An Update of Rowing Physiology

By Fredrick C. Hagerman, Ph. D.

I have had the opportunity over the last several years to compare training programs of the national and Olympic men's and women's teams with those of some of our college club programs and their effects on both ergometer and actual rowing performances. These numerous investigations were conducted during all training phases; from the preparation period through the competitive period, and also during the brief recovery period following seasonal competition. The results of these comparisons are both interesting and enlightening. First, the best rowing athletes appear to be divided into two groups: they differ because one group is made up more of transporters than users, while the other extremes are more users than transporters. The meaning of this dichotomy is that a rower who is more of a transporter has a very high cardiac output but tends to have a lower $a\text{-}vO_2$ difference (ability of muscle to extract and use oxygen); rowers who are primarily users have just the opposite qualities. These special physiological characteristics are, for the most part, probably hereditary gifts and the best of these groups finish a 2K equally, using their strongest but different assets to produce very similar efforts. What may turn out to be the most interesting observation of all is the striking common denominator for these two groups of apparent physiological extremes. That is, after comparing muscle biopsy samples taken from rowers’ major power muscle group, the quadriceps (front thigh muscle), the most successful of both groups of these athletes possess unusually large cross-sectional areas (diameters) and increased numbers of Type I or slow-twitch muscle fibers (cells). An average of results of several biopsies from male rowers show individual fibers ranging from 8000 to 10000 square microns in diameter and these slow-twitch fibers represent greater than 70 percent of the total number of fibers in a rower’s vastus lateralis; the rest being Type IIA or the oxidative fast-twitch fiber and the existence of a minimal number of IIB or true fast fibers or none at all. Female rowers possess similar characteristics but having only slightly smaller diameters and fewer numbers of slow-twitch fibers. During my almost 40 years of rowing research, I have discovered only five to six rowers (four men and two women) who have possessed both physiological extremes plus the abundance of slow-twitch fibers that I have just described and there is no question that this small group of rare talent significantly improved boat speed and helped their boats go very fast.

I have collected extensive physiological data on rowers over several years and VO2 max has long been the gold standard to represent the upper limit
of aerobic capacity. However, I have observed both during 2K ergometer tests and water 2K efforts, that VO2 max has a much lower correlation with rowing performance than the athlete's ability to sustain an average oxygen consumption, starting at the end of the first minute of exercise until completion, that is the ability to maintain an average oxygen consumption of 95 % or greater of VO2max or the highest VO2 value measured during a simulated 2K maximal effort on a Concept 2 ergometer. I discount the first minute of exercise as during this period the athlete is transitioning from mostly anaerobic work initially to aerobic dependency towards the end of the first minute. The rowing athlete therefore exceeds anaerobic threshold or gas exchange threshold during most of a 2K effort. It is critical that rowing athletes achieve an unusually high aerobic steady-state as early as possible in the 2K to insure a successful performance. In my many years of testing U.S. and foreign aerobic competitors, including several Olympic and World Champions training at U.S. Olympic Training Centers, I have yet to observe any of these athletes respond as quickly and as effectively with an increase in oxygen consumption to match the energy requirements of their exercise as rowing athletes.

Our laboratory was the first to accurately identify that aerobic energy sources account for 70 to 80 % of the energy needed during an all-out 2K effort. However, the smaller anaerobic component is critical very early and again late in the exercise. Many physiologists have suggested that aerobic capacity is less trainable than anaerobic capacity and although this is probably true, I have measured increases in the aerobic capacity of elite rowers as much as 30 % between the off-season and the beginning of competition. The average increase in VO2 max between elite and college club rowers from the off-season (September - November) to the in-season (June -August) differed significantly: 18 % increase for club rowers whereas only an 8 % increase for National and Olympic Team rowers. However, the elite rowers were able to increase their average VO2 during a simulated 2K maximal effort on a Concept 2 ergometer (see previous description) by almost 12 % from the off-season to the in-season whereas club rowers showed only a 6 % increase in average VO2 for the same time period. These comparative findings emphasize the importance of sustaining a very high aerobic response during a maximal 2K effort as opposed to generating an impressive VO2 max for a brief period. These contrasting results can probably best be explained by both inherited and training qualities; it may be that elite rowers have been blessed with a phenotype or genetic expression for maintaining an unusually high VO2 for several minutes as well as having the benefits of year-round training with the best athletes. Because of administrative restrictions and a shorter competitive season, college and varsity club rowers for the most part have
less time to train at high intensities and usually just prior to and during the competitive season, while elite groups of rowing athletes, with the exception of a week or two, train consistently very hard the whole year.

