The Physiological Demands of 'Pumping' in IMCO Windsurfing

A research study for the International Sailing Federation

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Summary

In 1996 the International Medical Commission (IMC) was requested by ISAF to investigate the physiological effects of pumping on IMCO windsurfers, following relaxation of Œno-pumping' rules during IMCO Olympic Class Windsurfing events. The investigation was conducted by a team of Greek and Italian investigators following the Rome International Regatta in Anzio in March 1998 and the European Championship in Athens in July 1998. The research was jointly financed by ISAF, the Italian and Greek Sailing Federations and brought together expertise and resources from British, Italian and Greek Universities. It is believed to be the first time ever that 15 highly ranked international competitors (10 men and 5 women) from 9 different countries have had their oxygen uptake (which indicates energy cost) measured during actual sailing conditions, and their ear-lobe blood sampled (for analysis of metabolites) immediately after sea practice and actual racing conditions.

Scientific study on water is always extremely difficult, but the team of investigators cracked the problem by using portable blood analysers and Œgas sampling masks' (see front page photo) radio linked to portable gas analysers (the electrical parts of which were strapped to the sailors chests under their wet suits),. The costly equipment did survive all that salt water splashing around and the effects of pumping the sail on the body's demands were recorded and are detailed in this report.

Analysis of the results suggests that sail pumping elevates energy cost and cardiorespiratory responses three-fold as compared to non-sail pumping, indicating this activity is as physically demanding (oxygen uptake of 3 L/min & heart rate of 170 beats/min) as most aerobic sport activities (e.g. cycling and distance running). In the context of dealing with a highly demanding athletic branch of sailing as part of the Olympic regatta, recommendations are made on how best to physically and dietary prepare for competition with reference to other, better studied, aerobic sports. Along these lines it is strongly recommended that windsurfers include the following three different types of physical training: a) highly-intense interval training with work and rest periods that closely resemble the pumping and relaxation periods, b) moderately-intense continuous training aimed at improving cardiovascular fitness and muscle aerobic capacity, and c) strength training to improve anaerobic power and capacity and to prepare the muscles for the explosive movements at the start and finish of a race and for getting around the marks. A diet rich in carbohydrates should be followed before and during training and racing days to maintain optimum glycogen level. During a race athletes need to ingest fluids in order to replenish fluid, glucose and minerals at the appropriate amount and rate.

Purpose of the Study

The purpose of the present investigation was to study the effects of sail pumping on the sailors' physiological responses. This was achieved by comparing a number of recorded physiological responses while sailing with and without sail pumping. To ensure that the results of the study were reliable and applicable to Olympic standard competition it was decided to invite a number of highly-ranked (based on the Official ISAF Rankings for Olympic Classes) IMCO windsurfers from different countries (including the world's number one male and female windsurfers) to participate in the study. Knowing that male athletes usually respond differently to a given exercise task as compared to female athletes we decided to include in our study a cohort of top-level female windsurfers. Furthermore, we wished to evaluate the effects of pumping on both upwind and downwind sailing legs and to compare the body's physiological responses between those sailing legs.

