# ANATOMICAL AND PHYSIOLOGICAL FACTORS IN ELITE FEMALE KAYAKERS

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Olympic-style kayak racing for women does not command the spectator appeal and media attention of events such as track and field, swimming, and gymnastics. Consequently, there have been a limited number of investigations designed to describe the anthropometric and physiological characteristics of these athletes. Much of the work that has been done has remained unpublished. National team coaches and trainers from such countries as Federal Republic of Germany, German Democratic Republic, Sweden, Hungary, Canada, and the United States have done assessments as part of evaluations but in general, these data are unavailable.

The purposes of this paper are to: (a) review the anthropometric and physiological data available on female Olympic-style kayakers; (b) present some unpublished evaluation data on U.S. paddlers, and (c) discuss the implications for application of anthropometric and physiological evaluations in canoe sport.

The anthropometric characteristics of female kayakers fall into a reasonably narrow range. The data in Table 1 have been drawn from several sources but predominently from the work of Lindsay Carter and the reports of the MOGAP project. Inspection of these data reveals: (a) age of the paddlers remained reasonably consistent, 23.3 to 25.7 years, from 1964 to 1976; (b) it should be noted that the mean age of the in-depth MOGAP study was only 20.6 years but that this was based on a sample of n=8; (c) subjective calculation of the ages of the competitors in Los Angles suggests a mean age of approximately 25.4 years; (d) heights have remained reasonably constant in the range of 165 to 170 cm; (e) weight has also been stable ranging between 62 and 65 kg; (f) the MOGAP study sample had a percentage of body fat, estimated on the basis of 6 skinfolds, of 15.2%; and (g) somatotype data are available from Mexico City, 3.0-4.5-2.5, and Montreal, 2.8-4.1-2.9, which are quite similar.

Carter carefully analyzed 12 anthropometric variables from the MOGAP data and concluded that the female kayakers were most like swimmers, track and field athletes, and rowers. It would appear to be warrented to conclude that successful paddlers appear to be athletic in somatotype and larger than average in height and weight.

TABLE 1

ANTHROPOMETRIC CHARACTERISTICS OF OLYMPIC FLATWATER WOMEN

| GROUP | AGE | HEIGHT | WEIGHT | SOMATOTYPE | %FAT |
|---|---|---|---|---|---|
| TOKYO N=30 | 25.0 | 165.6 | 62.0 | | |
| MEXICO CITY | | | | 3.0-4.5-2.5 | |
| MUNICH N=63 | 25.7 | 166.4 | 64.7 | | |
| MONTREAL N=43 | 23.3 | 169.4 | 64.5 | | |
| MONTREAL N=8 | 20.6 | 170.7 | 63.0 | 2.8-4.1-2.9 | 15.2 |

TABLE 2

SUMMARY OF PHYSIOLOGICAL DATA FROM THE LITERATURE

| REFERENCE | TASK | $V_{O_2}$ L/MIN | $V_{O_2}$ $ML/KG \cdot MIN^{-1}$ | RATIO OF ARM TO MAX $V_{O_2}$ | HR AT $V_{O_2}$ | POWER (W) |
|---|---|---|---|---|---|---|
| STENBERG, ET AL. 1967 N=4 | ARM SITTING | 1.94 | | 80 | 178 | 92 |
| N=4 | ARM LYING | 1.77 | | 71 | 174 | 66 |
| VANDER ET AL. 1984 N=10 | ARM CRANK | 1.60<br>.26 | 27.4<br>- | 79 | 169<br>12 | 75 |
| WASHBURN AND SEALS 1984 N=20 | ARM CRANK | 1.81<br>.36 | 29.2<br>4.9 | 83 | 174<br>36 | 86<br>13 |
| FALKEL, ET AL. 1986 N=8 | ARM CRANK | 2.26<br>.11 | 38.6<br>1.7 | 76 | 179<br>2 | 105<br>5 |
| CERRETELLI ET AL. 1979 N=3 | SLALOM BOAT | 2.92 | 44.2 | 81 | - | - |

