OXYGEN CONSUMPTION DURING KAYAK PADDLING

by

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A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF

THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF PHYSICAL EDUCATION

in

THE FACULTY OF GRADUATE STUDIES
School of Physical Education and Recreation

We accept this thesis as conforming to the required standard:

THE UNIVERSITY OF BRITISH COLUMBIA

September 1992

ABSTRACT

Over a typical 10,000 metre race, flatwater kayak paddlers frequently employ a technique termed "wash riding" in an effort to reduce energy expenditure. This technique is characterized by the kayak paddler travelling on his competitor's wake, and at a strategic moment dropping off the wake to sprint ahead. Investigations to determine actual energy expenditure during flatwater kayak paddling during tactical manoeuvers, to date, have been inadequate. Thus the purpose of this study was to investigate the effects of wash riding on energy expenditure in 10 elite male flatwater kayak athletes (age=25 ± 6.5 yrs., height.= 183.6 ± 4.4 cm, mass=83.9 ± 6.1 kg) while kayak paddling under "wash riding" (WR) and "non-wash riding" (NWR) conditions. The exercise test was designed to allow for comparison of minute ventilation (V_E), oxygen consumption ($V0_2$) and heart rate (HR) at submaximal velocities (10,000 metre "steady state" race pace). The exercise protocol consisted of a standardized warm-up, followed by a 2000 metre trial of either WR or NWR. The pace to be maintained (3.7 m/sec), was based on an extrapolation of the 1991 Canadian Canoe Association National Championship 10,000 metre race winning time. Following the first trial there was a twenty minute rest period, which was then followed by a second trial involving the alternate condition. V_E, $V0_2$ and HR were measured every 15 s over the full 2000 metre distance during both conditions using the Cosmed K2 portable telemetry system. Measurements recorded between the 500 and 1500 metre mark were used for analysis in order to examine the effects of wash riding during the steady state aerobic work.

A mean value of the eighteen measurements recorded for each variable between 500 and 1500 metres, was calculated for each subject. Statistical analysis of the mean values for V_E, $V0_2$, and HR was performed using the

Hotelling's T^2 statistic and revealed signifcant ($p < 0.05$) differences between the WR and NWR trials. Mean values for V_E ($L \cdot min^{-1}$) were (WR) 113 ± 16.5 and (NWR) 126.3 ± 15.7; $V0_2$ ($L \cdot min^{-1}$)= (WR) 3.22 ± 0.32 and (NWR) 3.63 ± 0.3 ; and HR (bpm) = (WR) 167 ± 9.9 and (NWR) 174 ± 8.0 . Confidence intervals calculated for V_E, $V0_2$, and HR revealed that all three dependent variables contributed to the overall significant difference.

There is a considerable saving (11%) in the energy cost of paddling at a standardized velocity utilizing the WR technique. This finding has implications for the design of training programs and competitive strategy plans for flatwater kayak racing.

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ACKNOWLEDGEMENTS

I would like to sincerely thank the subjects who participated in this study. In particular, I would like to express my deep gratitude to Greg Redman, who gave so freely of his time and energy to lead the wash riding trials. I would also like to thank Dr. Imre Kemescey and Diana Jespersen for their invaluable assistance with the data collection. I extend my sincere appreciation to my committee members: Drs. Don McKenzie, Gordon Matheson, Ken Coutts and Jack Taunton. I am particularly grateful to Dr. Don McKenzie for his assistance and guidance throughout my graduate studies. I would like to acknowledge Dr. Walter Boldt for his statistical expertise and assistance. Finally, I would like to thank my sister, Susan Gray, for her assistance with the drawing of the Figures.

I am very grateful to my family and close friends for their ongoing support and encouragement of my academic pursuits. I dedicate this work to the memory of my father, Gilbert Gray, who shared and inspired a love for learning.

I INTRODUCTION

Elite flatwater kayak paddlers compete in three racing classes; K-1 (one person), K-2 (two persons) and K-4 (four persons). At the Olympic Games, paddlers race over distances of 500 and 1000 metres, while at the World Championships they also race over 10,000 metres. Performance times of approximately 1:40, 3:30 and 42:00 minutes, respectively, have been achieved at the World Championship distances in the men's K-1 class.

Flatwater kayak racing is an activity which places exceptional physiological demands on the upper limb and trunk musculature (Astrand et al., 1968; Seliger et al., 1969; Vrijens et al., 1975). International calibre flatwater kayak paddlers have been found to possess high values for upper-body muscle strength, anaerobic capacity and endurance, in addition to high aerobic power (see Appendix A) (Fry et al., 1991; Tesch, 1983; Tesch et al., 1984; Thomson et al., 1978).

Elite kayak paddlers have been known to do well at all three distances. In 1973 at the World Championships, the Hungarian paddler Csapo won all three distances (Tesch, 1983). It has been suggested by Fry (1991) that the success of kayak paddlers such as Csapo may be due to the fact that the difference in physiological requirements for all three distances may be more subtle than those for other sports.

Energy requirements for the 10,000 metre event are chiefly supplied through aerobic metabolism and this race is considered to be an aerobic event (Shephard, 1987). However, tactical considerations often result in irregular and intermittent boat speeds requiring anaerobic energy sources.

Forward movement of the kayak is impeded by various external factors including; frictional resistance of the water, wave formation, drag and air resistance (Shephard, 1987). The boat travels at the boundary of two media (air and water) and this boundary is continually shifting on a vertical plane (Marchaj, 1982). The frictional resistance imposed by the water is much greater than that of the air, as the density of water is approximately 835 times that of air (Marchaj, 1982).

It is possible that energy expenditure could be altered by changing the resistance the kayak encounters. Resistances offered by environmental conditions are difficult, if not impossible, to alter. Strictly enforced guidelines regarding the size, weight and physical dimensions of the kayaks have precluded alterations to resistance through vessel design and construction (Shephard, 1987).

Although prohibited at the shorter distances, over the 10,000 metre distance, kayak paddlers frequently employ a technique termed "wash-riding" in an effort to reduce energy expenditure. This technique involves paddling on the wake of a competitor's boat, and at a strategic moment (e.g. to either avoid being baulked by the waves of an opponent's boat or to sprint ahead of an opponent) the paddler moves off of the wake.

The bow and stern of the kayak are responsible for two systems of wave-making, appropriately named bow waves and stern waves, which can be used for wash riding (Marchaj, 1982). (Figure 1) Bow waves, which consist of a series of short separate waves that travel at an angle of approximately 18-20 degrees tangentially to the direction of the motion of the hull, are most commonly used for wash riding (FFCK, 1988). (Figure 2)