Study Methods

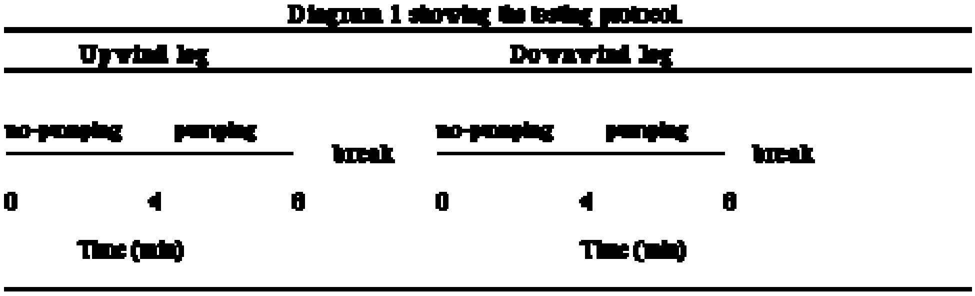
Recorded physiological variables

Before designing the experimental protocol we decided what variables we had to record in order to gain an insight into the physiological demands of windsurfing. Oxygen uptake, energy cost and heart rate were the most obvious variables which allowed us to classify the severity of the sport of windsurfing in relation to other sport activities. Furthermore, recordings of these variables allowed us to assess the severity of the pumping action in relation to sailing without pumping. Measurements of expired gases also facilitated the determination of the relative contribution of carbohydrates and fat as two different energy substrates. All the above observations were easily made by using portable oxygen, carbon dioxide and heart rate recorders. In addition, we were interested in measuring in blood the concentration of lactic acid which is a by-product of anaerobic metabolism (the type of metabolism which occurs independently of the presence of oxygen) that contributes to the development of muscular fatigue when produced at large amounts in the muscle.

Study Protocol

The duration of the data collection was a crucial issue because we wanted the measurements to reflect the real competitive conditions, and on the other hand to allow sufficient time for the physiological responses to achieve steady-state. (It takes approximately 3 to 4 min for the responses to achieve steady during exercise). Therefore, we decided to instruct the sailors to sail for 8 minutes on the upwind and 8 minutes on the downwind legs (see Diagram 1) . During the first 4 minutes of upwind sailing sailors were asked to keep their bodies still without pumping the sail, whereas during the remaining 4 minutes sailors were instructed to pump the sail as frequently and for as long as they could. Following the completion of the 8-minute upwind leg sailors were asked to stop and rest until the physiological responses returned to pre-testing conditions. During the interval a blood sample was taken. Following the rest period sailors were asked to sail downwind for 8 more minutes; during the first 4 minutes no pumping was performed whereas during the remaining 4 minutes sailors were asked to pump. After the end of the downwind leg a blood sample was taken.

Diagram 1 showing the testing protocol



Wind velocity conditions

Twelve out of fifteen tests were carried out under light wind velocity conditions that ranged form 6 to 10 knots. Only three tests were conducted in stronger winds that ranged from 16 to 20 knots.

Data analysis and presentation

One minute worth of data was used for the purposes of statistical analysis and graphical presentation. This minute worth of data corresponded to the last minute (3 to 4) of each 4 min sailing bout. This was done because as mentioned earlier it takes about 3 to 4 min for a variable to achieve steady state. Since comparisons had to be made between upwind and downwind legs and between pumping and no pumping activities, data used for analysis had to be recorded during steady state conditions.

Besides the on-water tests a number of off-water tests on a bicycle ergometer were performed on 8 out of 10 male athletes. This test was meant to assess the maximum capacity of the sailors' bodies to utilise oxygen (aerobic capacity). In addition, expression of the on-water oxygen uptake values as a percentage of the maximum values recorded on a cycle ergometer allowed us to estimate the relative intensity that the windsurfers exercised on water. Figures expressed as percentages of maximum allowed us to compare and relate the sailors' physiological responses to those in other sports.

Results and Discussion

The following two graphs show the average oxygen uptake and heart rate responses from all 15 competitors while sailing upwind and downwind with and without pumping. Comparisons of the sailors oxygen uptake and heart rate responses between the upwind and downwind legs revealed no significant differences. However, it is apparent from the graphs that downwind sailing appears to be slightly more physically demanding as compared to upwind sailing. This is the reason why it was decided to present in this report the physiological responses only for the downwind legs.

