

Training and performance characteristics among Norwegian International Rowers 1970–2001

Å. Fiskerstrand¹, K. S. Seiler²

¹Norwegian Rowing Federation, Oslo, Norway, ²Department of Health and Sports, Agder University College, Kristiansand, Norway
Corresponding author: Stephen Seiler, PhD, Institute for Sport, Department of Health and Sport, Agder University College, Service box 422, 4604 Kristiansand, Norway. Tel: +47-3814-1347, Fax: +47-3814-1301, E-mail: Stephen.Seiler@hia.no

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This study quantified changes in training volume, organization, and physical capacity among Norwegian rowers winning international medals between 1970 and 2001. Twenty-eight athletes were identified (27 alive). Results of physiological testing and performance history were available for all athletes. Twenty-one of 27 athletes responded to a detailed questionnaire regarding their training during their internationally competitive years. Maximal oxygen uptake ($\text{VO}_{2\text{max}}$) increased 12% (6.5 ± 0.4 vs. $5.8 \pm 0.2 \text{ L min}^{-1}$) from the 1970s to the 1990s. Similarly, 6-min ergometer rowing performance increased almost 10%. Three major changes in training characteristics were identified: (1) training at a low blood lactate ($<2 \text{ mM}$) increased from

30 to 50 h month^{-1} and race pace and supra-maximal intensity training ($\sim 8\text{--}14 \text{ mM}$ lactate) decreased from 23 to $\sim 7 \text{ h month}^{-1}$; (2) training volume increased by $\sim 20\%$, from 924 to 1128 h yr^{-1} ; (3) altitude training was used as a pre-competition peaking strategy, but it is now integrated into the winter preparation program as periodic 2–3-week altitude camps. The training organization trends are consistent with data collected on athletes from other sports, suggesting a “polarized” pattern of training organization where a high volume of low intensity training is balanced against regular application of training bouts utilizing 90%–95% of $\text{VO}_{2\text{max}}$.

Norway has developed a systematic organization for endurance training. The rowers, starting in the late 1960s and early 1970s, led this development, which in turn influenced the training of skiers, biathletes, kayak paddlers, and cyclists. The international success of the rowers is notable given an annual recruiting base of ≤ 300 competitive rowers between the ages of 15 and 21 over the last three decades.

From 1893 when the first “European Championship” was held to 1969, Norwegian athletes won only five bronze and one silver medals in the European, World, or Olympic Rowing Championships. Winning 34 medals (11 gold) from 1970 to 2001, Norwegian rowers have been roughly 10 times more successful since 1970. This abrupt increase is attributed to two changes that were instituted in 1969: (1) gathering the best rowers into an elite group and (2) systematic training information provided to the local clubs. Similar developments towards more systematic training organization and testing based selection processes occurred in East and West Germany, the USSR, New Zealand, the US, and other FISA federations by 1968.

Athletes and trainers are motivated to apply maximal tolerable training loads in an effort to break previous performance barriers. Even a small

(1%) enhancement in performance capacity improves results (Hopkins et al., 1999). Some reports provide quantitative data about the training of international athletes over a shorter time period (Jensen et al., 1993; Steinacker et al., 1998; Lucia et al., 2000; Billat et al., 2001; Schumacker & Mueller, 2002). However, few data are available to quantify changes in training and physical capacity over a period of years. In this study, we have quantified changes in training characteristics and physical capacity in a group of international rowing medal winners within a span of three decades.

Methods

Subjects

From 1970 to 2001, 28 male Norwegian rowers won 11 gold, 15 silver, and eight bronze medals at the senior European (three medals), World (23 medals), or Olympic Championships (eight medals) (Table 1). Norwegian athletes won medals in 27 of the 30 years in which they competed in championship events. The general strategy employed has been to concentrate on developing at least one international medal contending boat crew each year. The most successful boat was the double scull ($2 \times$) with gold medals won each decade. Medals were also won in single sculling ($1 \times$), quadruple sculling ($4 \times$), and the four-man sweep-oared events with and without