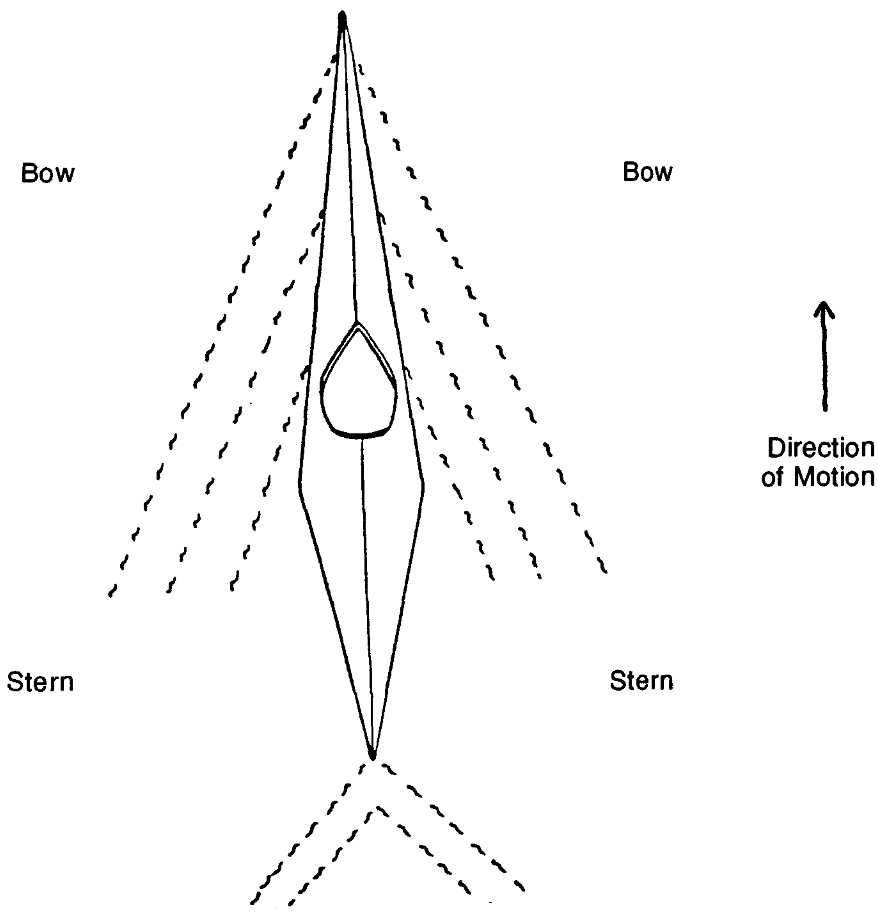


Figure 1 Overhead Schematic View of Divergent Bow and Stern Waves

When the boat is travelling "on the wash" it is effectively angled forward down the crest of the wave, decreasing the size of the wetted area and therefore the frictional resistance of the kayak (Marchaj, 1982). In addition, the boat receives impetus from the (water) surface flow, which is acting in the same direction as the forward movement of the boat (Marchaj, 1982). It is critical for the kayak paddler to maintain the boat's position on the crest of the wave in order to maximize the frictional and gravitational advantages afforded by the wave. Additional acceleration of the forward movement of the kayak is provided by a gravity force component due to the boat's weight (Marchaj 1982).

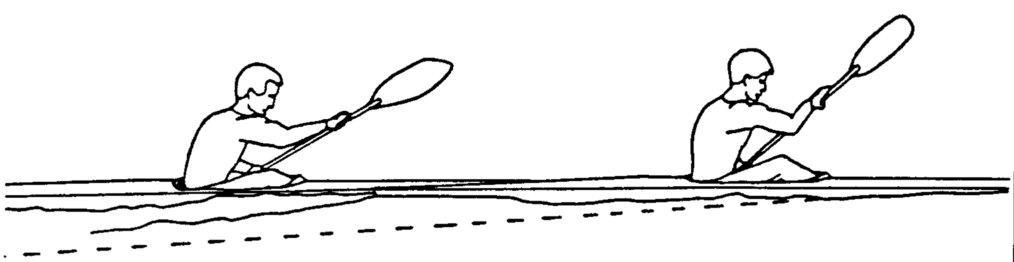


Figure 2 Schematic View of Wash Riding on a Divergent Bow Wave

The measurement of oxygen uptake (VO_2) during maximal and submaximal exercise has proven to be the most useful method for determining energy expenditure or "work efficiency" because of its accurate reflection of the rate of energy metabolism within the body (Astrand et al., 1961, Brooks et al., 1985; Rusko et al., 1978; Whipp et al., 1969). Oxygen uptake measurements during kayak paddling under field conditions have primarily been made using the Douglas bag method to collect and subsequently analyze expired gases (Astrand et al., 1986, Seliger et al., 1969; Tesch, 1983; Tesch et al., 1976). Used in the field setting during kayak paddling , this method imposes certain limitations on data collection capabilities. One limitation relates to the paddler having to physically open and close the valve of the Douglas bag at the beginning and completion of a specified collection period. In order to complete this task, the kayak paddler has to stop paddling, maintain his balance, and turn the valve to the open or closed position. Another limitation is the lack of temporal precision in measuring ventilatory variables during exercise performed over several minutes (Mathews et al., 1992). A single Douglas bag, used as the collection reservoir for exhaled gases throughout the exercise bout, provides only an average for the entire collection period, rather than precise (breath by breath), measurement of oxygen consumption (Astrand et al., 1986; Fox et al., 1981; Hagberg, 1981; Mathews et al., 1992).

To alleviate the problems encountered in obtaining field measurements with apparatus such as the Douglas bag, a new telemetric device has been developed. The Cosmed K2 is an integrated telemetric system which measures and calculates oxygen consumption ($V0_2$), minute ventilation (V_E) and heart rate (HR) at 15, 30 or 60 second intervals. The telemetric device, which is attached to the athlete's torso by a harness, is lightweight (800 grams) and allows the athlete almost complete freedom of movement.

Measurement of the possible energy savings, in terms of oxygen consumption, while riding wash, has not been determined. The purpose of this investigation was to measure the energy expenditure of elite male flatwater kayak athletes paddling at a 10,000 metre "steady-state" race pace under wash-riding and non-wash riding conditions. Specifically, the purpose was to determine whether oxygen consumption, minute ventilation, and heart rate would be lower during wash riding.

II METHODS

Subjects

Ten male kayak paddlers, all members or recent past members of the Canadian Kayak team, (including four members of the 1992 Olympic team) volunteered for the study (mean; age=25 $\pm$ 6.5 yrs.; height=183.5 $\pm$ 4.4 cm.; mass= 83.9 $\pm$ 6.1 kg) . Testing took place in the spring at the beginning of a training camp held between a pre-Olympic competition tour in Europe and the Barcelona Olympics.

Permission to complete this research was obtained from the University of British Columbia Clinical Screening Committee for Research and Other Studies involving Human Subjects. Written consent was obtained from each subject after they were informed of the procedures and possible risks involved in this study. All subjects were able to complete the entire study.

Experimental Procedures

Both trials of the experiment were conducted during a single session at Burnaby Lake, British Columbia. Prior to the start of the test session, ambient air temperature, barometric pressure and wind velocity were determined. Evidence of any measurable wind velocity precluded continuance of the test.

At the start of the session, age, height, and mass measurements were obtained and a screening history and physical examination were performed on every subject by the Canadian Kayak team physician (Dr. D.C. McKenzie). Athletes were randomly assigned to one of two test conditions of "wash riding" (WR) or "non-wash riding" (NWR). Following the first trial, a twenty minute rest period was provided for the athlete. The second trial used the alternate test condition. Each subject performed the two trials using his own boat and paddle.

The "leader" for the wash-riding trials was a single person (age=19 ; height=187.0 cm; mass=82.1 kg) used for all wash-riding trials. This person used the same boat (Jaguar model) and paddle (Patassi model, right twist) for all trials in order to standardize the test conditions. The "leader" did not participate as a subject in the study. During the WR trial, the subjects travelled on a bow wave produced by the leader's boat. The tip of the bow of the subject's boat, while on the leader's bow wave, was positioned at a distance of approximately one metre lateral and two metres behind the front of the cockpit of the leader's boat.

The exercise protocol consisted of a standardized warm-up, followed by a 2000 metre work bout ("trial") with the athlete either riding wash or not riding wash. Since wash riding is a technique used primarily during 10,000 metre races, the pace to be maintained was set at 3.7 metres/second. This value was established from an extrapolation of the 1991 Canadian Canoe Association National Championship 10,000 metre race winning time.

The pace of 3.7 m/sec is equivalent to "split" times of 67.5 seconds for every 250 metres. The investigators travelled alongside the kayak paddler(s) boat(s), in a motor boat, recording time, and calling out "faster" or "slower" (as required) to the the subject (and leader during wash riding trials). Split times and stroke rates were recorded every 250 metre mark along the course. Split times were doubly verified, taken by two individuals (in case of failure of one watch mid-trial) in the motor boat using hand held Seiko 10 bar 100 lap/split memory watches.

Data Collection

The responses of oxygen consumption (VO_2), minute ventilation (V_E), and heart rate (HR) were measured using the Cosmed K2 portable telemetry system. Manufacturer recommendations regarding operation and calibration of the unit were accurately followed.

The subjects were outfitted with the portable unit which consists of a transmitter, a battery, a face-mask/turbine flow meter assemby and a belt ECG monitor. The transmitter contains the electronic circuits, the expiratory gas sampling pump, the dynamic microchamber, the oxygen analyzer, the heart rate monitor and the radio transmitter. The transmitter and battery were connected to a harness (worn by the subject) by way of two Velcro retaining plates located next to the subject's chest and back.