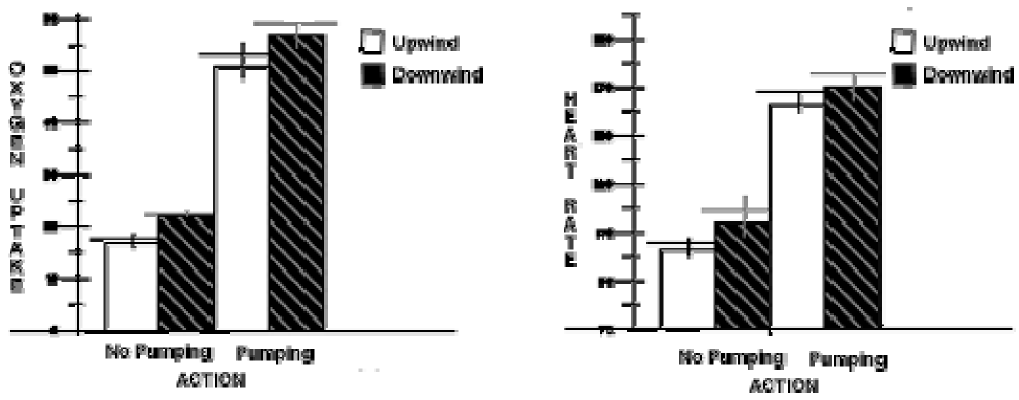


Figure 1: Comparisons of the sailors oxygen uptake and heart rate responses during upwind and downwind legs.

Figure 2 shows the average oxygen uptake and heart rate responses while sailing downwind with and without sail pumping. Analysis of the results suggests that sail pumping elevates energy cost and cardiorespiratory responses nearly three-fold compared to non-sail pumping, indicating this activity is as physically demanding as other aerobic sport activities such as cycling and distance running (see Figure 7: comparisons with other sports). It is hard to make comparisons between male and female responses since the on-water testing conditions were not identical for everybody and the number of female participants was smaller than that for the male. However, as in many other aerobic sports the data recorded during sail pumping reflect the lower aerobic capacity of female athletes as compared to the male counterparts.

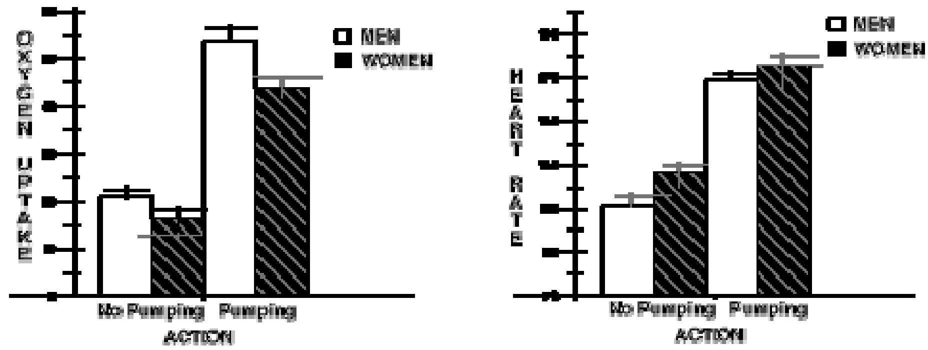


Figure 2: Comparisons of oxygen uptake and heart rate responses betrween pumping and no-pumping sailing conditions in 10 male and 5 female sailors

Figure 3 shows the average respiratory quotient [RQ, (an index of fuel utilisation) and the % carbohydrate utilisation while sailing downwind with and without sail pumping. The precise estimation of the % carbohydrate utilisation from RQ might be inappropriate due to the high blood lactate concentrations during sailing (see Figure 4). Nevertheless, the high RQ and lactate suggests an increased carbohydrate and a reduced fat utilisation during sailing. Therefore, glycogen appears to be the predominant energy fuel during sail pumping. Considering firstly that races last for about 40 min, secondly that there are usually two races each day and thirdly that windsurfing competition usually lasts 5 to 6 days, it is highly likely that a progressive glycogen depletion might occur in the sailors muscles. The data justify the need for proper dietary regimes before during and after competition.

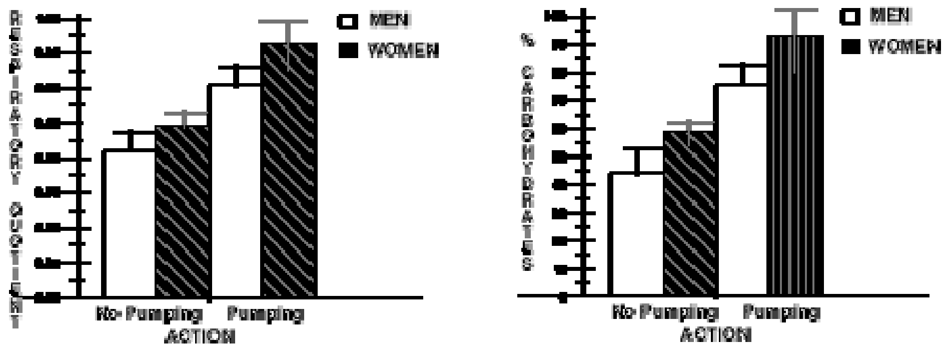


Figure 3: Comparisons of respiratory quotient and percentage carbohydrate utilisation between pumping and no-pumping sailing conditions in 10 male and 5 female sailors.

