

Physiological Evolution of the Rowing Athlete: a 25-year Study

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Introduction

It is well known that a 2000-m competitive rowing effort requires a substantial aerobic energy contribution (75-80%). Although anaerobic energy sources are only responsible for 20-25% of the total energy for this effort, they are no less important as they are needed most at critical periods of the race: at the start and again during the sprint at the finish. Optimal energy production is dependent on several complex and interdependent physiological responses which are often described as *utilization* and *transportation*. Utilization of stored energy in skeletal muscle fibers begins with the use of high energy phosphate compounds (ATP and Phosphocreatine) followed rapidly by the metabolism of intracellular carbohydrate (glycogen), fat, and protein which, when combined with oxygen, will provide the energy to sustain exercise. Transportation is represented by a series of important processes using such functions as neurological, cardiovascular, respiratory, and hematological, all working together to deliver oxygen and nutrients to the working muscle and stimulate its contraction.

Several aerobic sports and/or events are dependent on a similar energy component relationship as rowing, however, athletes in these sports and/or events are not required to generate as much muscular power as rowers and all involve individual participation. A crew is thus only as strong as its weakest member. The excessive energy demands of rowing and the emphasis on high muscular power output seem to attract several genetically gifted and hard working athletes whose skeletal muscle fiber composition and respiratory - cardiovascular delivery systems show extreme adaptations. These adaptations are represented by the development of some very unique physical and physiological qualities which have continued to evolve and improve as indicated by the comparative data that are presented in this paper. All of the comparisons represent observations of U.S. rowers over a 25-year period and include over 2000 subjects.

Athlete Profile

Physical Characteristics

Elite rowers are tall and muscular, and tend to have very low percentages of body fat. Oarsmen competing in the open division now average 89 kg in weight and 193 cm in height while women rowers now average 76 kg in weight and 176 cm in height. Percent body fat has steadily declined for both men and women so that men now average about 8.5% while women average about 16%. Table 1 summarizes changes in body composition of U.S. men's eight-oared crews every 5 years between 1972 and 1997. As illustrated in this table rowers have become taller and more muscular over the 25-year period with percent body fat decreasing significantly during this time. Because of weight restrictions lightweight men and

women tend to be smaller athletes: men average about 70 kg in weight and 177 cm in height while lightweight women average 57 kg and 172 cm respectively. As expected, both lightweight men and women have a high proportion of their body composition represented as fat-free mass: percent body fat usually ranges between 5-9% for men and 10-14% for women. There has been concern expressed by sports medicine doctors and scientists for the health and well being of lightweight rowers because of some of the potentially dangerous practices used to "cut" or "make" weight. Long term effects of these practices have not been identified but there is the possibility of severe muscle wasting and bone loss and even kidney and liver damage.

Table 1: Twenty-five year comparison of physical characteristics of U.S. National eight-oared crews: 1972-1997 (mean \pm SD)

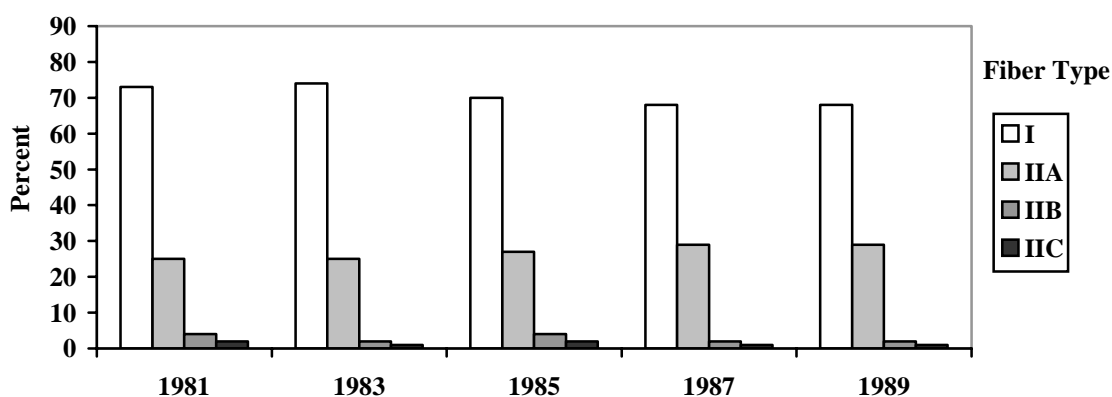
Year	Age (yrs)	Height (cm)	Weight (kg)	Bodyfat (%)
1972	23.8 ± 1.45	189.4 ± 2.92	87.4 ± 6.1	12.3 ± 2.3
1977	21.4 ± 2.5	194.3 ± 3.0	91.2 ± 4.8	11.5 ± 2.0
1982	22.8 ± 2.1	194.3 ± 4.3	90.2 ± 4.3	9.3 ± 1.6
1987	23.1 ± 3.3	195 ± 5.5	88.2 ± 3.7	8.5 ± 1.2
1992	24.2 ± 3.1	195.8 ± 5.1	92 ± 2.9	8.6 ± 1.1
1997	23.1 ± 3.4	196.3 ± 3.0	93.8 ± 2.7	8.9 ± 0.7
% change between 1972 & 1997	-2.9	3.6	7.3	-27.6