The face-mask/turbine unit worn by the subject was attached to the head by way of an elastic harness. The face-mask was attached to the photoelectric turbine. The sampling capillary tube was inserted into the turbine housing and then, along with the wire from the turbine, connected to the transmitter. The transmitter sent air flow data measured by the turbine, expired oxygen concentration measured by the 0_2 electrode, and HR obtained from the ECG, to the receiver unit. The receiver unit was kept within 600 metres (the maximum range of the system) at all times during the trials. An assistant to the investigator carried the receiver unit in the motor boat which followed alongside the kayak paddlers.

Continuous 15 second samples of V_E, $V0_2$, and HR were recorded over the full 2000 metres. Only the samples recorded between the 500 and 1500 metre mark were used for analysis in order to examine the effects of wash riding during steady state aerobic work. V_E, $V0_2$ and HR data were provided by the receiver every 15 seconds, in both LED and paper form. This information was later down-loaded to a portable computer in the laboratory for subsequent data analysis.

Recalibration of the Cosmed K2 was completed at the end of each trial and the rechargeable battery was replaced as required. One trial was restarted after battery failure occurred during the first 500 meters of his non-wash riding trial. The athlete was allowed a ten minute rest and the trial was begun again with a newly charged battery.

Statistical Analysis

The statistical analysis used to investigate the effect of "wash-riding" on V_E, $V0_2$ and HR was the Hotelling's T^2 statistic performed using BMDP:3D statistical software (UCLA, 1988) with the level of significance set a priori at $p < 0.05$. The mean value of the eighteen 15-second samples collected via the Cosmed K2 telemetry unit between the 500 and 1500 metre mark of the 2000 metre trial distance were calculated for V_E, $V0_2$, and HR for each subject under both conditions. Hotelling's T^2 statistic for dependent samples was used to compare means of V_E, $V0_2$, and HR between wash-riding and non-wash-riding conditions. This analysis was followed by calculation of confidence intervals.

Mean velocity was determined for each subject, for both wash riding and non-wash riding trials, based on time recorded over distance. Group means and standard deviations were calculated and differences between means were analyzed by use of a paired *t* - test.

III RESULTS

Description of Experimental Subjects

Anthropometric and kayaking equipment data is provided in Table 1. A summary of the mean values, as well as each subject's raw data, of ventilatory and heart rate responses during the two experimental conditions is found in Appendix B.

Table 1. Anthropometric and Kayak Equipment Data

Subject	Age (yrs)	Ht (cm)	Mass (kg)	Kayak Model	Paddle Model	Paddle Twist
MA	21	185	79.5	Cleaver	Patassi	Right
RJC	23	186.5	89.9	VanDusen	Patassi	Left
PG	22	190	86.2	VanDusen	Patassi	Right
DI	37	188	87	Jaguar	Shaw	Left
LJ	24	182	90.5	VanDusen	Patassi	Left
SK	20	178	79	Jaguar	Patassi	Left
IM	22	178	72	Kirton Tiger	Swiss	Right
KP	24	187	86.2	Cleaver X	Patassi	Left
JR	22	183	87	Cleaver X	Patassi	Left
CS	38	178	77.3	Orion Syrangi	Patassi	Left
MEAN	25.0	183.6	83.9			
SD	6.5	4.5	6.1			

Subject Comments

All subjects reported that the K2 equipment did not interfere with their kayak paddling. Many of the subjects complained of discomfort on the bridge of the nose secondary to the airtight application of the face mask.

Some of the more experienced kayak paddlers found the wash riding trial difficult. They felt that the pace was too slow to "comfortably" ride the wash.

Two reported that they had to work harder (and, at times, effectively decelerate) to stay on the wash compared to during the non-wash riding trial.

The kayak paddlers who benefited most, in terms of energy savings, were the same ones who reported that the wash riding trial was "easier" than the non-wash riding trial.

Ventilatory and Heart Rate Responses

The group means and mean differences for V_E, VO_2 and HR during both experimental conditions are shown in Table 2. Figures 3, 4 and 5 present the mean V_E, VO_2 and HR, respectively, during wash riding and non-wash riding. Two subjects (SK and JR) showed an increase (2.0 and 17.3 l/min, respectively) in V_E during wash riding compared to the rest of the subjects whose V_E was found to decrease. (Figure 3) VO_2 also increased (0.22 and 0.24 l/min) for two subjects (KP and JR, respectively) while the others showed a decrease. (Figure 4) All subjects demonstrated a decrease in HR during the wash riding trial. (Figure 5)

Table 2. V_E, VO_2 and Heart Rate Values during both experimental conditions (Mean ± SD)

	Wash-Riding	Non-Wash-Riding	X Diff.	%Δ
V_E(l/min.)	113 ± 16.5	126.3 ± 15.7	-12.9 ± 16.7	9.8
VO_2(l/min.)	3.22 ± 0.32	3.63 ± 0.3	-0.41 ± 0.4	11.0
HR(bpm)	167 ± 9.9	175 ± 8.0	-8.0 ± 3.0	4.8

Figure 3 V_E During Both Experimental Conditions

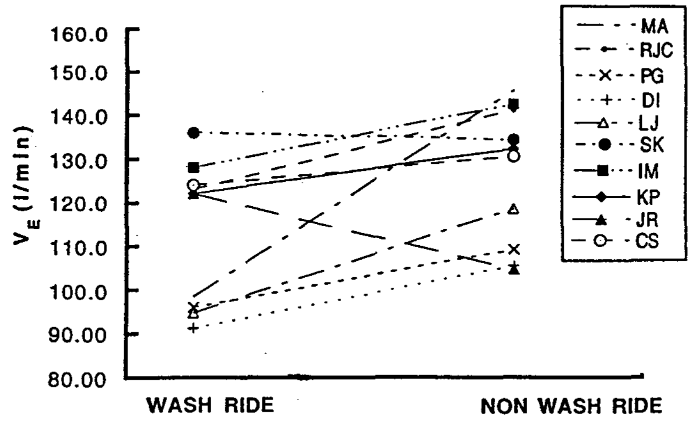


Figure 4 VO_2 During Both Experimental Conditions

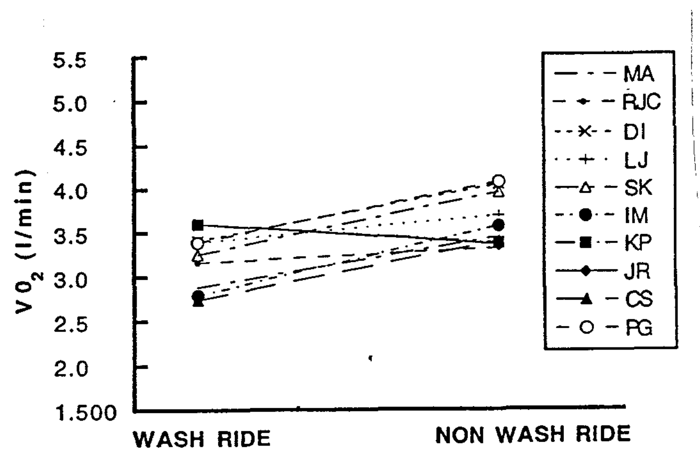
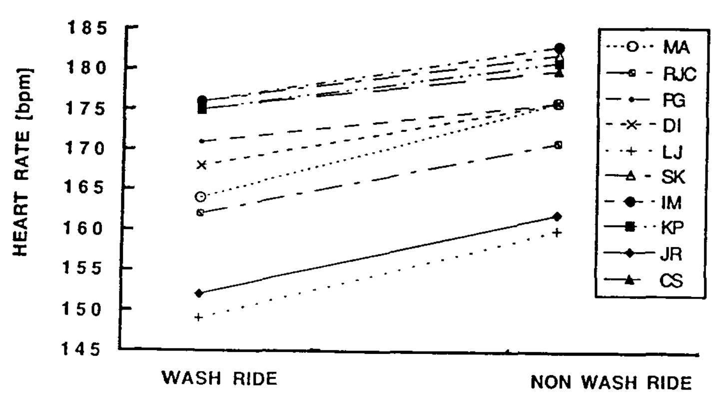


Figure 5 HR During Both Experimental Conditions



The dependent sample Hotelling's T^2 statistic revealed a value of 184.45; an associated F value of 47.83, with degrees of freedom 3 and 7, and p-value of 0.000. With $p < 0.05$, it is possible to reject the null hypothesis and state that there is a significant difference in V_E, $V0_2$, and heart rate between wash riding and non-wash riding trials.