These authors were unable to locate any published physiological data specifically on women kayakers. In an attempt to review the literature, however, Table 2, which summarizes data on upper body aerobic power in women, has been prepared. The subjects in these investigations have been active normal subjects who have not specifically done upper body training. The task used for testing has generally been arm cranking on some type of a modified cycle ergometer using a progressive step-wise protocol. The work of Cerretèlli, Pendergast and others (1979) at Buffalo has been an exception. In their studies they used trained kayakers and did in-boat evaluations in a circular tank. As shown in Table 2 the absolute aerobic power of the normal subjects tested for these four studies has ranged from 1.60 to 2.26 l/min and has been obtained at less than age-predicted maximum heart rate, $\bar{X}$=174.8 bpm. The three paddlers tested by Cerretelli achieved a peak $VO_2$ of 2.92 l/min or approximately 55% higher than the other subjects. Each of the investigators has also calculated the ratio of peak $VO_2$ obtained with the arms to $VO_2$ max measured on a treadmill or cycle ergometer. The range of these ratios is from 71% to 83% with a mean value of 77.8%. The three paddlers were able to use 81% of their running $VO_2$ max while paddling. The limited capacity for upper body work of the untrained subjects is also suggested by inspection of the power output required to elicit peak $VO_2$ , $\bar{x}$=84.8 W.

Over the approximately 10 years that this investigator has been involved in the sport, attempts have been made to evaluate physiological capabilities of U.S. paddlers. We have employed paddleboards, arm cranking ergometers, a kayak ergometer, in-boat testing, and treadmills to evaluate aerobic power. One of the goals of this type of work is to obtain valid sport-specific data with a minimal amount of instrumentation and interference with the paddlers performance. Some of the data representative of these efforts will now be presented.

Table 3 summarizes data on four national team paddlers. These paddlers obtained mean peak $VO_2$ of 2.87 l/min. on the paddleboard using blades approximately 7.5 cm in width. It should be noted that since kayaking is not a weight-supported sport, i.e. the boat supports the weight of the paddler and the drag is not linearly related to weight, that the absolute aerobic power is more important than the relative values. Relative values in $ml/kg \cdot min^{-1}$ and $ml/kg\ LBM \cdot min^{-1}$ are, however, presented in Table 3. These same subjects were also tested using a standard treadmill protocol and obtained values of 3.32 l/min and 54 $ml/kg \cdot min^{-1}$ . Evaluation of these data certainly reveals that the paddlers are high in both general and sport-specific aerobic fitness. The ratio of their peak $VO_2$ on the paddleboard to treadmill max was 85%. We would expect this ratio to be higher on the paddleboard than in a boat because of the added stability provided by the paddleboard.

In an attempt to obtain a more sport-specific evaluation a kayak ergometer was developed. The data presented in Table 4, reveal that it had the ability to differentiate between national team level competitors and members of the training squad. The women on the national team had oxygen uptakes that were approximately 40 percent higher than other women tested. An important side benefit to

TABLE 3
COMPARATIVE PADDLEBOARD AND TREADMILL DATA, 1978-79

| SUBJECT | OXYGEN UPTAKE | | | | | | RATIO $V_{O_2}$ PADDLEBOARD / TREADMILL |
|---|---|---|---|---|---|---|---|
| | PADDLEBOARD | | | TREADMILL | | | |
| | L[a] | ML[b] | ML-LBW[c] | L[a] | ML[b] | ML-LBW[c] | |
| C.F. | 2.71 | 44 | 49 | 3.48 | 56 | 62 | 78 |
| L.K. | 3.14 | 48 | 52 | 3.86 | 59 | 64 | 83 |
| A.T. | 3.05 | 42 | 50 | - | - | - | - |
| L.W. | 2.59 | 46 | 51 | 2.64 | 47 | 52 | 98 |
| $\bar{x}$ | 2.87 | 45 | 50 | 3.32 | 54 | 59 | 85 |
| MEN | | | | | | | |
| $\bar{x}$ | 4.16 | 53 | 56 | 5.41 | 68 | 71 | 79 |