There seems to be a disagreement among exercise and sport physiologists as to how much effect heredity has on aerobic capacity and other important physiological factors that determine the quality of responses to rowing training and subsequent competitive efforts. The range of percentages of inherited qualities that have been suggested to have a strong influence on physical performance vary from a low of less than 10% to a high of 95%. There are currently no accurate data to support the relative influences of nature or nurture, but evidence is growing that indicates that several specific human phenotypes probably exist and can express such factors as skeletal muscle fiber type, cardiac output, aerobic and anaerobic capacities and other important physical performance-related factors. The balance of the effects of nature and nurture on human performance will, no doubt, some day be known but for now we can only speculate. It is my opinion that heredity may account for as much as 50% to an athlete’s capacity to train for and compete in a 2K rowing race.

As early as 1965, our results of rowing ergometer testing indicated that the unusually high maximal VO2's measured for these athletes represented a major role for the aerobic energy system in the production of the common energy currency, ATP. Although our finding was substantiated in more detail during further testing over the next several years, the results may have sent the wrong message to some rowing coaches and athletes. Reporting the physiological importance of aerobic capacity to rowing performance at that time was interpreted by many rowing coaches as "carry on with business as usual" and continue the use of over-distance training to improve aerobic capacity. However, the 1960's were a time for re-evaluation in training methods and the recognized leader was Dr. James Counsilman, swimming coach at Indiana University, who was one of the first U.S. coaches in any sport to successfully use interval training to improve aerobic capacity, a training formula devised by two Germans in the 1930's, a track and field coach and a physiologist. Although their successful training formula was forgotten because of world events during the late 1930's and early 1940's, it was quickly "found" in the early 1950's and propelled Roger Bannister to his record-breaking mile run in 1954. The success of East Germany in rowing during the 1970's and 1980's appeared to have validated the importance of over-distance training especially since rowers in the DDR were taking over-distance training to the extreme. However, East German athletes were "taking a lot of things"
to extremes and thus it is difficult to determine how much their competitive and training performances were influenced by illegal performance-enhancing products.

Our studies of rowers over the years have not shown that aerobic capacity benefits from long, medium to light, steady-state rowing of several kilometers at relatively low stroke ratings and blade pressure. We have accumulated extensive longitudinal oxygen consumption data on rowers at all competitive levels ranging from National and Olympic Team members to Concept 2 ergometer research subjects who were introduced to rowing for the first time as participants in several of our studies conducted over a period of almost 40 years. We can report conclusively that rowing continuously at low work intensities for 60 - 90 minutes has very little effect on maximal aerobic capacity. VO2max seems to improve significantly only if there is a major challenge to both transport and utilization (cardiovascular-respiratory and skeletal muscle) systems. This means working at 80 -90 % of maximal aerobic capacity which translates into a heart rate range of 150 -170 beats per minute if maximal heart rate is 190 beats per minute. It appears that if improvement of aerobic capacity is the training goal, then the training stimulus must significantly load the cardiovascular-respiratory systems. These recommendations are substantiated by recent comparative studies we have conducted with highly trained novice rowers who served as their own controls during a two-year study where they were divided and then assigned at random to one of two experimental groups; a long distance low intensity-primarily continuous rowing group (LDLI) or an interval- high intensity-intermittent rowing group (IHI). Training was conducted for 30 weeks followed by a 30-week detraining period for both groups. The subjects then switched groups and trained for another 30 weeks. Each group trained three times per week on Concept 2 rowing ergometers during the training periods and those subjects assigned to the LDLI group performed ergometer work sessions beginning at 10 minutes and building up to as long as 60 minutes of continuous rowing; all work was done at sub-anaerobic threshold intensity. The IHI subjects began with 5 X 3 minute intervals with 3 minute recovery periods between work intervals and were able to tolerate 4 X 15 minute work intervals with 3 minute recovery periods between work intervals. All training intervals were performed at intensities at or above anaerobic threshold. Aerobic capacity was measured by open circuit spirometry during a test of progressing exercise intensity on a Concept 2 ergometer. The average initial VO2 max readings for the 20 male and 20 female subjects prior to the first 30 week training period were 43 ml/kg/min and 31.5 ml/kg/min, respectively. Anaerobic thresholds for the women were observed at 63 % of VO2max, while for men AT occurred at 68 % of VO2
max. Following 30 weeks of training, male subjects achieved an average relative VO2 max of 48.5 ml/kg/min (12.8 % improvement); AT was improved to 70 % of VO2 max (3 % increase). Female subjects improved their AT more than the men from 63 % to 67 % of VO2 max (6%). Both IHI-trained males and females achieved significantly higher VO2 maxs and anaerobic thresholds than the LDLT-trained subjects. The IHI-trained males increased VO2 max to an average of 55 ml/kg/min (28 % increase) while the IHI-trained females elevated their average VO2 max from 31.5 to 41.0 ml/kg/min (30 % increase). Anaerobic thresholds were 72 % for the IHI-trained women and 78 % for the IHI-trained men or increases of 14 and 14.7 % respectively.