Table 1. International Championship results of Norwegian male rowers 1970–2001

| | 1970–1979 | 1980–1989 | 1990–2001 |
|--|---------------------------|------------------|----------------------|
| Medal distribution | G: 6; S: 6; B: 2 | G: 3; S: 3; B: 3 | G: 2; S: 6; B: 3 |
| Rowers winning medals (four athletes won medals in two decades) | 17 | 6 | 9 |
| Boat classes | 4+, 4–, 2 ×, LW2 ×, LW 4– | 4 ×, 2 ×, 2– | 4 ×, 2 ×, 1 ×, LW1 × |

Medal counts are based on number of boats winning medals. G, S, and B = gold, silver, and bronze, respectively. Boat type abbreviations: 1 ×, 2 ×, and 4 × = single, double, and quadruple sculling boats. 2– and 4– = 2 and 4 man sweep-oared events without coxwain. 4+ = 4 man sweep-oared boat with coxwain. Of 34 medals, three were won in European Championships, 23 in World Championships, and eight in the Olympic Games.

coxwain (4+, 4–). Twelve coaches were identified as having had responsibility for the national team or specific rowers. Physiological data and competition results on all national team athletes were recorded. An additional questionnaire from the former and current athletes was completely voluntary in compliance with the ethical standards set by the Norwegian Sport Federation. The human subjects committee of the Department of Health and Sport, Agder University College approved the study.

Physiological testing

VO_{2max}

Historically, VO_{2max} expressed in liters per minute has been the most frequently used predictor of performance capacity in talented rowers (Secher et al., 1982; Hagerman & Staron, 1983; Steinacker, 1993). VO_{2max} was measured using open circuit spirometry in three laboratories over the 30-year period: the Institute of Work Physiology, the Norwegian University of Sport, and the Norwegian Olympic Training Center. Gas measurements were calibrated using certified test gasses that were independently analyzed using the micro-Scholander technique (Enghoff, 1946). All VO_{2max} data presented are from running tests performed to exhaustion on a motorized treadmill with an elevation of 3%–5% and gradually increasing velocity. VO_{2max} was measured during February or March each year throughout the 30-year period. In contrast, physiological testing using rowing ergometry has become standardized only over the last ~ 15 years. Rowing ergometer testing is now standardized to 60 s, 2000 m, and 5000 m tests on the Concept II rowing ergometer in the annual talent identification and training evaluation process.

Training history survey

Training history documentation is based on survey information collected from the athletes. Of the 28 identified athletes, 27 were living at the time of the survey. The former and current athletes were delivered a questionnaire via mail complete with full instructions. Twenty-one of the 27 athletes responded to the survey. In addition, substantial information such as physiological test and performance results, age at time of medal achievement, age at retirement, and altitude camp participation, was available for non-responders. Since the 1970s, it has been common to maintain a training diary with specific definitions established for effective training duration and different prescribed training methods/intensities (Table 2). Therefore, the self-report information regarding training volume and the distribution of training across types of training was considered valid despite the varying time of recall. Many of the athletes making up this group were also subjected to frequent intensity control measurements using

lactate and heart rate as part of various physiological investigations.

Analysis

Where appropriate, data are presented as means and 95% confidence intervals. In some cases results are presented as frequency distributions. Physiological data collected during the 1970s, 1980s, and 1990s were treated inferentially and compared using one-way ANOVA with a Tukey's post hoc test. A *P*-value of 0.05 was considered statistically significant.

Results

Rowing performance

International gold medals in open Olympic or World Championships were achieved in each 10-year period, with the most recent a World Championship in the men's heavy weight single in 2001 (Table 2). The average age of gold medal winners at the time of their last gold medal performance (nine individuals) was 28.5 ± 5 years, (range 23–34).

On average, medal winners began rowing at age 15 ± 2 years. They began high-level training at age 19 ± 2 years, competing in their first international championship (EC, WC, OG) at an age of 21 ± 2 years. They won their first international championship medal at age 24 ± 2 years and their last at 27 ± 4 years. Gold medals were won typically between the ages of 24 and 28 years. Thirteen of the athletes had also competed in Junior International Championships, but only five (18%) senior international medal winners also won international medals as junior competitors including one gold. Three senior international medal winners did not row at all as juniors, but came to rowing from other competitive sports. The average age at retirement from international competitive rowing for the entire group was 29 ± 4 years. Reported reasons for retiring were primarily academic studies, work, and lack of motivation to continue high-level training. Two athletes retired from competition due to injury.

