – 323.
59. Kindermann W., Simon G., Keul J. The significance of the aerobic-anaerobic transition for the determination of workload intensities during endurance training. Eur J Appl Physiol, 1979, 42: 25 – 34.
60. Klusiewicz A., Faff J., Zdanowicz R. The usefulness of PWC_{170} in assessing the performance determined on a rowing ergometer. Biol Sport, 1997, 14: 127 – 133.
61. Koutedakis Y., Sharp C.C. Lactic acid removal and heart rate frequences during recovery after strenuos rowing exercise. Brit J Sports Med, 1985, 19: 199 – 202.
62. Koutedakis Y., Sharp C.C. A modified Wingate test measuring anaerobic work of upper body in junior rowers. Br J Sports Med, 1986, 20: 153 – 156.

63. Kramer J.F., Leger A., Peterson D.H., Morrow A. Rowing performance and selected descriptive field and laboratory variables. Can J Appl Physiol, 1994, 19: 174 – 184.
64. LaFontaine T.P., Londeree B.R., Spath W.K. The maximal steady state versus selected running events. Med Sci Sports Exerc, 1981, 13: 190 – 192.
65. Lakomy H., Lakomy J. Estimation of maximum oxygen uptake from submaximal exercise on a Concept II rowing ergometer. J Sports Sci, 1992, 11: 227 – 232.
66. Lamb D.H. A kinetic comparison of ergometer and on-water rowing. Am J Sports Med, 1989, 17: 367 – 373.
67. Larsson L., Forsberg A. Morphological muscle characteristics in rowers. Can J Appl Sports Sci, 1980, 5: 239 – 240.
68. Lormes W., Debatin H.J., Grünert-Fuchs M., Müller T., Steinacker J.M., Stauch M. Anaerobic rowing ergometer tests – test design, application and interpretation. In: Advances in Ergometry (ed. N. Bachl, T. Graham, H. Löllgen), Berlin, Heidelberg, Springer, 1990: 477 – 482.
69. Mahler D., Nelson W., Hagerman F. Mechanical and physiological evaluations of exercise performance in elite national rowers. JAMA, 1984, 252: 496 – 499.
70. Mahler D., Parker H., Andersen D. Physiological changes in rowing performance associated with training in collegiate women rowers. Int J Sports Med, 1985, 6: 229 – 233.
71. Mahler D.A, Shuhart C.R, Brew E, Stukel T. A. Ventilatory responses and entertainment of breathing during rowing, Med Sci Sports Exerc, 1991, 23: 186 – 192.
72. Mahony N., Dome B., O´Brien M. A comparison of physiological responses to rowing on friction-loaded and air-braked ergometers. J Sports Sci, 1999, 17: 143 – 149.
73. Malina R.M. Physical activity and training: effects on stature and the adolescent growth spurt. Med Sci Sports Exerc, 1994, 26: 759 – 766.
74. Martin A.D Anthropometric assessment of bone mineral. In: Anthropometric Assessment of Nutrional Status, (ed. J. Himes), Wiley-Liss, New York, 1991: 185 – 196.

75. Martin A.D., Spenst L.F., Drinkwater D.T., Clarys J.P. Anthropometric estimation of muscle mass in men. Med Sci Sports Exerc, 1990, 22: 729 – 733.
76. McKenzie D.C., Rhodes E.C. Cardiorespiratory and metabolic responses to exercise on a rowing ergometer. Aus J Sports Med, 1982, 14: 21 – 23.
77. Medbø J.I., Mohn A., Tabata I., Bahr J., Vaage O., Sejersted O.M. Anaerobic capacity determined by maximal oxygen deficit. J Appl Physiol, 1988, 64: 50 – 60.
78. Messonnier L., Freund H., Bourdin M., Belli A., Lacour J. Lactate exchange and removal abilities in rowing performance. Med Sci Sports Exerc, 1997, 29: 396 – 401.
79. Mickelson T.C, Hagerman F.C. Anaerobic threshold measurements of elite oarsmen. Med Sci Sports Exerc, 1982, 14: 440 – 444.
80. Morgan D.W., Martin P.E., Kohrt W.M. Relationship between distance-running performance and velocity at VO_{2max} in well-trained runners. Med Sci Sports Exerc, 1989, 18: 37.
81. Morris F., Payne W. Seasonal variables in the body composition of lightweight rowers. Br J Sports Med, 1996, 30: 301 – 304.
82. Peltonen J., Rusko H. Interrelations between power, force production and energy metabolism in maximal leg work using a modified rowing ergometer. J Sports Sci, 1992, 11: 233 – 240.
83. Piotrowski J., Sklad M., Krakczyk B., Majle B. Somatic indices of junior rowers as related to their athletic experience. Biol Sport, 1992, 9: 118 – 125.
84. Rienks N.H., van der Pol A.J., Toussaint H.M. De evaluatie van conditie en techniek bij top: en toproeiers op een isokinetische roeergometer. Gneeskunde an Sport, 1991, 2: 34 – 39.
85. Rodriguez F.A. Physical structure of international lightweight rowers. In: Kinanthropometry III (ed. T. Reilly, J. Watkins, J. Barnes), London, E & FN Spon, 1986: 255 – 261.
86. Rodriguez R.J., Rodriguez R.P., Cook S.D., Sandborn P.M. Electromyographic analysis of the rowing stroke biomechanics. J Sports Med Phys Fit, 1990, 30: 103 – 108.
87. Roth W. Physiological-biomechanical aspects of the load development and force implementation in rowing. FISA Coach, 1991, 2: 1 – 9.