Skeletal Muscle Qualities

Because of the emphasis on both muscular power and cardiorespiratory endurance it was originally hypothesized that the dominant muscle fiber in rowing muscles would be the normally larger fast IIA or Fast-Twitch-Oxidative fiber. However, to our surprise most of the fibers turned out to be of the Slow-Twitch or Type I variety (similar to a marathon runner's muscle) but unusually large in diameter. Average percentages of 70-75% for Type I fibers have been consistently observed in the vastus lateralis muscle of rowers as opposed to 20-25% Type IIA fibers and almost no Type IIB or Fast-Twitch-Glycolytic fibers represented (see Figure 1). The average representation of Type IIB fibers in rowers is somewhat misleading since most elite oarsmen do not have any of this fiber type: the average value for IIB fibers was strongly influenced by a few athletes having only a small number of these fibers. The most unique adaptive architectural response to rowing appears to be the development of unusually large Type I fibers, many having cross-sectional areas of greater than 8000 μm^2 . It is noteworthy that results of serial biopsy data accumulated for the same 12 highly competitive oarsmen over an 8-year period have shown consistent fiber type proportions (see Figure 1). Most of these subjects were initially sampled between ages 20 - 22 years and, with no exception, displayed very similar fiber type proportions and cross-sectional areas throughout the entire test period. Despite some differences in training over the years and possible cumulative effects of training, fiber type proportions and cross-sectional areas remained stable. This is in contrast to similar studies conducted with elite cyclists who exhibited changes in fiber type proportions over time most of which favored an increase in oxidative fiber types (increase in Type IIA) (Coyle et al., 1992). It is not certain what accounts for the differences in the adaptive responses between elite rowers and cyclists, however it

may be possible that rowing training simply causes more rapid and complete adaptive responses early in an elite oarsmen's exposure to training. These responses may be due to the unique muscular power and endurance demands of the rower. It has been confirmed that either endurance or power training causes significant conversion of IIB (low oxidative fast-twitch) to IIA (high oxidative fast-twitch) (Staron et al., 1989, 1991, 1996). Since most elite rowers in the U.S. are not exposed to their sport until age 18 or older, it is possible that the conversion from IIB to IIA fibers has been completed by the time muscle biopsy sampling occurs when the athletes become candidates for National or Olympic Teams. Since there is very little or no evidence to indicate that Type I slow-twitch fibers in human subjects are susceptible to conversion, heredity may have the most significant influence on the relative presence of these fiber types in rowers.