Table 2. Form and intensity definitions used to quantify training among elite Norwegian rowers

| Term | Definition |
|-------------------------------|---|
| Long distance training | Rowing at an intensity maintaining blood lactate between 1 and ~ 2.5 mM, work durations of 60–180 min |
| Land-based endurance training | Cycling, running, XC skiing at intensities corresponding to long-distance training in the boat |
| Interval training | 3–10 min long intermittent bouts eliciting 85%–95% $VO_{2\max}$ and blood lactate of ~ 5–10 mM |
| Race pace training | Set distances (500–1500 m) performed at 2000 m competition intensity – 100%–105% $VO_{2\max}$ |
| Over-speed training | Intermittent rowing bouts (~ 500 m) at near maximal intensity – velocities above 2000 m race pace |
| Strength training | Strength training loads equal to 75–90% 1RM, 8–12 reps |
| Strength-endurance training | Strength training with loads equal to ~ 50% 1RM and up to 50 repetitions per set |
| Flexibility training | Exercises used to ensure maintenance of optimal range of motion in the ankles, knees, hips, and shoulders |

$VO_{2\max}$, maximum oxygen uptake; 1RM, one repetition maximum.

Table 3. Physical characteristics of rowing medal winners

| | 1970–1979 | 1980–1989 | 1990–2001 |
|------------------------------------|-----------|-----------|-----------|
| N | 9 | 6 | 8 |
| Height (cm) | 191 | 192 | 191 |
| Weight (kg) | 89 | 87 | 89.5 |
| $VO_{2\max}$ ($L\ min^{-1}$) | 5.8 | 6.4* | 6.5* |
| 95% CI | 5.7–6.0 | 6.2–6.55 | 6.1–6.9 |
| Highest value | 6.3 | 6.5 | 7.15 |
| 6 min ergometer ($Kp\ min^{-1}$) | 2419 | 2653* | 2640* |
| 95% CI | 2326–2514 | 2586–2718 | 2539–2741 |
| Highest value | 2577 | 2748 | 2723 |

To facilitate comparisons, five lightweight class medal winners (four in the 1970s and one from after 1990) are excluded from these data. One athlete won international medals in both the 1970s and 1980s, while two athletes won medals in both the 1980s and 1990s. Their data are included in the averages for both decades.

* $P \leq 0.01$ vs. average for 1970–1979. Of the six athletes winning medals in the 1980s, five won World Championship or Olympic gold medals.

Physical characteristics

The average height and body weight of this elite population were stable over three decades (Table 3). Between 1970 and 1979, the nine heavyweight medallists averaged 191 cm and 89 kg. In the period 1990–2001, the eight heavyweight medallists averaged 191 cm and 89.5 kg.

$VO_{2\max}$ increased by ~ 12% across three decades of testing ($P < 0.001$). The increase in $VO_{2\max}$ was matched by a similar ~ 10% increase in average power for the 6-min Gjessing ergometer test ($P < 0.001$, Table 3). The largest increase in rowing mechanical power occurred from the 1970s to 1980s.

Changes in training volume

Training volume was reported as hours of effective training each month, with specific type of training and intensity of training recorded. Total annual training volumes are quantified as hours per year. Average annual training volume increased from 924 (range 600–1020) $h\ yr^{-1}$ during the 1970s, to 966 (range 840–1140) h in the 1980s, to 1128 (range

1104–1200) h in the 1990s. The training year for competitive rowers can be divided into two nearly equal halves, the preparatory period from October to March, and the competition period from April to September. Figure 1 depicts changes in seasonal training volume among athletes winning medals in the 1970s, 1980s, and 1990s. While training volume increased across the training year, most of the increase in volume occurred during the preparation period.