Confidence intervals were calculated as a post hoc test of the multivariate process (Huck, 1974). For V_E, the mean difference of measures was -12.9 with a 95% confidence interval of $-24.77 \leq \mu_{D_1} \leq -0.93$. The mean difference for $V0_2$ was -0.41 with a 95% confidence interval of $-.681 \leq \mu_{D_2} \leq -.129$ and for HR a mean difference of -8 with a 95% confidence interval of $-0.97 \leq \mu_{D_3} \leq -6.1$. The confidence intervals for V_E, $V0_2$, and HR indicate that all three dependent variables contributed to the overall significant difference (Huck, 1974).

Kayak Velocity

Individual mean velocities of the kayak during the two trials can be found in Appendix D. Maintaining consistent kayak velocity during the two trials was sometimes difficult for the kayak paddlers. Overall, the athletes tended to travel faster during the wash riding trial, with a mean velocity of 3.84 ± 0.05 m/sec compared to 3.75 ± 0.07 m/sec during the non-wash riding trial. Differences between means were analyzed by use of a paired *t* - test . (Table 3)

Table 3. ***t*-Test for Kayak Velocity (m/sec) during the Two Experimental Conditions.**

Condition	X	SD	*t*
Wash Riding	3.84	0.05	5.079*
Non-Wash Riding	3.75	0.07	

*significant at $p < 0.05$

"Economy" is defined as the submaximal oxygen consumption per unit body mass (VO_2 calculated in ml/kg/min^{-1}) required to perform a given task (Cavanagh et al., 1985). A *t* - test revealed that there was a significant difference in economy between WR and NWR trials (Table 4).

Table 4. ***t*-Test for VO_2 (ml/kg/min) during the Two Experimental Conditions.**

Condition	X	SD	*t*
Wash Riding	38.46	2.59	-3.318*
Non-Wash Riding	43.64	4.68	

*significant at $p < 0.05$

Reliability and Validity of the Cosmed K2

The reliability and/or validity of the Cosmed K2 system have been analyzed by both the Allan McGavin Sports Medicine Centre Exercise Physiology Division and the United States Olympic Committee (USOC) Sports Science Division.

In the Allan McGavin laboratory, the Cosmed K2 was found to be a valid instrument in comparison to the Medical Graphics 2001 system, for measuring $V0_2$, V_E, and HR responses. (Appendix C). Validity correlation coefficients of 0.95, 0.96 and 0.97 were found for V_E, $V0_2$, and HR, respectively.

A study conducted in the USOC Sports Science Division laboratory, demonstrated that the Cosmed K2 was both a valid and reliable instrument when compared to the Douglas bag method (Lucia, 1992).

IV DISCUSSION

This is the first study to examine the physiologic response to wash riding in elite flatwater kayak paddlers. In the present study, highly trained kayak paddlers were studied during on-water, steady state kayak paddling to investigate the influence of wash riding on energy expenditure. The exercise test was designed to allow for comparison of V_E, $V0_2$ and HR at identical submaximal velocities during wash riding and non-wash riding conditions. The results showed that there was a signifcant decrease in energy consumption during wash riding when compared to non-wash riding, as indicated by a decrease in V_E, $V0_2$ and HR.

The V_E was decreased 9.8 % during the WR trial in comparison to NWR. Examination of the raw data indicates that this decrease was due to a reduction in respiratory frequency rather than a change in tidal volume. This decrease in V_E indicates a reduction in the stimulus to breathe indicating that there is less need for ventilation to supply the muscle oxygen needs. This finding is supported by the $V0_2$ data which demonstrates a parallel decrease (11.0%) in $V0_2$ during the WR trial. Thus, during WR the athletes are working at a lower percentage of their $V0_{2max}$. The velocity actually increased (2.5%) in the WR trial, yet overall, the oxygen demand remained decreased. Therefore the energy cost of WR, based on the VO_2 data, indicates (and perhaps even underestimates) a significant savings. The advantages of working at a lower percentage of $V0_{2max}$ include; decreasing the demands on the oxygen transport system, decreasing the depletion of energy sources (e.g. glycogen), and delaying the onset of fatigue (Brooks et al.,1985). In terms of performance, the advantage is reflected in the ability of the athlete to travel at a similar and/or greater velocity at a lower physiological cost.

In contrast to the overall mean decrease in V_E and $V0_2$ during WR, one subject demonstrated an increase in both variables, and two other subjects demonstrated an increase in one of either V_E or $V0_2$. All subjects experienced a decrease in HR. It is difficult to explain definitively why there would be an increase in one or both of V_E and $V0_2$ with a concomitant decrease in HR.

Overall, the WR trial was more economical, as indicated by comparison of the mean values of $V0_2$ (calculated in ml/kg/min) which were significantly lower when compared to the NWR trial values. Examination of the individual data reveals WR was less economical for the two subjects whose $V0_2$ was elevated compared to the NWR trial.

It is interesting to note, that while the kayak velocity increased significantly during the WR trial, the stroke rate (paddle revolutions per minute) of the paddlers did not significantly increase. This indicates that there was likely a change in the stroke mechanics employed by the paddlers (e.g. the actual pulling phase of the stroke may have been shorter). Verification of any changes in the stroke mechanics is not possible as the trials were not recorded on video tape.

Few studies have examined actual energy expenditure during activities which, like kayak paddling, require tactical manouevers and/or varying rates of speed. McCole et al. (1990), examined the effects of drafting during cycling on energy expenditure ($V0_2$) in 28 male competitive cyclists at speeds similar to those encountered in competitive events (32-40 km/h). They examined drafting single as well as multiple riders, drafting vehicles, and altering the aerodynamics of the bicycle. Drafting was found to reduce $V0_2$ by 18 - 39 %, depending on rider speed, formation, and number of riders being drafted. Drafting a vehicle at 40 km/h resulted in a 62% reduction in $V0_2$ and riding an aerodynamic bicycle lowered $V0_2$ by 7%.

In the present study, the mean V_E for five of the subjects who were previously tested in the laboratory on the kayak ergometer during a maximal exercise test (four minutes, maximum intensity) was 181.8 l/min, compared to 106.82 and 123.74 l/min (WR and NWR, respectively), indicating that both trials were performed at a submaximal level (McKenzie, unpublished data). This finding is supported by measurements obtained on $V0_2$ for the same five subjects who performed the same tests; 5.26 l/min compared to 3.28 and 3.58 l/min for the WR and NWR trials, respectively. Thus, 10,000 metre, steady-state kayak racing represents a submaximal work. The difference between WR and NWR, expressed as a percentage of $V0_{2max}$ in these subjects is 6% which may be sufficient to influence performance outcome. However, the comparison of $V0_{2max}$ data collected in the laboratory to data collected in a field situation may not be valid.

Heart rate was the one variable that consistently, and significantly, reduced (4.8%) during WR when compared to NWR. Once again, this reflects the reduced metabolic demand during the WR trial. For four of the athletes examined in this study, as well as previously under maximal conditions in the laboratory, the HR values for WR and NWR, expressed as a percentage of maximum were 10% and 5% lower, respectively (McKenzie, unpublished data).

The significant difference in kayak velocity between the two trials is unfortunate but should not adversely affect the results of the study. The fact that there was a significant decrease in V_E, $V0_2$ and HR during the wash riding trial, in spite of the significantly higher boat speed, should alternatively lend greater support to the use of wash riding as an energy saving technique.

The K2 apparatus worn by the athletes during this study did not interfere with the athletes' ability to kayak paddle and the integrated telemetric system provided fifteen second interval measures of V_E, $V0_2$, and HR. Both of these factors suggest that the K2 is an easier and more effective device for measuring ventilatory and heart rate variables in the field setting, compared with the Douglas bag method.