[a] $\dot{V}_{O_2}$ IN L/MIN.
[b] $V_{O_2}$ IN ML/KG·MIN$^{-1}$
[c] $V_{O_2}$ IN ML/KG LBW·MIN$^{-1}$

TABLE 4
KAYAK ERGOMETER -- COMPARATIVE PHYSIOLGOICAL DATA

| SUBJECT | $V_{O_2}$ L/MIN | $V_{O_2}$ ML/KG·MIN$^{-1}$ |
|---|---|---|
| NATIONAL TEAM - WOMEN N=2 | | |
| L.K. | 3.10 | 47.5 |
| C.F. | 2.88 | 46.3 |
| $\bar{x}$ | 2.99 | 46.9 |
| TRAINING SQUAD - WOMEN N=5 | | |
| | 2.35 | 34.3 |
| | 2.14 | 32.5 |
| | 2.05 | 31.2 |
| | 2.05 | 30.7 |
| | 2.12 | 30.4 |
| $\bar{x}$ | 2.14 | 31.82 |
| NATIONAL TEAM - MEN N=5 | | |
| $\bar{x}$ | 3.68 | 47.06 |
| TRAINING SQUAD - MEN N=11 | | |
| $\bar{x}$ | 3.08 | 41.25 |

TABLE 5

ARM CRANK ERGOMETER -- COMPARATIVE PHYSIOLOGICAL DATA

| SUBJECT | WEIGHT | $V_{O_2}$ L/MIN | $V_{O_2}$ ML/KG·MIN$^{-1}$ | WORK (W) |
|---|---|---|---|---|
| | 1984 U.S. OLYMPIC TEAM N=4 | | | |
| S.C. | 66.6 | 3.50 | 52.6 | 210 |
| L.K. | 67.5 | 3.68 | 54.5 | 225 |
| S.D. | 63.3 | 3.48 | 55.0 | 195 |
| A.T. | 73.5 | 3.81 | 51.8 | 225 |
| $\bar{x}$ | 67.72 | 3.66 | 54.0 | 214 |
| | TRAINING SQUAD N=3 | | | |
| C.H. | 72.2 | 3.68 | 51.0 | 195 |
| B.S. | 71.5 | 3.45 | 48.3 | 195 |
| J.S. | 69.7 | 3.47 | 49.8 | 210 |
| $\bar{x}$ | 71.1 | 3.53 | 49.7 | 200 |
| | 1984 U.S. MENS OLYMPIC TEAM N=7 | | | |
| $\bar{x}$ | 84.0 | 4.82 | 57.70 | 285 |

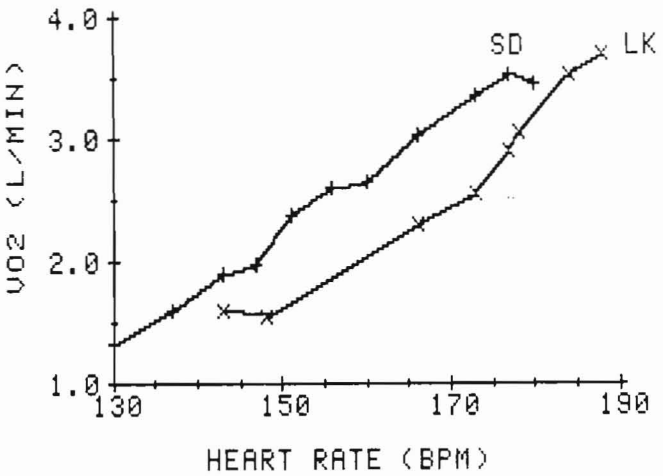


FIGURE 1. COMPARISON OF HEART RATES AND PERCENTAGE OF PEAK OXYGEN UPTAKE FOR TWO PADDLERS

use of this type of ergometer is the ability to measure absolute power output. For example in 1979 when Hugh Fisher was tested he had the highest absolute power output capacity of the 26 subjects tested -- 361 W.