Changes in training organization

Training sessions were categorized based on the specific goals and conditions of the session (Table 2). Figure 2 depicts the distribution of the winter preparation period load across training types. Long-distance training volume (running, cross-country skiing, ergometer and on-water rowing) increased each decade. In addition, strength endurance training, movements such as squats performed at ~ 50% of one repetition maximum for up to 50 repetitions, was increasingly used in the 1980s and 1990s. The

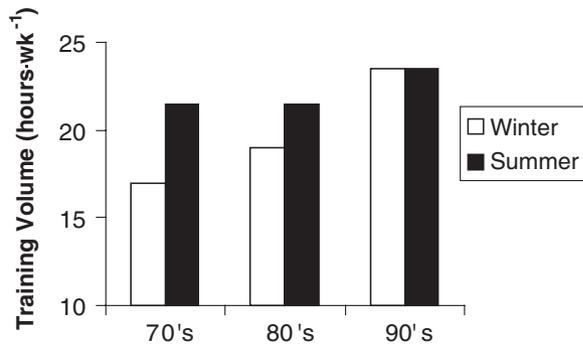


Fig. 1. Average total weekly training volume (hours) among Norwegian male rowers winning international medals in the 1970s, 1980s and 1990s. Training volume is divided into winter (preparation) and summer (competition) halves of the annual training cycle.

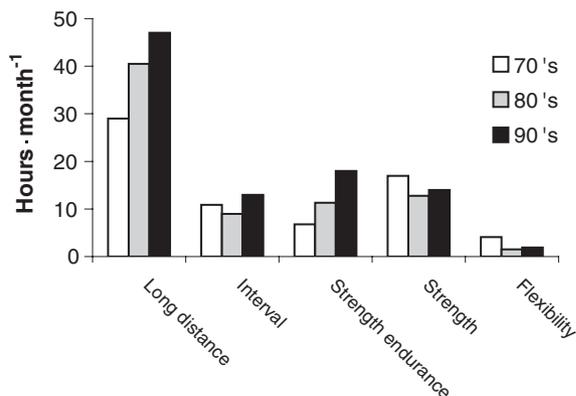


Fig. 2. Changes in distribution of training volume among training types during the winter preparation period of the annual cycle (October–March) from the 1970s to the 1990s. Refer to Table 2 for explanation of training types.

increase in winter training volume was due to long-distance endurance training and strength endurance training. Figure 3 depicts the training load distribution during the competitive season. From the 1970s to 1990s, long-distance training in the boat was increasingly emphasized. Both the absolute and relative volume of boat training at race pace or above race pace intensities were reduced, from $\sim 23 \text{ h month}^{-1}$ of race pace or over-speed training in the 1970s to less than 7 h month^{-1} during the 1990s (Fig. 4). From the 1970s to 1980s, a large increase in the total volume of training performed at low intensity (blood lactate concentration $\leq 2 \text{ mM}$), and a small decrease in the total volume of high intensity training (interval, race pace, over-speed training) were observed. Since the 1980s, the training organization has remained fairly stable, with small shifts in training load away from very high intensity sprint bouts toward longer-interval training at 85%–95% $\text{VO}_{2\text{max}}$.

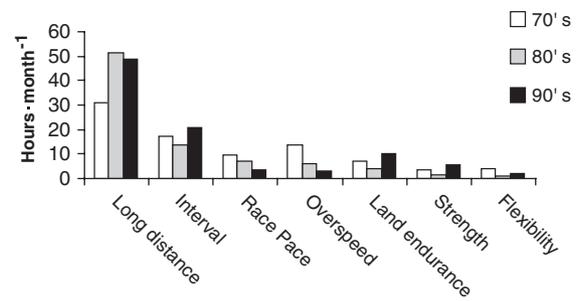


Fig. 3. Changes in distribution of training among training types during the summer competition period of the annual cycle (April–September) from the 1970s to the 1990s. Refer to Table 2 for explanation of training types.

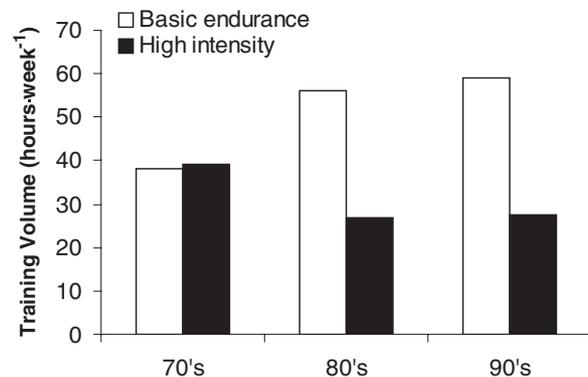


Fig. 4. Overall distribution of training volume (h week^{-1}) between extensive long-distance training and highly intensive training among medal winners from the 1970s, 1980s, and 1990s.