The athletes who showed the greatest reduction in VO_2 during the wash riding trial, in terms of the ventilatory and heart rate responses, were the same athletes who are considered to be the most proficient at wash riding (personal communication, Canadian National Kayak Coach). Wash riding is an acquired skill and as such requires instruction and practice (FFCK, 1988). The degree to which a coach and/or athlete incorporates wash riding into a training program is highly variable, therefore, it follows that ability might also be highly variable. Other factors affecting wash riding are the weight, technique and speed of the "leader" as well as the weight and experience of the "follower".

The more "elite" paddlers (i.e. the athletes who consistently finish in the top five at Canadian Team Trials) tended to describe the wash riding trial as "difficult", complaining that the pace was too slow. In order for them to feel "comfortable" on the wash, they prefer to be travelling at near maximal speeds, otherwise they feel as though they have to work (vs. ride) to stay on the wash. Once they "felt" the wash, they described having to decelerate and/or manoeuver to stay on the wash which effectively negated any advantage they might gain. Two of the athletes who described difficulties riding the wash were the same athletes who had higher V_E and/or VO_2 values during the wash riding trial.

In summary, the purpose of this study was to investigate the effects of wash riding on energy expenditure in 10 elite male flatwater kayak paddlers while kayak paddling under WR and NWR conditions. The results showed that there is a considerable savings (11 %) in the energy cost of paddling at a standardized velocity utilizing the WR technique. This finding has implications for the design of training programs and competitive strategy plans for flatwater kayak racing.

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APPENDIX A

Review of Literature

Review of Literature

Physiologic Profile of the elite male kayak paddler

The physiology of elite flatwater kayak paddlers has been studied by several investigators over the last few decades, in both the laboratory and field settings. (Dal Monte et al., 1976; Fry et al., 1991; Logan et al., 1985; Seliger et al., 1969; Shepard, 1987; Telford, 1980; Tesch, 1983; Tesch et al., 1984; Tesch et al., 1984; Tesch et al 1976; Thomson et al., 1978; Vrijens et al., 1975). The following will provide a summary of the physiologic attributes of elite male kayak paddlers described, to date.

Height and Body Mass

Table 1 provides a summary of the mean height and body mass values of elite male kayak paddlers (Cermak et al., 1975; DalMonte et al., 1976; Fry et al., 1991; Seliger et al., 1969; Tesch, 1983; Tesch et al., 1984; Tesch et al., 1984; Tesch et al 1976; Thomson et al., 1978; Vrijens et al., 1975). Fry et al. (1991) found that elite level Australian kayak paddlers (n=7) were significantly taller (179.9 ± 5.04 cm versus 175.21 ± 5.17 cm, $p < 0.05$)) and heavier (81.05 ± 10.26 kg versus 70.66 ± 7.99 kg, $p < 0.01$) than less successful paddlers (n=31).

Tesch (1983) calculated body composition from skeletal and skinfold measurements in kayak paddlers, bodybuilders, water-skiers and non-athletes. Body fat percentage in the paddlers was predicted to be 6% (± 2) which was significantly lower than that found in the non-athletes (9% ± 3) but higher than that observed in the bodybuilders (4% ±1). In another study reported one year later, and using the same measurement technique, Tesch and Lindebergh (1984) compared percent body fat of kayak paddlers with weight/power lifters, bodybuilders and non-athletes. They found that body builders had a signifcantly lower percentage of body fat (4.3 ± 1.5) than all groups and that kayak paddlers were significantly lower (5.4 ± 1.1) than the other two groups (7.2 ± 1.4 and 9.9 ± 3.0, respectively).

Fry et al. (1991) took the sum of eight skinfolds measurements to calculate adipose composition of kayak paddlers. He found that higher levels of body fat were associated with increasingly poorer performances at longer race distances.

TABLE 1. Height and Body Mass Values of Kayakers.

Reference	Height (cm)	Mass (kg)
Cermak (1975)	179	75.5
Dal Monte & Leonardi (1976)	180	79.7
Fry (1991)	179	81
Seliger (1968)	178	76.2
Tesch (1983)	185	80
Tesch & Karlsson (1984)	183	75
Tesch & Lindeberg (1984)	186.2	82.4
Tesch, Piehl et al (1976)	-	78
Thomson (1978)	-	75.3
Vrijens (1974)	178.7	77.6

Aerobic performance tests

Investigations of the aerobic performance of elite kayakers have been conducted in both the laboratory and field settings. Several investigators have chosen both the traditional "total body" methods of evaluation (treadmill or bicycle ergometry) as well as sport-specific performance tests (kayak ergometry and/or actual on-water paddling). (Table 2)

An important determinant of the maximal oxygen uptake is the mass of muscle employed in performing the task (Astrand et al., 1961; Bergh et al., 1976; Gollnick et al., 1972). It is well known that activity involving the legs has been shown to result in a higher level of oxygen uptake when compared to exercise performed primarily by the arms (Asmussen et al., 1958; Astrand et al., 1986; Bergh et al., 1976; Thomson et al., 1978; Vrijens et al., 1975). In kayak paddling, work primarily involves the muscles of the back, shoulders, and arms, therefore, it is not surprising that kayak paddlers have been shown to demonstrate lower oxygen consumption during paddling compared with treadmill or bicycle ergometer testing. (Fry et al., 1991;Thomson et al., 1978; Vrijens et al., 1975).

In experiments conducted by Tesch and colleagues (Tesch, 1983; Tesch et al., 1984; Tesch et al., 1984; Tesch et al 1976), the $V0_2$ attained during the arm exercise tests were between 78% and 88% of $V0_2$ attained during the treadmill test.

TABLE 2. Values of V02(L·min^{-1}), VE (L·min^{-1}) and HR (bpm) recorded for legs and arms in the laboratory.

Reference	Test	LEGS VO2	LEGS VE	LEGS HR	ARMS VO2	ARMS VE	ARMS HR	ARMS % Leg
Dal Monte & Leonardi (1976)	Kayak erg.				3.36	144.2	187	N/A
Fry (1991)	Kayak erg.				4.78	124.9	178.8	N/A
McKenzie (1991)	Kayak erg.				5.13	182	186.5	N/A
Tesch (1983)	Treadmill	5.36	-	195				
	Mech. braked erg.				4.3	-	190	80%
Tesch & Karlsson (1984)	Treadmill	5.3	-	-				
	Mech. braked erg.				4.5	-	-	85%
Tesch & Lindeberg (1984)	Treadmill	5.4	-	-				N/A
Tesch, Piehl et al (1976)	Treadmill	5.4	-	-				
	Mech. braked erg.				4.6	-	-	85%
Thomson (1978)	Treadmill	4.6	173	186				
	Kayak erg.				3.4	129	176	74%
Vrijens (1974)	Bicycle erg.	4.42	128	183				
	Kayak erg.				3.91	115	181	88%

Vrijens et al. (1975), looked specifically at the maximal oxygen uptake and circulatory adaptations to training with arms versus legs by comparing athletes who primarily train with their arms (paddlers) and a control group (non-paddlers). Five elite Belgian paddlers were compared to a control group of nine physical education students (4 team sport participants, 3 runners and 2 swimmers). Both groups performed two maximal work tests (progressive resistance tests), one on a bicycle ergometer and the other on an arm ergometer. Oxygen consumption was determined utilizing the Douglas bag method and heart rate was recorded continuously with a telemetric device.

In the group of paddlers, maximal oxygen uptake and workload during the arm exercise resulted in 88% and 80% of the scores obtained in the leg exercise. In the control group, the differences were 81% and 65%. Vrijens concluded that the data illustrate the importance of measuring total muscle mass involved in the work, and that the difference in results (between groups) could be explained by changes in regional blood flow and adaptation of size and fiber composition of muscle groups in response to training.