Figure 1: Longitudinal comparisons of fiber type distributions of elite U.S. oarsmen



Metabolic Capacity

Absolute maximal and peak oxygen consumptions of elite rowers are among the highest ever observed for an elite endurance athlete (Hagerman, 1994). We have recorded absolute peak \dot{V}_{O_2} values exceeding $7 \text{ L}\cdot\text{min}^{-1}$ in several elite oarsmen, the highest being $7.48 \text{ L}\cdot\text{min}^{-1}$, and more than $5.5 \text{ L}\cdot\text{min}^{-1}$ in a number of female rowers. Relative values higher than $80 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ have been measured for some men and values in excess of $70 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ have been recorded for a small number of women. With the exception of earlier ergometer testing, (6:00 min standard maximal effort test for 1972 through 1977), all of our ergometer tests have been conducted for a 2000m simulated competitive effort on a Concept II ergometer. Ergometric performances have improved over time (see Table 2) and these faster efforts are reflected by compatible increases in utilization and transport of oxygen and increases in anaerobic capacity. Both absolute and relative oxygen consumptions have increased since 1972 after comparisons of eight-oared crews' data over a 25-year period (see Table 3). These changes have been accompanied by higher lactate tolerance ($16.0 \text{ mmol}\cdot\text{L}^{-1}$ in 1972 and $19.8 \text{ mmol}\cdot\text{L}^{-1}$ in 1997) and increased O_2 delivery: O_2 pulse improved from $31.6 \text{ ml}\cdot\text{beat}^{-1}$ to $36.1 \text{ ml}\cdot\text{beat}^{-1}$ (see Table 4). Since peak HR changed very little over the 25-year period it appeared that heart stroke volume and thus cardiac efficiency was increased. Recent echocardiographic data from our laboratory have substantiated cardiac output data for oarsmen measured invasively by our group earlier (Hagerman, 1994). Maximum cardiac outputs for oarsmen have ranged from 29 to $45 \text{ L}\cdot\text{min}^{-1}$ with the highest values observed for those oarsmen whose

heights exceeded 199 cm, weights did not exceed 90 kg, percent body fat did not exceed 9%, peak V_{O_2} was $6.7 \text{ L}\cdot\text{min}^{-1}$ or higher and average V_{O_2} was at least 98% of peak V_{O_2} during the 2000 m simulated rowing effort on a Concept II ergometer and average power output for this effort was 500 w or higher. Both oxygen transportation and utilization improved over time and no doubt also contributed to improved mechanical efficiency (ME) for the modern day oarsmen (see Table 4). It is difficult to isolate a single important physical or physiological factor responsible for the improved fitness of oarsmen, however today's athletes are more muscular, stronger, possess greater endurance capacity, and row more efficiently. They have also benefited from better equipment, coaching, training, and nutrition, all of which work together to improve rowing fitness and performance.

Table 2: Twenty-five year comparison of ergometric performances of U.S. National eight-oared crews: 1972-1997 (mean \pm SD)

Year	Rowing Time (min)	Average Power (Watt)
1972*	6:00.0	386.6 ± 12.6
1977*	6:00.0	402.4 ± 13.3
1982	6:05.1 ± 16.1	460.1 ± 10.2
1987	6:00.8 ± 13.7	478.8 ± 9.6
1992	6:03.4 ± 12.6	465.9 ± 11.4
1997	5:58.4 ± 8.0	488.1 ± 10.9
% change between 1982 & 1997	-1.8	6.1

(* = 6-minute erg test: gamut ergometer)

Table 3: Twenty-five year comparison of respiratory-metabolic responses of U.S. National eight-oared crews: 1972-1997 (mean \pm SD)

Year	peak VE (BTPS) (L/min)	peak VO ₂ (STPD) (L/min)	peak VO ₂ (STPD) (ml/kg/min)
1972	187.6 ± 18.2	5.87 ± 0.1	65.5 ± 5.0
1977	191.4 ± 11.1	5.9 ± 0.3	64.3 ± 1.1
1982	212 ± 18.6	6.0 ± 0.2	67.1 ± 2.9
1987	189.9 ± 9.7	5.9 ± 6.3	67.2 ± 8.2
1992	200 ± 12.3	6.31 ± 0.5	68.6 ± 5.8
1997	201.2 ± 20.1	6.62 ± 0.4	71.3 ± 6.1
% change between 1972 & 1997	7.3	12.8	8.9

Table 4: Twenty-five year comparison of transportation data (heart rate - oxygen pulse), lactate tolerance, and mechanical efficiency of U.S. National eight-oared crews: 1972-1997 (mean \pm SD)