Altitude training

In Table 4, the number of altitude camps ($\sim 2000 \text{ m}$ above sea level) attended by the athletes during each decade is presented. Altitude camp attendance is divided into the preparation and competitive periods. During the 1970s, the first altitude camps were used in an experimental way. During the 1980s, altitude training became quite common, with most of these 14–21-day camps held in the final weeks prior to major competitions. During the 1990s, altitude training played an even more prominent role in the overall training program. However, the goal of altitude training shifted from pre-competition “peaking” to improving the basic condition of the athletes. Athletes began training at altitude several times during each winter preparation period and altitude training during the competitive season was reduced.

Discussion

This study provides a time-line quantifying the 30-year evolution of both training organization and

Table 4. Number of altitude training camps attended by athletes during each decade

| Decade | Summer competition period | Winter preparation period |
|-----------|---------------------------|---------------------------|
| 1970–1979 | 3 | 3 |
| 1980–1989 | 26 | 2 |
| 1990–2001 | 14 | 36 |

Values represent the number of camps completed by the national team. All medal winners did not attend every camp.

basic physical characteristics among a group of world-class endurance athletes specializing in an event lasting 6–7 min. Over the period, the athletes represented were all among the best performers in international rowing. During that time span the performance of the “best” got better. Compared with the athletes winning medals in the 1970s, medal winners in the 1990s had about 12% higher $\text{VO}_{2\text{max}}$, without an increase in body mass. An average $\text{VO}_{2\text{max}}$ of $\sim 6.5 \text{ L min}^{-1}$ is probably a prerequisite for international success in rowing, with values approaching $\sim 7.0 \text{ L min}^{-1}$ becoming a “Gold Standard”. It is interesting to note that these large (85–100 kg) athletes now have relative $\text{VO}_{2\text{max}}$ values between 72 and $78 \text{ mL kg}^{-1} \text{ min}^{-1}$, about $10 \text{ mL kg}^{-1} \text{ min}^{-1}$ below the best runners and skiers, who are typically 15–25 kg lighter. The values reported are consistent with published data on top rowers over the last 30 years (Secher et al., 1982; Steinacker, 1993; Hagerman, 1994).

These data do not establish a causal relationship between training changes and physiological improvements. However, in the elite coaching milieu, it is accepted that developments in training volume and organization have contributed to the continued improvements in rowing performance in Norwegian rowers and have been necessary for these athletes to compete successfully in international championships. The three major training changes observed are: (1) redistribution of day-to-day training intensity resulting in more emphasis on training at intensities below the first lactate turn-point, (2) a $\sim 20\%$ increase in total training volume achieved primarily via a similar increase in training frequency, and (3) a dramatic increase in the incorporation of altitude training throughout the annual training cycle.

In the late 1960s, national class Norwegian rowers trained five to seven times per week and were not internationally competitive. Then, during the 1970s, the development of an elite training group and systematic training and physiological testing methods resulted in a large increase in the quality and quantity of training, culminating in the winning of international medals. Through the 1970s, the train-

ing frequency increased to two sessions per day for portions of the season and annual training volume exceeded 900 hr^{-1} . This annual volume corresponded to about 17 h week^{-1} effective training during the winter and $\sim 22 \text{ h week}^{-1}$ during the competitive season. Training volume was almost equally divided between long distance, aerobic sessions and high intensity sessions placing a high stress on anaerobic energy pathways.

During the 1980s, training volume increased only modestly, but the organization of training changed dramatically. In keeping with a growing understanding of the physiological factors limiting performance in the 2000-m rowing race, more emphasis was placed on building up the aerobic capacity, and less on training the anaerobic capacity. Greater emphasis was placed on accumulating a large volume training (more kilometers of on-water rowing) at lower intensity. Long-distance rowing volumes increased from ~ 7.5 to $\sim 12.5 \text{ h week}^{-1}$. Besides promoting muscular adaptations, the high rowing volume at low stroke rates was used to improve technical stability. To accommodate this increase, all other training forms were relatively less emphasized, particularly training at very high intensities. Corresponding to these changes in training, the physical capacity of the athletes increased by almost 10%, whether measured as $\text{VO}_{2\text{max}}$ or power for a 6-minute maximal test on the Gjessing rowing ergometer.