Many investigators agree that specificity of testing is required in order to properly evaluate the functional capacities of elite athletes (Seliger et al., 1969; Sleeth, 1982; Telford, 1980; Tesch, 1983; Tesch et al., 1976; Vrijens et al., 1975). Several investigators have utilized kayak ergometers in order to simulate paddling for data collection in the laboratory (Dal Monte et al., 1976; Fry et al., 1991; Thomson et al., 1978; Vrijens et al., 1975).

McKenzie (unpublished data 1992) observed a mean oxygen uptake value of 5.13 l/min in a group of four elite male Canadian kayak paddlers tested on a kayak air braked ergometer, paddling at a simulated 1000 metre race pace. Fry (1991) reported an oxygen uptake value of 4.78 l/min. in seven elite male Australian kayak paddlers, also using the air braked ergometer. All of the field studies to date (Table 3) have been completed utilizing the Douglas bag method of expired gas collection to evaluate oxygen consumption while kayak paddling (Seliger et al., 1969; Tesch, 1983; Tesch et al., 1984; Tesch et al., 1976).

Seliger (1969), investigated energy expenditure in thirteen high performance Czechoslovakian paddlers, kayaking over 500 metres at a speed of 4.16 m/second. The oxygen consumption averaged 2.9 l/min, V_E 111.4 l/min and maximum HR 176 beats per minute. In comparing the speeds attained in the "experimental" race with those of an actual race Seliger found that the former amounted to 90% of the latter. He concluded that when evaluating the results of this study, the fact that the subjects were not putting up an actual racing performance during the experimental race, must be taken into consideration.

In two of Tesch's studies, paddlers were evaluated for oxygen consumption while kayak paddling on the water. Tesch et al. (1976), tested the subjects under simulated racing conditions at the three international distances. The 500 metre distance was completed in two minutes with a VO_2 of 4.0

l/minute. The average VO_2 over the 1,000 metres (completed in 4 minutes) was 4.7 l/min. and over the 10,000 (completed in 45 minutes), 4.5 l/minute.

The shorter racing distance of 500 metres resulted in a lower peak oxygen uptake (4.2 l/min) which the authors speculate to be due to the shorter work time. Oxygen uptake was shown to increase when the athletes performed against the wind, which prolonged the work period, compared to races under normal conditions.

In 1983, maximal oxygen uptake and heart rate was recorded by Tesch in five Swedish athletes while treadmill running, arm cranking on an air braked ergometer and while paddling on the water at a maximal effort for 6 minutes. The maximal VO_2 and HR values achieved during the paddling were 4.67 l/min. and 192 bpm, respectively.

TABLE 3. Values of VO_2 ($L{\cdot}min^{-1}$), V_E ($L{\cdot}min^{-1}$) and HR (bpm) recorded during paddling.

Reference	Test	V02	VE	HR	% Leg V02
Seliger (1968)	500 m.	2.9	111.4	176	N/A
Tesch (1983)	6 mins. M.I.*	4.67	-	192	87%
Tesch & Karlsson (1984)	6 mins. M.I.*	4.7	-	-	88%
Tesch, Piehl et al (1976)	500 m.**	4.2	-	-	78%
	1,000 m.**	4.7	-	-	87%
	10,000 m.**	4.5	-	-	83%

* M.I. = maximum intensity

**Simulated race conditions

Muscular Strength and Endurance

Another critical factor in performance testing is examination of muscle strength and endurance. Isokinetic muscular strength and endurance have been found to be greater in elite kayak paddlers when compared to other athletes (Fry et al., 1991; Tesch, 1983). Tesch (1983) measured shoulder extensor strength and endurance in six elite Swedish kayak paddlers using the Cybex II Isokinetic dynamometer and compared them to bodybuilders, waterskiers and non-athletes (fighter pilots). For the assessment of strength, the subjects were tested for maximal isometric strength at 120° and peak torque during maximal isokinetic shoulder extension (0 - 180°) performed at 15, 60 and 180°/second. No statistically significant differences were noted among the different categories of athletes when comparing the values for isometric strength and peak torque at the various joint velocities. To study muscle fatigue and power characteristics, fifty consecutive, maximal voluntary contractions were performed at an angular velocity of 180°/second. The "fatigue index" or muscle endurance was calculated as the peak torque declined from the first to the 48-50th contraction. The decline in muscle force was significantly less in the kayak paddlers when compared to the waterskiers. Average peak torque was calculated from the peak torque values recorded for each of the fifty contractions and was found to be greatest in kayakers.

Fry (1991) compared "selected" kayak paddlers (those who achieved a top four position in the performance of 500, 1000, 10,000 and 42,000 metre races) (n=7) with "non-selected" kayak paddlers (all those below the top four) (n=31) for muscular strength and endurance. The Cybex II was used to determine strength, power and muscular endurance during a simulated kayak stroke. Isokinetic peak torque was measured at speeds of 30°/sec. and 120°/second. Strength, power and muscular endurance were all found to be significantly greater ($p < 0.01$) in selected kayakers.

Muscle Fibre Type

The deltoid muscle has frequently been chosen for biopsies as it is one of the principle muscles used during kayak paddling and is relatively easy to sample (Logan et al., 1985; Tesch et al., 1976). Tesch et al., (1976) examined muscle fibre composition of the deltoid muscle in nine former elite Swedish paddlers. Most paddlers successful at the 500 metre races had a high proportion of fast twitch (FT) fibres (52-59% FT), at the 1000 metres a more varied composition (26-59% FT) and a relatively low percentage of FT in successful 10,000 metre competitors (26 - 52% FT). Tesch did note that one athlete who was twice the World Champion over the 500 metre sprint distance, but also very successful over the 1,000 and 10,000 metre distances, had 75% FT fibre composition.

Muscle Glycogen Content

The glycogen content of the deltoid muscle has been examined by Tesch et al., (1983) before and after maximal 2 minute and 45 minute pool experiments (the kayak was in a fixed position in the pool) as well as in regular competition before and after a 10,000 metre race. Selective glycogen depletion was examined following a 10,000 metre race after which subjects demonstrated that 80% of their slow twitch (ST) fibres and 10% of their fast twitch (FT) fibres were almost completely emptied or completely emptied of their glycogen content.

Blood Lactate Levels

Blood lactate levels have been found to be slightly lower in paddlers after arm exercise (kayak ergometry and/or paddling) when compared to treadmill running. Tesch (1983) reported blood lactate values of 14.2 ± 2.7 mmol$\cdot l^{-1}$, 13.5 ± 3.0 mmol$\cdot l^{-1}$, and 14.0 ± 4.1 mmol$\cdot l^{-1}$ following treadmill runnning, arm cranking and kayak paddling, respectively. It has been suggested that the lower values seen during arm exercise can be attributed mainly to the smaller muscle mass involved and the less well trained state of muscles when compared to leg exercise (Tesch et al., 1976).

Tesch and Lindebergh (1984) examined blood lactate accumulation during arm exercise comparing elite kayak paddlers to weight/power lifters, bodybuilders and non-athletes. A continuous, progressive intensity, arm cranking exercise was performed by all subjects with blood samples taken following the completion of each work load. Blood lactate concentration was found to be significantly lower through all power output levels in male kayak paddlers. Upper-body muscle mass, however, was significantly greater in the weight-lifters and bodybuilders in comparison to the kayak paddlers. Tesch suggests that these results support the concept that peripheral adaptations associated with endurance training, as opposed to muscle volume per se, results in lower lactate concentrations during progressive arm exercise.

In a field study, Tesch et al., (1976) observed peak blood lactate concentrations which were comparable after 500 and 1000 metre races . Blood lactates after 500 metre races averaged 13.2 ± 1.2 mmol$\cdot l^{-1}$, after 1000 metre races 12.9 ± 1.1 mmol$\cdot l^{-1}$, and after 10,000 metre races 10.2 ± 1.4 mmol$\cdot l^{-1}$.

Summary

This review suggests that the successful kayak paddler tends to be a large individual with a relatively low percentage of body fat, and a high level of aerobic fitness, upper body muscular strength and endurance.