The most complete set of data on female kayakers that we have obtained is on the U.S. Olympic Team of 1984. These data were gathered using a continuous step-wise protocol, on an arm crank ergometer with increments of 15 W/min. The data are summarized in Table 5--weight 67.72 kg, $VO_2$ 3.66 l/min or 54.0 $ml/kg \cdot min^{-1}$, and power required to elicit peak $VO_2$ 214 W. It is interesting to note that the aerobic ability of this group is basically 200% of the normal subjects described earlier. The power required to elicit peak $VO_2$ is also approximately 250% that of the of normals.

Given these oxygen uptake and power output values, one is tempted to suggest that because of the absolute values required for success a relatively large physical size becomes prerequisite. This logic is not entirely supported, however, by inspection of the data in the second tier of Table 5. These three subjects are relatively large, 71.1 kg, and muscular. Their aerobic and power output capabilities are only slightly lower than the four team members. Personal knowledge of these individuals suggests that the ability to skillfully apply the available physiological capabilities in a flatwater kayak was quite different between the two groups.

The heart rate achieved at peak VO for these seven members of the Olympic and national team and national team training squad was 187.4 bpm. The importance of this is that it is notably higher than peak heart rates elicited in the untrained subject groups referenced in Table 2, 174.8 bpm, and comparable to what would be expected as a heart rate maximum.

The bottom panel of Table 5 presents the data for seven of the men on the 1984 U.S. Olympic Team. Naturally, the absolute oxygen uptake values are higher for the men. If, however, oxygen uptake and power output are reported relative to weight or LBW the values for the females and males become very comparable. As shown in the table, the values for $VO_2$ in $ml/kg \cdot min^{-1}$ are 54.0 and 57.7 respectively for the females and males. The power required to elicit peak $VO_2$ was actually higher for the females, 3.15 W/kg than for the males, 2.81 W/kg. These data indicate that the females were as well trained in this sport-specific task as the men. Both Washburn and Seals (1984) and Falkel et al. (1986) have reported that when peak upper body oxygen uptakes are normalized for muscle mass the differences between the sexes disappears. Falkel et al. reported values of .89 and .85 ml $O_2$ /ml arm $volume \cdot min^{-1}$, for females and males, respectively. Washburn and Seals concluded that the differences in peak $VO_2$ are, "... not due to any specific sex-related differences in oxygen delivery or oxygen utilization capacity of the active muscle itself." (p. 956.)

An additional type of data that was obtained during the testing of the U.S. Olympic team in 1984 was heart rates at varying percentages of peak $VO_2$ . These values were of interest because the national team training program was written on the basis of all intervals being done at a designated percentage of maximum effort. Therefore, by knowing the HR at varying percentages of oxygen uptake appropriate training

TABLE 6

HR AT PERCENT OF MAXIMUM OXYGEN UPTAKE*

| SUBJECT | HEART RATE | | | | |
|---|---|---|---|---|---|
| | 55% | 65% | 75% | 85% | 100% |
| S.C. | 144 | 154 | 163 | 172 | 186 |
| L.K. | 157 | 167 | 174 | 180 | 188 |
| S.D. | 144 | 152 | 160 | 167 | 180 |
| A.T. | 142 | 154 | 162 | 171 | 182 |