By the beginning of the 1990s, a program of individual financial aid to qualified athletes made it possible for the best rowers to take time off from work or studies during important training periods. There was an additional increase in total training volume. From the 1980s to the 1990s, the training volume increased by about 15% and now averages over 1100 hr^{-1} among Norwegian international medal winners. This figure is also consistent with unpublished reports from other successful international rowing programs. In fact, Roth (1979) reported training volumes of 1000 hr^{-1} already in the late sixties and 1970s among German rowers. Most of the increase in training volume over the last decade has occurred during the winter preparatory period. The absolute and relative contribution of boat training at or above racing speeds has been further reduced. This type of training is associated with blood lactate concentrations between 10 and 15 mM (Hartmann & Mader, 1990), as well as very high stress-hormone responses (Naveri et al., 1985; Strobel et al., 1998).

Since the 1980s, the physical capacity of the Norwegian medal winners has stabilized when measured as treadmill VO_2 or rowing ergometer performance. The further increases in training volume achieved in the 1990s were not associated

with statistically significant increases in physical capacity. This comparison may be slightly misleading, however. The more recent development of standardized tests on the Concept II ergometer has resulted in a reduced emphasis on these other tests, a trend that might have had impact on the test results. These tests were performed at the end of the preparation period. They therefore cannot capture a potential effect of a greater volume foundation in the “peaking” process used to help athletes reach maximal performance levels at international championships, which come near the end of the summer season, ~ 5 months after the end of the general preparation period. The physiological consequences of some of the practices used, such as repeated altitude training exposure and strength endurance training methods, on athletes of such high performance level have not been documented. Experimental studies recreating the training loads and time frames relevant for international class endurance athletes are absent from the literature. Further, the increase in performance capacity that is meaningful for these athletes (~ 1%) is not possible to delimit statistically with practical sample sizes (Hopkins et al., 1999). The training practices of these athletes are perhaps best viewed as the result of an iterative process of year after year of annual training cycles, evaluation of results, and adjustment.

For the international class rower, the goals of the annual training cycle are to enhance all relevant aspects of physical capacity, engrain technical mastery, and then enable the athlete to mobilize these capacities and deliver maximal performances during international championship regattas. For medal winners, this usually means successfully timing the performance peak to a single decisive final race. While athletes maintain a high level of fitness throughout the year, the high training volume exposure during the winter and early summer is at the threshold of what is tolerable. Performance capacity is intentionally depressed during overreaching phases to facilitate a supercompensation effect prior to key competitions. Speculatively, the higher training volume performed in the 1990s may facilitate long-term endocrine adaptations (Kjaer, 1998), and greater capacity for sympathetic mobilization following supercompensation training periods and tapering for major races. In support of this explanation, international class rowers were found to have significantly higher postrace growth hormone levels, and anticipatory cortisol levels than national team and medium performance level rowers (Snegovskaya & Viru, 1993). The magnitude of the growth hormone responses to acute exercise appears to be linked to the degree of central adrenergic activation (Weltman et al., 2000).

Boat velocity in international finals continues to increase. Some of this improvement is attributable to equipment refinements (blade, boat, and hardware changes in the early 1990s), and the continuing evolution of technique (small refinements at best). However, the performance trend has also continued over the last decade, despite the fact that no meaningful equipment changes have occurred since 1992. In the 2002 World Championships, all-time world best performance times (world records are not recognized in rowing) were achieved in nine of 24 events. New world standards were also achieved for both men and women during international indoor rowing championships and many of these superior Concept II ergometer performances were achieved by the same rowers who had won medals at outdoor world championships or the Olympic Games. These developments suggest that the physical capacity of the rowers continues to improve. In Norway, the improvements quantified cannot be attributed to improved recruitment of talented persons to the sport, as rowing recruitment has declined somewhat since the 1970s.