APPENDIX B

Descriptive Data of Subjects

Appendix B(i)

Summary of VE, V02 and HR During the Two Experimental Conditions (Mean + SD)

Subject	VE				V02				HR			
	WR	NWR	Δ *	%Δ**	WR	NWR	Δ *	%Δ**	WR	NWR	Δ *	%Δ**
MA	98.4	145.5	-47.1	-33.0	2.88	3.45	-0.57	-17.0	164	176	-12	-7.0
RJC	123	141	-18.4	-13.0	3.16	3.32	-0.16	-5.0	162	171	-9	-6.0
PG	96	109.1	-13.1	-12.0	3.39	4.08	-0.69	-17.0	171	176	-5	-3.0
DI	91.3	105.4	-14.1	-14.0	3.41	4.05	-0.64	-16.0	168	176	-8	-5.0
LJ	94.7	118.5	-23.8	-20.0	3.39	3.69	-0.30	-8.0	149	160	-11	-7.0
SK	136	134.3	02.0	1.0	3.25	3.96	-0.71	-18.0	176	182	-6	-3.0
IM	128	142.4	-14.1	-10.0	2.79	3.57	-0.78	-22.0	176	183	-7	-4.0
KP	122	132.2	-10.3	-8.0	3.6	3.38	0.22	6.0	175	181	-6	-4.0
JR	122	104.6	17.3	16.0	3.6	3.36	0.24	7.0	152	162	-10	-6.0
CS	124	130.5	-06.9	-5.0	2.74	3.4	-0.66	-20.0	175	180	-5	-3.0
MEAN	**113**	**126.3**	**-12.9**	**-9.8**	**3.22**	**3.626**	**-0.41**	**-11.0**	**167**	**174.7**	**-8**	**-4.80**
SD	**16.5**	**15.72**	**16.7**	**12.8**	**0.32**	**0.3**	**00.4**	**10.6**	**9.94**	**8.07**	**3**	**1.62**

* WR vs NWR
** % WR < NWR

Summary of Individual Subject Data

1 A Trial 1 WR - MA

Distance (m)	VE (l/min)	VO2 (l/min)	HR (bpm)
500	97.6	2.98	163
	107.6	3.29	164
	111.2	3.40	164
	95.6	2.76	164
	98.6	2.85	163
	104.3	3.10	164
	96.3	2.39	161
	97.3	2.65	164
1000	99.4	2.79	164
	93.9	2.79	162
	92.4	2.90	163
	98.1	2.92	164
	94.7	2.89	164
	90.4	2.69	168
	101.3	2.93	167
1500	96.6	2.87	165
MEAN	**98.5**	**2.89**	**164**

1B Trial 2 NWR - MA

Distance (m)	VE (l/min)	VO2 (l/min)	HR (bpm)
500	136.0	3.26	170
	139.7	3.46	172
	140.4	3.48	171
	139.6	3.46	174
	145.1	3.48	174
1000	139.6	3.23	173
	144.8	3.23	175
	143.6	3.44	175
	151.2	3.75	173
	147.1	3.52	179
	147.4	3.53	177
	148.5	3.44	178
	147.4	3.53	179
	143.8	3.45	179
1500	153.0	3.67	180
	148.7	3.44	179
	151.1	3.37	180
	151.8	3.39	179
MEAN	**145.5**	**3.45**	**175.9**

2 A Trial 1 NWR - RJC

Distance (m)	VE (l/min)	VO2 (l/min)	HR (bpm)
500	155.8	3.47	168
	139.3	3.33	165
	139.7	3.45	169
	141.5	3.27	166
	142.6	3.17	162
	134.4	3.21	164
	138.9	3.21	165
1000	132.3	3.38	168
	137.8	3.29	173
	140.0	3.23	175
	142.0	3.39	177
	146.3	3.50	177
	140.4	3.36	176
	133.1	3.18	179
1500	149.6	3.45	181
MEAN	**140.9**	**3.33**	**171**

2 B Trial 2 WR - RJC

Distance (m)	VE (l/min)	VO2 (l/min)	HR (bpm)
500	131.8	3.48	163
	130.3	3.22	162
	128.6	3.18	158
	118.9	3.14	158
	125.0	3.40	158
	122.0	3.12	160
	122.2	3.02	157
	121.9	3.01	159
1000	115.8	3.05	157
	118.3	3.12	161
	116.2	3.06	160
	120.7	3.08	164
	117.3	3.00	166
	123.3	3.35	168
	128.6	3.39	170
	129.5	3.20	168
1500	114.9	3.03	169
MEAN	**122.7**	**3.17**	**162.2**

3A Trial 1 NWR - PG

Distance (m)	VE (l/min)	VO2 (l/min)	HR (bpm)
500	122.9	4.16	175
	115.3	4.00	175
	116.7	4.34	175
	113.6	4.22	175
	110.0	4.18	174
	104.5	4.06	174
	103.5	3.93	173
	106.5	4.05	174
	102.6	3.90	174
1000	103.6	3.94	175
	104.7	3.98	175
	108.8	4.14	172
	106.4	3.96	179
	108.5	4.12	180
	108.6	4.13	181
	110.8	4.21	181
1500	108.8	4.05	181
MEAN	**109.2**	**4.08**	**176.1**

3B Trial 2 WR - PG

Distance (m)	VE (l/min)	VO2 (l/min)	HR (bpm)
500	105.2	3.48	171
	107.2	3.54	172
	101.7	3.53	169
	101.3	3.52	169
	102.0	3.54	171
	103.0	3.49	172
	103.7	3.60	172
	99.7	3.46	172
	89.9	3.27	172
1000	96.4	3.50	172
	89.5	3.18	170
	91.2	3.31	170
	87.4	3.25	170
	88.8	3.30	170
	88.6	3.29	168
	89.2	3.24	170
	91.9	3.34	173
1500	92.5	3.29	173
MEAN	**96.1**	**3.40**	**170.9**

4 A Trial 1 WR - DI

Distance (m)	VE (l/min)	VO2 (l/min)	HR (bpm)
500	89.8	3.17	
	93.1	3.28	
	92.8	3.27	
	93.4	3.29	169
	94.9	3.35	168
	89.1	3.22	168
1000	90.5	3.41	168
	91.5	3.45	170
	92.2	3.48	170
	89.8	3.46	169
	87.0	3.42	168
	89.9	3.54	168
	92.6	3.65	166
	91.6	3.68	166
1500	90.9	3.58	170
MEAN	**91.3**	**3.42**	**168.3**

4 B Trial 2 NWR - DI

Distance (m)	VE (l/min)	VO2 (l/min)	HR (bpm)
500	101.9	3.93	174
	104.8	3.95	175
	96.3	3.79	174
	103.6	4.08	175
	101.8	4.17	174
	97.8	3.77	178
	104.5	3.94	178
	102.3	4.19	176
1000	107.0	4.12	178
	103.2	4.06	179
	114.5	4.32	179
	108.5	4.00	179
	104.8	3.78	177
	105.3	3.89	177
	108.4	4.18	176
	114.0	4.39	176
1500	112.6	4.25	178
MEAN	**105.4**	**4.05**	**176.6**

5A Trial 1 WR - LJ

Distance (m)	VE (l/min)	VO2 (l/min)	HR (bpm)
500	93.6	3.39	146
	94.3	3.42	147
	91.0	3.30	146
	92.6	3.36	145
	91.3	3.31	148
	98.8	3.42	148
	91.9	3.26	151
	98.9	3.50	151
1000	93.8	3.40	150
	92.5	3.35	150
	100.9	3.58	149
	94.4	3.35	148
	96.1	3.41	150
	93.9	3.40	153
	94.4	3.35	151
	91.1	3.23	151
	92.6	3.36	152
1500	103.6	3.76	149
MEAN	**94.8**	**3.40**	**149.2**

5 B Trial 2 NWR - LJ

Distance (m)	VE (l/min)	VO2 (l/min)	HR (bpm)
500	107.8	3.29	154
	110.3	3.55	154
	113.8	3.66	154
	110.6	3.65	154
	111.7	3.50	156
	121.2	3.80	159
	126.4	3.96	160
1000	127.7	3.79	160
	114.0	3.29	161
	124.3	3.89	162
	115.4	3.42	161
	124.3	3.79	162
	117.5	3.68	165
	128.4	4.13	169
1500	125.0	4.02	170
MEAN	**118.6**	**3.69**	**160.1**