Figure 4 shows the average energy expenditure between pumping and no-pumping sailing conditions in 10 male and 5 female sailors and blood lactic acid levels between first-upwind & second-downwind legs, and immediately after the end of an actual race. Consideration of the results suggests that the energy cost of an average race is in excess of 600 kcal. Furthermore considering that there are two races per day and that sailors sail in between races the average energy cost is estimated to be around 2000 kcal per day; this reinforces the earlier suggestion for properdietary preparation. The lactate values indicate appreciable involvement of the anaerobic metabolism that might represent a limiting factor to muscular performance especially in the relatively small but hard working upper body muscles.

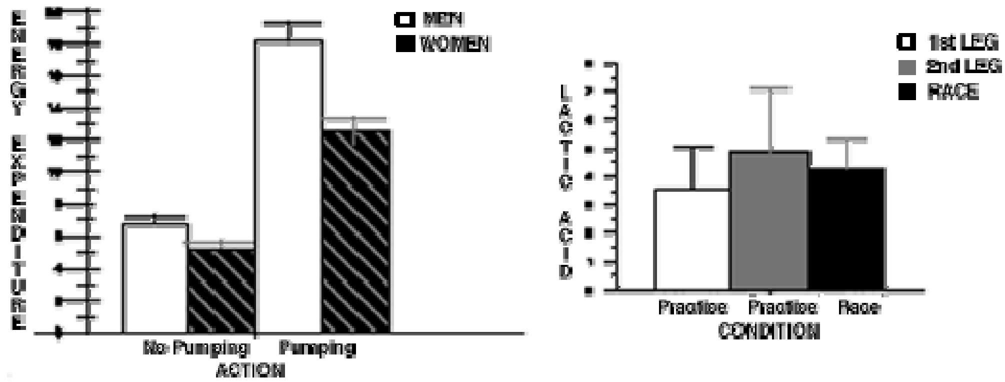


Figure 4: Comparisons of energy expenditure between pumping and no-pumping sailing conditions in 10 male and 5 female sailors and blood lactic acid between upwind and downwind legs and immediately after an actual race.

The following graphs demonstrate the dramatic increases in oxygen uptake and heart rare responses which occurred once sailors initiated the pumping action following the completion of the first 4 minutes (240 seconds) of sailing without pumping. Data in these graphs are reported at intervals of 30 seconds for the whole 8-minute (480 sec) period of downwind testing. This format of data presentation will facilitate an appreciation of the three-fold increase in the physiological variables that occurred during the sail pumping manoeuvre. Furthermore, the reader can clearly see the difference in oxygen uptake responses between male and female athletes which is consistent during both pumping and no-pumping conditions, thus reinforcing the point made earlier regarding the lower aerobic capacity of the female athletes. In contrast the female athletes' heart rate responses were very similar to the male responses, hence suggesting that the cardiovascular strain that is imposed on male and female athletes is quite similar. Nevertheless, it is interesting to know that the average heart rate while pumping was approximately 85 percent of the age-related maximum heart rate for these sailors, whereas the heart rate during the non-pumping period was only around 55 to 60 % of the predicted maximum. Although the high heart rates seen during pumping are indicative of highly sustained aerobic activity, it should be remembered that emotional factors might also be accounted to some degree for the increase in heart rate. Therefore in order to subjectively assess the severity of the pumping activity and classify it according to its severity we had to: 1) focus on the oxygen uptake figures, 2) to compare these figures to those of other vigorous aerobic sport activities and 3) to express the figures as percentages of maximum. Figures 6 and 7 serve exactly these purposes.