Year	peak HR (L/min)	O ₂ pulse (ml/b)	post LA (mmol/L)	ME (%)
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1972	186.0 ±8.0	31.6 ±2.9	16.0 ±2.0	18.9 ±1.2
1977	181.0 ±7.2	32.6 ±1.9	15.8 ±2.0	19.2 ±1.1
1982	194.0 ±10.4	30.9 ±2.1	15.6 ±1.8	18.8 ±0.5
1987	188.0 ±8.6	31.4 ±2.3	13.6 ±2.1	19.2 ±0.6
1992	189.0 ±7.3	33.4 ±2.1	17.3 ±2.2	19.6 ±1.9
1997	184.0 ±10.4	36.0 ±2.7	19.8 ±2.4	22.3 ±3.2
% change between 1972 & 1997	-1.1	13.9	23.8	3.4

Performance

Despite the differences in climatic and environmental conditions among regatta sites, competitive results have continued to improve on an average of about 0.5 to 1.0 second per year since the 1956 Olympic Games however, more recent results have improved at a more rapid rate (see Table 5). The average improvement in four common men's Olympic events from 1956 to 1997 was about 0.5% per year with the pair without coxswain showing the most improvement during this 41 year period. Average improvement for women in four events from 1988 to 1997 was almost 20 seconds: single sculls and pair-oared without coxswain showed the greatest improvement (see Table 5). Because there are few comparative Olympic performance data between men and women it is difficult to explain the apparent gender-related differences. When World Rowing Championship data are included as part of the comparison and performance data from other aerobic sports are added it is clear that certain anatomical (larger skeletal and cardiac muscle mass) and physiological (larger blood volume) favor the male rowers but when relative values based on body weight and fat-free mass are considered, competitive efforts for men and women are now almost equal. As indicated in Table 5 women have improved performances substantially from 1988 to 1996. For the events summarized in Table 5, the men were, on an average, almost 50 seconds faster than the women in 1988 but this difference had been reduced to 40 seconds faster by 1996, the one exception being the eight-oared event in which the men showed more improvement between 1988 and 1996. Faster 2000m times for both men and women over the years have been a result of better equipment, better and more experienced athletes, and improved training programs. It does appear that women are now improving at a faster rate than men and this can be accounted for by the attraction of better athletes and the accumulation of more experience at the 2000m distance.

More recent ergometric and physiological data indicate that rowers are still evolving into better athletes, and if equipment and racing conditions keep pace with the physiological growth of the rowing athlete then the expectations of rowing performances will continue to increase.

Table 5: A comparison of Olympic Games performance times (min:sec) over 2000m for four common boat classes for men and women (1997 world champion results are also included)

Men

Year	Single Scull	Double Scull	Pair-oared without coxswain	Eight-oared with coxswain
1956	8:03	7:24	7:55	6:35
1960*	7:14	6:48	7:02	5:57
1964	8:23	7:11	7:33	6:18
1968	7:48	6:52	7:27	6:07
1972	7:10	7:02	6:53	6:09
1976	7:29	7:13	7:23	5:58
1980	7:10	6:24	6:48	5:49
1984	7:00	6:36	6:45	5:41
1988	6:50	6:21	6:37	5:46
1992	6:51	6:17	6:28	5:29
1996	6:45	6:17	6:20	5:42
1997	6:45	6:13	6:28	5:27
↑ based on 1956	16.1%	16.0%	18.3%	17.2%

* = racing distance short of 2000m

Women

Year	Single Scull	Double Scull	Pair-oared without coxswain	Eight-oared with coxswain
1976**	4:06	3:44	4:01	3:33
1980**	3:41	3:48	3:31	3:03
1984**	3:41	3:27	3:32	3:00
1988	7:47	7:01	7:28	6:15
1992	7:26	6:49	7:06	6:03
1996	7:32	6:57	7:01	6:19
1997	7:29	6:51	7:08	6:02
↑ based on 1988	3.8%	2.4%	4.5%	3.5%

** = racing distance 1000m

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