88. Roth W, Hasart E, Wolf W, Pansold B. Untersuchungen zur Dynamic der Energiebereitstellung während maximaler Mittelzeitausdauerbelastung. Med Sport, 1983, 23: 107 – 114.
89. Russell A.P., le Rossignol P.F., Sparrow W.A. Prediction of elite schoolboy 2000-m rowing ergometer performance from metabolic, anthropometric and strength variables. J Sports Sci, 1998, 16: 749 – 754.
90. Secher N.H. Rowing. In: Physiology of sports (ed. T. Reilly, N. Secher, P. Snell, C. Williams), 1990: 259 – 286.
91. Secher N.H. The physiology of rowing. Int J Sports Med, 1983, 1: 23 – 53.
92. Secher N.H. The physiology of rowing. Sports Med, 1993, 15: 23 – 53.
93. Secher N.H. Vaage O. Jackson R. Rowing performance and maximal aerobic power of oarsmen. Scand J Sports Sci, 1982, 4: 9 – 11.
94. Secher N.H, Vaage O., Jensen K., Jackson R. Maximal aerobic power in oarsmen. J Appl Physiol, 1983, 51: 155 – 162.
95. Shephard R.J. Science and Medicine of rowing: A review. J Sports Sci, 1998, 16: 603 – 620.
96. Siri W.E. The cross-composition of the body. Adv of Biol Med Physiol, 1956, 4. 239 – 280.
97. Smith T.B.R.J, Hopkins W.G, Taylor N.A. S. Respiratory responses of elite oarsmen, former oarsmen, and highly trained non-rowers during rowing, cycling and running. Eur J Appl Physiol, 1994, 69: 44 – 49.
98. Stegman H., Kindermann W., Schnabel A. Lactate kinetics and the individual anaerobic threshold. Int J Sports Med, 1981, 2: 160 – 165.
99. Steinacker J.M. Methoden für die Leistungsdiagnostik und Trainingssteuerung im Rudern und ihre Anwendung. Rudern (ed. J. Steinacker) Berlin, Heidelberg, Springer, 1988: 39 – 54.
100. Steinacker J.M. Physiological aspects of rowing. Int J Sports Med, 1993, 1: 3 – 10.
101. Steinacker J.M., Lormes W., Lehmann M., Altenburg D. Training of rowers before world championships. Med Sci Sports Exerc, 1998: 1158 – 1163.
102. Szal S.E, Schoene R.B. Ventilatory response to rowing and cycling in elite oarsmen. J Appl Physiol, 1989, 67: 264 – 269.

103. Szögy A., Cherebetieu G. Physical work capacity testing in male performance rowers with practical conclusions for their training process. J Sports Med, 1974, 14: 218 – 223.

104. Tanaka K., Matsura Y. Marathon performance, anaerobic threshold, and onset of blood lactate accumulation. J Appl Physiol, 1984, 57: 640 – 643.

105. Tokmakidis S.P., Leger L.A., Pilianidis T.C. Failure to obtain a unique threshold on the blood lactate curve during exercise. Eur J Appl Physiol, 1998, 77: 333 – 334.

106. Urhausen A., Weiler B., Kinderman W. Heart rate, blood lactate and catecholamines during ergometry and on-water rowing. Int J Sports Med, 1993, 14: 20 – 23.

107. Vaage O. Textbook of work physiology. McGraw-Hill, New-York, 1986: 673.

108. Wolf W.V., Roth W. Validät Spiroergometricher Parameter für die Weltkampfleistung im Rudern. Med Sport, 1987, 27: 162 – 166.

109. Womack C.J., Davis S.E., Wood C.M., Sauer K., Alvarez J., Weltman A., Gaesser G. A. Effects of training on physiological correlates of rowing ergometry performance. J Strength Cond Res, 1996, 10: 234 – 238.

110. Yoshida T., Chida M., Ichioka M., Suda Y. Blood lactate parameters related to aerobic capacity and endurance performance. Eur J Appl Physiol, 1987, 56: 7 – 11.