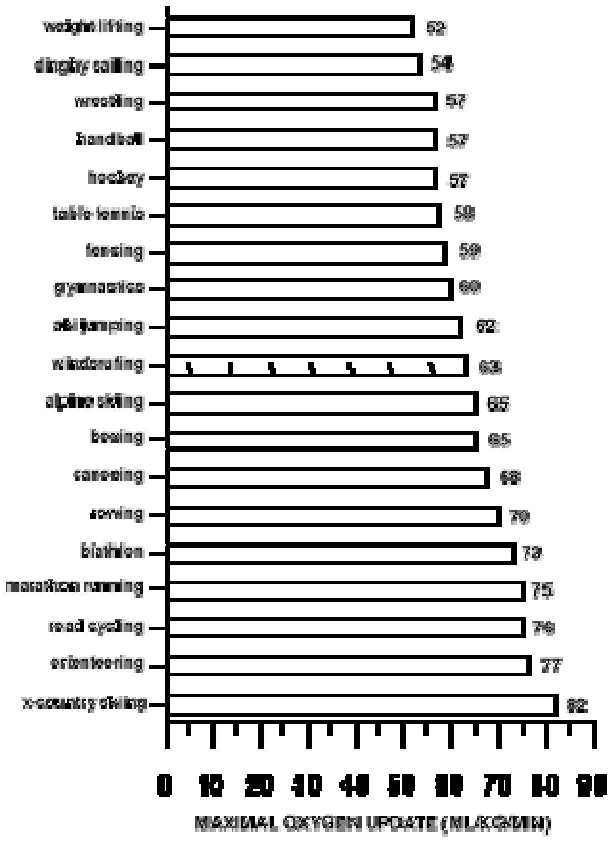


Figure 5: Average oxygen uptake and heart rate responses recorded every 30 seconds during sailing without pumping (0 to 240 sec) and during sailing with frequent and sustained pumping (240 to 480 sec).

Figure 6 shows the average maximum oxygen uptake recorded from 8 male windsurfers during a laboratory bicycle ergometer test in comparison to the maximum oxygen uptake of high performance athletes in other sports (Reilly and Secher 1990). The use of the bicycle ergometer for the assessment of the sailors maximum oxygen uptake (better known as aerobic capacity) may underestimate the true aerobic capacity of the windsurfers since it lacks specificity in relation to the demands of windsurfing and it stresses only lower body muscles which don't work hard during windsurfing. Even so, it is evident that the windsurfers aerobic capacity is considerably developed and compares favourably to the values of other aerobic sports. These results are very similar to those reported in a previous windsurfing investigation by DeVito and Italian co-workers 1997 and confirm that the physiological profile of the male windsurfer is compatible to that of an endurance athlete.