A third development observed over the last three decades was an increase in the integration of training periods at moderate altitude (1800–2500 m above sea level) into the annual training cycle. Prior to the Mexico City Olympics in 1968, coaches probably underestimated the effects of altitude on maximal performance and fatigue. More than 80 collapse incidents occurred during the first days of the rowing races, and specific crews even stopped and started again during these races at altitude (Hagerman, 1994). This experience coupled with reports of early positive results from altitude training on sea-level endurance performance by Daniels and Oldridge (1970) and Dill and Adams (1971) ushered in an era of altitude training camps during pre-race preparation. However, over 30 years later, the effect of altitude training on sea-level performance remains equivocal. Many coaches are positive (Baumann et al., 1994), while some physiologists suggest that coaches overestimate the altitude training effect as evidence is lacking (Wolski et al., 1996). One study reporting a lack of effect of altitude on $\text{VO}_{2\text{max}}$ and performance included some of the Norwegian rowers described here (Jensen et al., 1993).

There is consensus regarding the physiological factors that limit endurance performances (Joyner, 1991; Coyle, 1995; Hawley & Stepto, 2001). In contrast, consensus on the optimal volume and organization of training necessary to maximize these adaptations, while avoiding overtraining, remains elusive. Much of the literature is based on short-term intervention among untrained subjects. The results are at odds with the methods used successfully at the elite level. Specifically, training studies on untrained

subjects demonstrate that training intensities corresponding to the lactate threshold are effective in increasing physical performance (Yoshida et al., 1982; Denis et al., 1984; Keith et al., 1992; Takeshima et al., 1993; Gaskill et al., 2001). The focus on the lactate threshold as a physiological marker of an appropriate intensity has led to that much of the total training volume is performed at or around this intensity. In contrast, the training organization of top performers in marathon running (Billat et al., 2001), rowing (Steinacker et al., 1998), pursuit cycling (Schumacker & Mueller, 2002), and cross-country skiing (unpublished data) suggests that their training is focused on balancing the application of large volumes of training at intensities substantially below the lactate threshold intensity with doses of training at intensities between the maximal lactate steady-state intensity and the minimum intensity eliciting $\dot{V}O_{2\max}$ (about 85%–95% $\dot{V}O_{2\max}$). Relatively little training volume is performed at the lactate threshold intensity. For example, Hartmann and Mader (1990) reported the results of extensive training data collected on national team rowers in West Germany. During the preparation period, more than 90% of the training performed by these internationally successful athletes was performed at an intensity eliciting <2 mM blood lactate, vs. 7% performed at 2–4 mM blood lactate. In the pre-competition period, the percentage of training volume performed at this low intensity continued to account for nearly 75% of total training sessions compared to only 18% of training sessions performed at intensities between 2 and 4 mM lactate. Steinacker et al. (1998) reported data from junior rowers preparing for World Championships. About 75% of training was performed at an intensity eliciting an average blood lactate of about 1.5 mM, while the remainder was performed at lactate of 6.5 mM, or higher for race pace training.

Perspective

Over the last three decades, the maximal aerobic capacity of international medal winners in rowing appears to have increased by more than 10%, based on data from 28 international rowing medal winners from Norway collected between 1970 and 2000. A $\dot{V}O_{2\max}$ of 6.5–7.0 L min⁻¹ (72–78 mL kg⁻¹ min⁻¹ at 90+ kg) is common among top international heavyweight male performers. During the same time period, at least three important changes in training have occurred. Annual training volume has increased by about 20%, with most of the increase occurring during the winter period. International medal winners in rowing currently train between 1100 and 1200 h yr⁻¹. The organization of training intensity has changed dramatically. Large increases in basic endurance training at intensities clearly below the first lactate turn point have been utilized. Training at high intensities, at or above race pace (105%–115% $\dot{V}O_{2\max}$) has been de-emphasized compared to the 1970s. Greater emphasis has been placed on training at intensities requiring 90%–95% of $\dot{V}O_{2\max}$, most often in the form of long interval bouts lasting 4–8 min. Finally, repeated periods of altitude training, consisting of 14–21-day stays at ~2000 m above sea level has become a common practice, although the benefits of repeated altitude among well-trained athletes remain undocumented. This study supports and provides a historical context for data from elite endurance athletes suggesting that the optimal training organization for maximal performance is a polarized model of training with about 75% of training performed well below the lactate threshold and 15%–20% well above that intensity.

Key words: rowing, training organization, elite athletes, endurance training, maximal oxygen consumption, lactate threshold.

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