9. KOKKUVÕTE

Käesoleva uurimustöö eesmärgiks oli uurida võistlustulemust iseloomustaviad antropomeetrilisi ja funktsionaalseid näitajad kergekaalu ja raskekaalu paarisaeru sõudjatel. Samuti, leida milline anaeroobse läve määramise meetod on kõige sobivam sõudmise võistlustulemuse iseloomustamisel. Uuringus osales 21 Eesti tasemel meessõudjat vanuses 21,5±5,0 aastat, nende hulgas kaheksa kergekaalu (182,1±5,9 cm; 73,1±3,89 kg) ja 13 raskekaalu (190,0±5,5 cm; 88,6±4,3 kg) sõudjat.

Antropomeetrilistest näitajatest mõõdeti vaatlusalustel pikkus, keha mass, keha massi indeks (BMI), keha rasva protsent, keha rasvavaba mass (LBM), lihasmass, skeletimass ja reie ristlõike pindala (reie RLP). Funktsionaalsetest testidest sooritasid vaatlusalused kasvava koormustega testi sõudeergomeetril, mille käigus määrati maksimaalne hapniku tarbimine (VO_{2max}), maksimaalne aeroobne võimsus (Pa_{max}) ja anaeroobne lävi. Anaeroobse läve määramiseks kasutati järgmiseid erinevaid mooduseid: LT, LT_1, LT_{LOG}, LT_D, LT_{MOD}, P2, P3 ja P4. Statistilise analüüsi tulemusel iseloomustas 2500 meetri sõudeergomeetri võistlustulemust kõige paremini LT_{LOG} meetod, mida kasutati edasise töö käigus vaatlusaluste anaeroobse läve iseloomustamiseks. Teise testi käigus tuli vaatlualustel sõuda maksimaalselt 2500 meetrit (T_{2500}) sõudeergomeetril. Kolmas test koosnes 20 maksimaalsest tõmbest sõudeergomeetril (P20) (anaeroobne laktaatne võimsus) ja peale 10 minutilist puhkust sooritati 5 maksimaalset tõmmet sõudeergomeetril (P5) (anaeroobne alaktaatne võimsus).

2500 meetri sõudeergomeetri testi sooritamise aeg oli statistiliselt oluliselt väiksem raskekaalu sõudjatel võrreldes kergekaalu sõudjatega (500,6±13,5 vs. 535,9±20,2 s). Seevastu statistiliselt olulised erinevused puudusid keskmise ja maksimaalse südame löögisageduse ning vere laktaadi sisalduses kolmandal taastumisminutil. Mõõdetud antropomeetrilistest näitajatest olid kõik parameetrid statistiliselt oluliselt suuremad raskekaalusõudjatel. Samuti olid statistiliselt oluliselt paremad raskekaalu sõudjate funktsionaalsed näitajad võrreldes kergekaalu sõudjatega, välja arvatud $VO_{2max/kg}$ näitaja (vastavalt 58,9±4,5 ja 58,7±7,7 ml.min^{-1}kg^{-1}). Antropomeetrilistest näitajatest olid statistiliselt usutavad seosed 2500 meetri sõudeergomeetri võistlustulemuse ja keha rasva% ning LBM vahel (r = 0,76 – -0,91) kergekaalu sõudjatel ja 2500 meetri sõudeergomeetri võistlustulemuse ning lihasmassi ja reie RLP vahel (r = -0,81 – -0,88) raskekaalu sõudjatel. Funktsionaalsetest näitajatest leiti statistiliselt olulised seosed veel 2500 meetri sõudeergomeetri võistlustulemuse ja P5, P20, Pa_{max}, VO_{2max} ning $VO_{2max/kg}$ näitajate vahel (r = -0,80 – -0,98) kergekaalu sõudjatel ja P5, P20, AT, Pa_{max} ning VO_{2max} näitajate vahel (r = -0,68 – -0,93) raskekaalu sõudjatel.

Regressioonanalüüsi tulemusena leiti, et parima tulemuse kergekaalu sõudjate 2500 meetri võistlustulemuse prognoosimisel saame kasutades ainult funktsionaalseid näitajaid: Aeg (s) = 701,882 – 0,245 x P20 (W) – 9,766 x VO_{2max} (l.min.$^{-1}$). Raskekaalusõudjate puhul saadi 2500 meetri sõudeergomeetri võistlustulemuse parimaks iseloomustamiseks võrrandi kasutades kombineeritult nii antropomeetrilisi kui ka funktsionaalseid näitajaid : Aeg (s) = 606,695 – 1,359 x lihasmass (kg) – 0,116 x AT (W).

Kokkuvõtteks võib öelda, et sõudmises anaeroobse läve määramise meetoditest annab võistlustulemuse iseloomustamisel parima tulemuse kui anaeroobne lävi määratakse LT_{LOG} meetodil, kui log (laktaat) vastandatakse log (võimsus). Kergekaalusõudjate võistlustulemuse iseloomustamisel on olulised funktsionaalsed (P20 ja VO_{2max}) näitajad, seevastu raskekaalu sõudmise võistlustulemuse iseloomustamisel on olulised nii antropomeetrilised (lihasmass) kui ka funktsionaalsed (anaeroobne lävi) näitajad.