For the next 30 weeks all subjects discontinued rowing completely and with the exception of a few subjects who swam, jogged, roller-bladed, cycled, or walked on a rather regular basis but at a moderate intensity, all subjects resumed life styles similar to the ones they followed before the rowing study began. All of the subjects resumed some activity, most engaging in recreational sports such as golf, tennis, basketball, and softball. After 30 weeks of rowing detraining all subjects performed another VO2 max ergometer test and the results indicated that their aerobic capacities had returned to levels similar to pre-training values observed 62 weeks earlier, including two weeks of pre-and post-training testing; previously LDLT-trained men achieved an average VO2 max of 45 ml/kg/min, IHI-trained men = 47 ml/kg/min (average for all male subjects was 45.7 ml/kg/min); pre-training max was 43 ml/kg/min. Previously LDLT-trained women achieved an average VO2 max of 33.2 ml/kg/min while female IHI-trained group achieved a max of 34.3 ml/kg/min (overall average was 33.4 ml/kg/min); pre-training average max value for all women was 31.5 ml/kg/min. Anaerobic threshold measurements for all subjects had returned to pre-training values following detraining.

Following measurement of VO2 max and AT, the subjects began training and completed another 30-week training period but participating in the training group opposite the one in which they had participated during the initial 30 week training study. With the subjects serving as their own controls, VO2 max and AT results following this second and final training period mirrored the results of the first 30-week training period. Subjects in the IHI group significantly improved VO2 max and AT; from 45.0 to 56.0 ml/kg/min for men and from 33.2 to 42.9 ml/kg/min for women, or improvements of 24 and 29 % respectively. The men in the LDLT-trained group improved their VO2 max from 47.0 ml/kg/min to 50.1 ml/kg/min (6.6 % increase) while the women in the LDLT-trained group increased VO2 max from 34.3 ml/kg/min to 37.5 ml/kg/min (9.3 % increase). Increases in
anaerobic thresholds were similar as those reported for the initial 30-week study. Increases in AT of 65 % to 73 % of VO2 max for women and 70 % to 80 % of VO2 max for the men were noted for the IHI group and a 61 % to 66 % increase for women and a 63 % to 69 % increase for men for the LDLI group were observed. Results of this extensive study clearly demonstrated a significant benefit of the Interval-High Intensity training program on aerobic capacity and anaerobic threshold compared to the significantly lower effects of the Long-Distance Low Intensity training regimen.

A highly-trained rower should be able to sustain work at anaerobic threshold for 20 - 30 minutes until failure to maintain this exercise intensity. I firmly believe quality of training is more important than quantity for performance improvement in rowers. This is especially true for college varsity and club crews because coaches have so little time for preparing their athletes for competition and the competition period is relatively brief. I am convinced that two 20 - 30 minute training sessions or 3 - 5 X 10 minute sessions at or above anaerobic threshold, and at relatively high cadences, are more effective in elevating aerobic capacity of rowers than long rows of 60 - 90 minutes duration at 60 - 70 % of maximal working capacity. This higher intensity and cadence rowing also promotes effective biomechanically-related task specificity responses. Accumulation of extensive longitudinal rowing data for 40 years indicate that long and slow continuous rowing may be aerobically beneficial for the novice rower who is in the preliminary stages of training and rows of longer duration are an important recovery tool on recovery days between severe aerobic or anaerobic training sessions or during warm-up or cool-down periods.

If a rower wants to improve aerobic capacity that applies to 2K racing then rowing continuously at a high intensity for no longer than 10K at a time will provide the best stimulus.

Our research has been funded consistently over the last 20 years by Concept 2, Inc., Ohio University Foundation and US Rowing.

Professor of Physiology

Department of Biomedical Sciences

College of Osteopathic Medicine

Ohio University

Athens, Ohio 45701