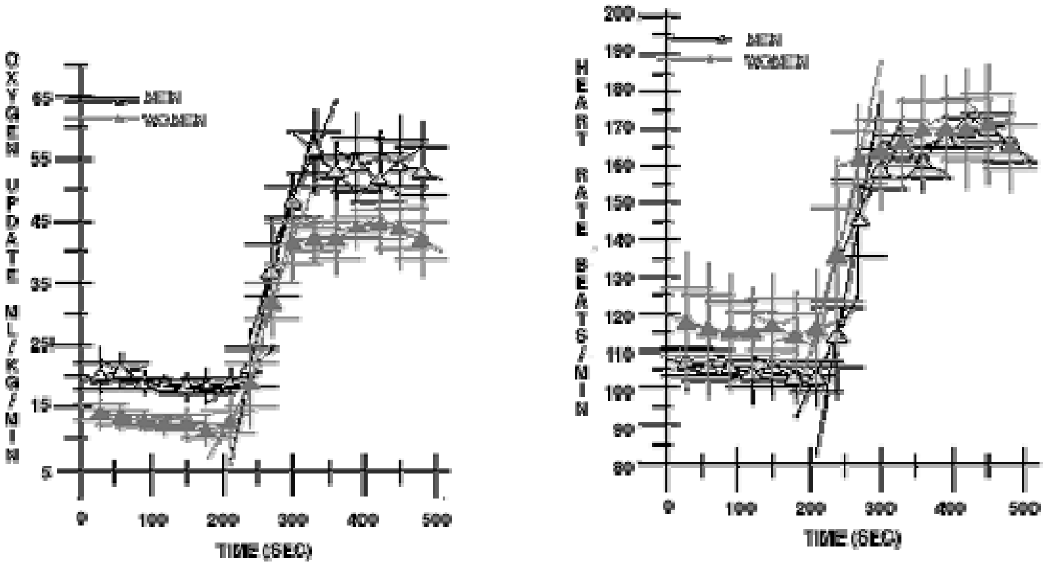


Figure 6: Average maximum oxygen uptake in 8 male windsurfers as this compares to the average aerobic capacity of high performance athletes in different sports. Note the relatively low maximum oxygen uptake for the Laser dinghy sailors (Vogiatzis et al., 1995) in comparison to that of the windsurfers .

Confirmation of the suggestion that the windsurfers aerobic capacity is well developed is also provided by the following graph that shows how the windsurfers average oxygen uptake responses during sail-pumping compare to the oxygen uptake demands of other sports (Reilly and Secher 1990). Such a comparison suggests firstly that during sail pumping the sailors aerobic capacity is taxed to a degree that is comparable to other aerobic sports (e.g. running, cycling, rowing) and secondly, that sail-pumping can be classified as a highly demanding aerobic activity. Furthermore, expressed as a percentage of the sailors maximum oxygen uptake (4.4 l/min) the average oxygen uptake demand during sail pumping (3.4 l/min) corresponds to approximately 75 % of the sailors aerobic capacity. Thus, the sail pumping manoeuvre when undertaken frequently during a 45 minutes windsurfing race can be classified as a highly demanding aerobic activity. The fact that the average blood lactic acid concentration after the races and practice testing sessions (Figure 4) was between 4 and 5 mmol/l, i.e. just above the so called 'lactate threshold' or 'onset of blood lactate accumulation' reinforces the suggestion that windsurfers, as many other endurance athletes, work predominantly aerobically with some contribution from anaerobic metabolism.

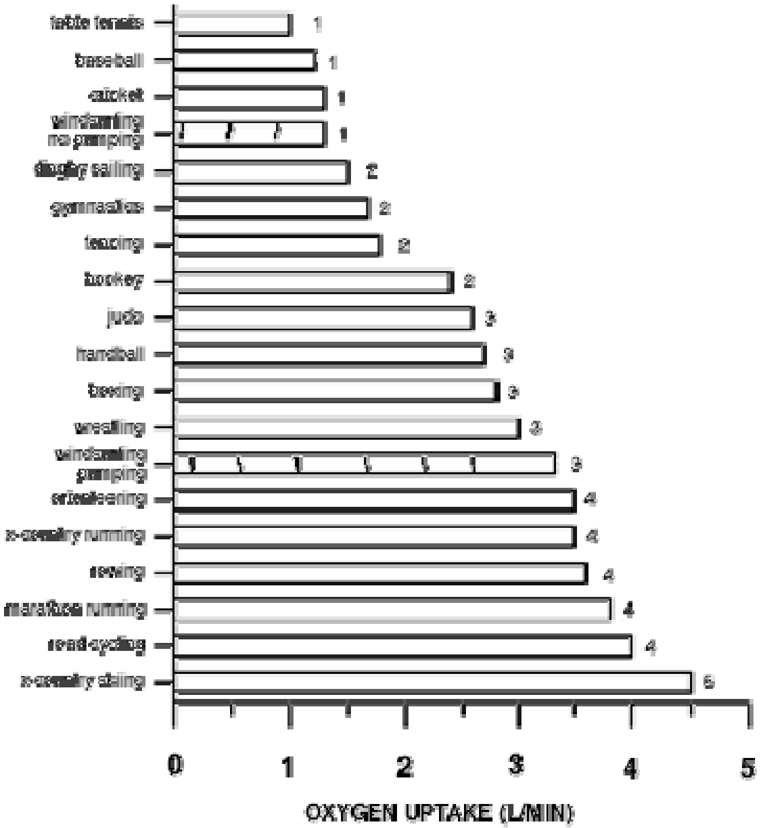


Figure 7: Average oxygen uptake responses in 10 male windsurfers during pumping and no-pumping sailing conditions as compared to the oxygen uptake demands recorded from athletes in other sports.