*DATA FROM WOMEN ON 1984 U.S. OLYMPIC CANOE/KAYAK TEAM

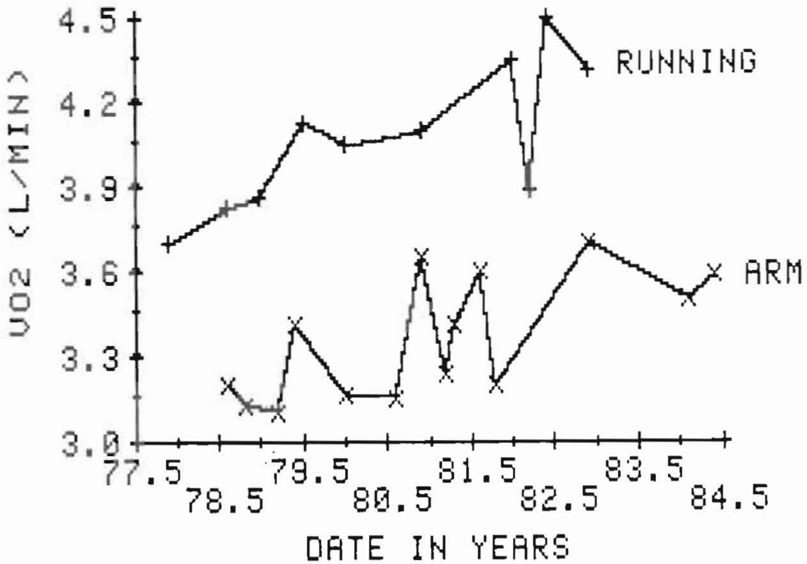


FIGURE 2. GAINS IN RUNNING AND UPPER BODY OXYGEN UPTAKE OVER TIME

heart rates could be established. Figure 1 presents the data for two of the athletes who trained and raced the K-2. It can be observed that the slopes of the $VO_2$ vs. HR plots are fairly similar but that paddler L.K.'s plot is shifted to the right indicating a higher HR at any given percentage of peak $VO_2$. These data are presented in Table 6. To be working at the same relative intensity L.K. would need to use a HR of 13-14 bpm higher than S.D.--for example at 75% the appropriate values would be 174 and 160 bpm, respectively. This type of information proved to be of practical value in conducting training sessions in team boats. If in fact different training HRs are needed the athletes should be aware of this to avoid both overtraining and sub-optimal training.

When discussing the application of sport science to athletes one of the comments that is frequently made is that the testing must be repeated over time to be of any significance. Figure 2 summarizes the data from one athlete who competed at the international level from 1978 through 1985. The top line in this figure, +s, represents treadmill assessments of maximum oxygen uptake. The lower line, Xs, represents the data from a variety of upper body tests: paddleboard, arm crank, kayak ergometer, and in-boat measures. Trend analysis of these data reveals that the subject was improving running $VO_2$ at a rate of .11 $l/min \cdot year^{-1}$ and peak arm $VO_2$ at a rate of .08 $l/min \cdot year^{-1}$. The ratio of peak arm $VO_2$ to $VO_2$ max was 82% in 1978 and 80% in 1984. These data support the importance of developing general fitness level in concert with sport-specific capabilities.

To this point we have not reported data from in-boat testing. The reason for this is that we do not have access to any organized data on females. There have been in the past and continue to be a number of centers where excellent physiological data are being collected with in-boat systems. This series of slides represents the system being used in Norway. It presents only minimal interference to the paddler and only requires one brief motion to open the collection bag and to close it and stop the timer. We have used a similar system at the University of Kentucky as have researchers here in Canada, in Federal Republic of Germany, Sweden, Poland, German Democratic Republic , and other countries. The Swedish team working with Per Tesch have been doing some excellent work in evaluating paddling OBLA from repeated trials at increasingly faster speeds. This work has the capability of evaluating anaerobic as well as aerobic contributions to kayaking performance and can be very applicable in assessment of training status.

Our summary of the data available on the anthropological and physiological characteristics of Olympic-style paddlers leads us to conclude the following: (a) optimal performance levels are not obtained until the mid-twenties; (b) continued improvements in physiological capabilities appear to be possible throughout an athlete's career; (c) above average height and weight in association with an athletic-type build are needed for success in paddling; (d) paddlers tend to be well above average in general aerobic fitness as assessed by max $VO_2$ ; (e) paddlers have exceptionally high aerobic and power output capabilities on a wide variety of upper body work tasks; (f) relative to body size, female members of the 1984 U.S.A. Olympic team were as well trained in the upper body musculature as the men;

(g) a considerable effort needs to be made to collect, summarize, and disseminate the anthropometric and physiological data that have been obtained on this group, and (h) attempts need to be made to coordinate efforts of the various groups working with female paddlers so that efforts can be directed toward the most meaningful types of evaluations.

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