Recommendations for Athletes, Coaches and Race Organisers

Physical preparation

In order to improve the ability to sustain a high percentage of maximal oxygen uptake (75 % plus) while pumping the sail for long periods of time without accumulating large amounts of lactic acid in the muscle that can cause fatigue and limit performance two basic training formats may be employed.

1) The first format attempts to load the metabolic systems at or just above the so called Œlactate threshold' or Œonset of blood lactate accumulation'. The training stimulus should be at 75 to 85 % of maximum oxygen uptake. Short recovery periods between bouts of exercise should be included. For example high intensity pumping on water, or exercise on a rowing machine if dry-land training is performed, for periods lasting between 30 and 90 seconds should prove to be an effective training stimulus. The training heart rate, if monitored, should be around 80 to 85 % of the age related maximal heart rate (around 160 to 170 beats per minute), with an active recovery rate of approximately 120 to 130 beats per minute before beginning the next pumping or rowing bout. As progress is made, the number and length of exercise periods should be increased while the recovery interval is shortened. The training volume and intensity should increase in a progressive manner. This type of interval training not only loads the aerobic system but also stresses the muscle's anaerobic ability to supplement energy when aerobic energy production is not sufficient. Also the individual's tolerance to lactic acid accumulation and removal capacity of lactic acid is improved.

2) The objective of the second continuous form of training is the improvement of the ability of the heart to transport large amounts of oxygenated blood to the muscles and the ability of the muscles to generate large amounts of energy in the presence of oxygen. This has the advantage of minimising the production of lactic acid that could contribute to the development of muscle fatigue and ultimately limit muscular performance. Training sessions may last 60 to 90 minutes, including warm-up and warm-down. The mode of exercise can be running, cycling and if possible sessions of simulated rowing in a gym. (Rowing exercises stress the upper body muscles a great deal; the muscles adapt by improving their local circulation and enzymatic activities). The training heart rate, if monitored, should be around 65 to 75 % of the age related maximal heart rate (about 140 to 150 beats per minute).

3) Successful windsurfing racing requires both anaerobic speed and power for effective pumping at the start of the race or when going around marks. Therefore the windsurfer has to improve his/her anaerobic power and capacity by working at intensities above 90 % of his/her maximum aerobic capacity. Since such intensity is difficult to sustain, interval training, on-water or in a gym, is recommended. High intensity pumping periods of 10 to 40 seconds, should be interspersed with 30 to 60 seconds of active recovery. Results may be achieved with 6 to 10 repetitions and an active recovery interval that is twice the duration of work. Not more than two or three training sessions per week of this type of training is recommended in contrast to the first two types of training which may alternate throughout the week.

Sea training

It is well recognised that training at an exercise intensity equivalent to the individual athlete's lactate threshold produces optimum adaptations and maximises performance. The accessibility of portable automated blood lactate analysers has led to an increased interest, by coaches and athletes, in using the lactate threshold approach to prescribe training intensities. Exercise intensities equivalent to individually estimated lactate thresholds can be tolerated for approximately an hour before fatigue sets in. It is therefore advisable to estimate the relative exercise intensity that corresponds to the individual sailor's lactate threshold from laboratory measurements and use this intensity to practice on-water. Heart rate recordings and blood sampling are useful approaches that can be relatively easily performed on-water to ensure optimum exercise conditions and results. Furthermore, the sail-pumping and relaxation periods should be of specific duration and may alternate in such a manner that firstly would allow the windsurfer to exercise long enough in order to achieve optimum aerobic adaptations, and secondly the windsurfer would avoid the detrimental effects of muscle fatigue.

Nutrition for competition

As discussed earlier and demonstrated in Figure 3 is highly likely that the predominant energy fuel during sail pumping is glycogen. Again it should be emphasised that the estimation of carbohydrate utilisation during sailing from the respiratory quotient (RQ) might present a limitation to the study due to the exercise-induced metabolic acidosis (as suggested by the high blood lactate concentrations during pumping). Nevertheless, the higher RQ and lactic acid levels suggest an increased carbohydrate oxidation and a reduced fat oxidation during sailing. Dietary manipulation to increase muscle glycogen content by a diet rich in carbohydrates in the few days prior to competition has been extensively recommended for endurance athletes (Maughan 1990) and can be applicable to sailors. During the racing days it is generally recommended that the pre-race meal should be low in fat and high in carbohydrate and should be taken at least 3 hours before competition begins; following races meals should be consumed within 2 hours after competition has ended. Because glycogen resynthesis is related to carbohydrate intake, researchers now recommend increasing the daily carbohydrate intake to 70 % of total calories (approximately 8 to 10 gr/kg for 3500 calories) or even higher to prevent the depletion of glycogen stores during successive days of competition.

Fluid and carbohydrate replacement during competition

During competition windsurfing performance may be limited by the availability of carbohydrate as a fuel for the relatively small working muscles of the upper body. Furthermore, the ability to sustain a high work rate in hot environments requires replacement of water loses to prevent dehydration. Fluid ingestion during competition and training therefore has the twin aims of providing a source of carbohydrate fuel to supplement the body's limited stores and of supplying water to replace the losses incurred by sweating. The optimum formulation for rehydration purposes during windsurfing will vary, depending on the relative requirements for fluid replacement and substrate provision, which in turn will depend on environmental conditions and exercise intensity. Where water replacement is the first priority an isotonic solution containing glucose and sodium will be most effective. Most commercial sports drinks contain 6-8 % carbohydrate and about 20-25 mmol/l sodium and low 4-5 mmol/l concentrations of potassium (Teraddos and Maughan 1995). These formulations represent a compromise between that which will give the highest rates of fluid replenishment and that which can provide most carbohydrate. Personal observations from regattas and questionnaires given to sailors suggest that most sailors do not drink sufficiently to match fluid losses during competition although the international regulations allow them to carry one litre of fluid in the so called Œcamel bag'. Usually sailors claim that they perform better without the bag and they prefer to ingest fluid between races. However, it has been shown in other similarly demanding sports that in hot weather fluid replenishment should take place every 15 min and should correspond to 1/4 of a litre. Furthermore it is advised that 1/2 of fluid is ingested before and immediately after each race. To achieve such a frequent fluid replenishment strategy sailors should practice drinking during training to develop their own strategies and to be accustomed to the sensation of exercising with fluid in the stomach.

Race officers / organisers

In hot and humid environmental conditions during prolonged racing days race officers should allow sufficient time (at least 1/2 an hour) between races for windsurfers to adequately rehydrate and rest before a subsequent race.

Adequate supply of water should be considered by the race organisers on those days. In addition, race officials should be educated to recognise warning signs of thermal injuries and be trained to deal with such eventualities.

If possible events should be scheduled early in the morning and later in the afternoon. If necessary the race organisers should avoid having more than two races in hot and low wind velocity days.

Conclusion & References

In conclusion it was shown that sail pumping presents a truly aerobic and highly demanding challenge to the sailors bodies. Pumping elevates energy cost and cardiorespiratory responses nearly three-fold compared to non-sail pumping, classifying this activity to be as strenuous as most aerobic sport activities. Anaerobic metabolism was shown to supplement aerobic energy production at a significant rate. Interestingly enough the majority of sailors were found to sail at intensities slightly above the so called Œlactate threshold' suggesting that training should use this threshold as a reference point. In the context of dealing with a highly aerobic and demanding athletic branch of sailing as part of the Olympic regatta, recommendations on how best to physically and dietary prepare for competition were made always with reference to other better studied aerobic sports.

It was therefore suggested that windsurfers should improve those capacities that are called upon during actual competition. Three different types of physical training were suggested: a) highly-intense interval training, b) moderately intense continuous training, and c) strength training to improve explosive power and capacity. A diet rich in carbohydrates and ingestion of fluids should be part of training and race strategies. Race officers and organisers need to be aware of the detrimental effects of dehydration and the risks of hyperthermia. If necessary they should avoid having more than two races in hot and windless days. Even though they should allow sufficient time for recovery and rehydration between races and should make sure that there is provision of water to all athletes.

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