6 A Trial 1 WR - SK

Distance (m)	VE (l/min)	VO2 (l/min)	HR (bpm)
500	134.2	3.19	175
	145.4	3.34	175
	135.4	3.22	174
	141.2	3.36	175
	141.8	3.26	174
	139.5	3.32	174
	139.1	3.31	172
1000	131.6	3.13	171
	130.5	3.10	174
	132.6	3.15	175
	128.1	3.05	177
	137.8	3.39	178
	136.6	3.36	178
	136.6	3.36	179
	132.7	3.16	181
	136.6	3.25	181
1500	138.5	3.41	181
MEAN	**136.4**	**3.26**	**176.1**

6 B Trial 2 NWR - SK

Distance (m)	VE (l/min)	VO2 (l/min)	HR (bpm)
500	124.3	3.87	179
	126.7	3.95	179
	135.4	4.00	179
	131.3	3.77	180
	133.5	3.83	180
	135.2	3.88	180
	130.1	3.84	181
	128.8	3.91	181
1000	131.8	4.00	182
	133.5	3.94	182
	140.3	4.03	184
	135.6	4.00	184
	138.8	3.98	183
	140.0	4.02	184
	137.8	4.07	182
	136.8	4.15	184
	139.9	4.02	185
1500	139.3	4.11	185
MEAN	**134.4**	**3.96**	**181.9**

7 A Trial 1 WR - IM

Distance (m)	VE (l/min)	VO2 (l/min)	HR (bpm)
500	129.4	2.89	173
	134.2	2.99	172
	132.4	2.84	173
	128.3	2.76	171
	131.2	2.82	173
	127.2	2.73	174
	127.5	2.74	174
1000	124.2	2.67	175
	122.3	2.63	175
	132.0	2.94	178
	124.9	2.68	178
	126.5	2.82	178
	121.3	2.71	179
	132.8	2.85	180
	132.8	2.85	181
1500	125.9	2.81	182
MEAN	**128.3**	**2.80**	**176**

7 B Trial 2 NWR - IM

Distance (m)	VE (l/min)	VO2 (l/min)	HR (bpm)
500	139.8	3.35	179
	143.5	3.44	179
	143.0	3.66	179
	141.9	3.52	180
	142.4	3.41	181
	141.0	3.38	182
	141.1	3.50	183
	141.4	3.62	183
1000	142.3	3.53	183
	141.8	3.75	185
	141.9	3.63	185
	145.6	3.85	185
	145.9	3.62	186
	140.5	3.60	187
	141.4	3.62	187
	142.9	3.66	186
	143.6	3.56	187
1500	143.8	3.68	187
MEAN	**142.4**	**3.58**	**183.6**

8 A Trial 1 WR - KP

Distance (m)	VE (l/min)	VO2 (l/min)	HR (bpm)
500	124.3	3.59	172
	124.9	3.60	173
	117.9	3.40	172
	128.9	3.72	173
	125.2	3.71	174
	122.4	3.73	175
	124.8	3.81	175
1000	125.4	3.82	175
	124.5	3.69	176
	120.4	3.47	175
	116.2	3.35	176
	114.8	3.22	177
	118.4	3.51	177
	121.9	3.82	179
	114.3	3.39	179
1500	127.2	3.77	178
MEAN	**122.0**	**3.60**	**175.4**

8 B Trial 2 NWR - KP

Distance (m)	VE (l/min)	VO2 (l/min)	HR (bpm)
500	139.0	3.55	181
	131.7	3.36	180
	138.2	3.53	178
	132.9	3.29	179
	124.0	3.27	180
	128.7	3.29	180
	134.2	3.54	180
	123.9	3.27	180
1000	133.1	3.40	180
	131.2	3.46	181
	141.9	3.39	182
	132.9	3.29	183
	129.5	3.31	182
	126.6	3.34	183
	138.9	3.66	184
	134.8	3.44	184
1500	127.1	3.25	184
MEAN	**132.3**	**3.39**	**181.2**

9 A Trial 1 WR - JR

Distance (m)	VE (l/min)	VO2 (l/min)	HR (bpm)
500	127.0	3.78	150
	123.0	3.66	151
	115.7	3.63	150
	125.7	3.84	153
	126.4	3.76	153
	122.9	3.65	149
	122.5	3.64	153
	121.7	3.62	154
1000	117.4	3.59	151
	121.6	3.61	150
	120.2	3.58	154
	120.8	3.49	155
	119.8	3.37	156
	122.0	3.43	156
1500	123.2	3.46	151
MEAN	**122.0**	**3.61**	**152.4**

9 B Trial 2 NWR - JR

Distance (m)	VE (l/min)	VO2 (l/min)	HR (bpm)
500	108.7	3.50	156
	102.3	3.21	159
	102.5	3.30	159
	98.8	3.18	166
	104.1	3.44	152
	105.1	3.47	151
	101.9	3.45	164
	105.6	3.49	163
	112.4	3.62	161
1000	110.3	3.55	163
	105.9	3.24	169
	110.3	3.37	165
	106.3	3.42	166
	104.8	3.29	163
	101.5	3.27	165
	102.1	3.20	160
	104.4	3.36	163
1500	97.5	3.14	168
MEAN	**104.7**	**3.36**	**161.8**

10 A Trial 1 WR - CS

Distance (m)	VE (l/min)	VO2 (l/min)	HR (bpm)
500	116.4	2.58	168
	117.2	2.50	168
	119.7	2.55	167
	119.2	2.64	173
	112.6	2.59	172
	127.2	2.92	175
	127.7	2.93	177
1000	115.8	2.47	176
	127.8	2.83	179
	131.0	2.79	179
	125.2	2.67	177
	129.1	2.75	175
	129.1	2.86	176
	124.8	2.66	178
	129.3	3.08	179
1500	126.6	3.11	181
MEAN	**123.7**	**2.75**	**175**

10 B Trial 2 WR - CS

Distance (m)	VE (l/min)	VO2 (l/min)	HR (bpm)
500	123.0	3.23	175
	127.5	3.35	174
	124.6	3.17	177
	131.1	3.44	178
	125.6	3.50	179
	125.0	3.28	178
	132.3	3.36	179
	135.1	3.43	179
1000	128.7	3.27	181
	125.5	3.29	178
	138.4	3.52	182
	135.8	3.68	182
	133.6	3.51	183
	129.4	3.18	183
	127.5	3.35	183
	135.2	3.55	182
	134.8	3.76	184
1500	136.2	3.46	184
MEAN	**130.5**	**3.41**	**180.1**

Split Times (sec) and Stroke Rates (spm)

MA

Distance (m)	WR Splits	WR Strk Rate	NWR Splits	NWR Strk Rate
250	64.8	90	63.3	84
500	62.6	84	66.5	94
750	64.7	78	66.4	94
1000	66.7		67.1	94
1250	64.9	84	67.1	94
1500	65.9	88	66.0	94
1750	65.5	84	67.0	90
2000	63.7	84	64.0	
MEAN -Mid 1 km	**64.9**	**83.5**	**66.6**	**94**

RJC

Distance (m)	WR Splits	WR Strk Rate	NWR Splits	NWR Strk Rate
250	61.9	96	61.3	90
500	60.8	90	62.1	84
750	63.5	84	65.6	82
1000	65.9	84	65.9	82
1250	63.1	84	64.1	84
1500	64.1	84	63.2	82
1750	64.2	84	65.9	90
2000	64.8	82	65.0	84
MEAN - Mid 1 km	**63.5**	**85.2**	**64.2**	**82.8**

Split times (sec) and Stroke Rates (spm)

PG

Distance (m)	WR		NWR	
	Splits	Strk Rate	Splits	Strk Rate
250	65.5	86	64.2	96
500	62.4	86	63.7	92
750	65.4	84	65.5	86
1000	65.6	80	69.3	90
1250	67.1	86	66.4	90
1500	64.9	86	64.0	90
1750	65.7	86	66.0	90
2000	65.2	86	65.9	90
MEAN - Mid 1 km	**65.1**	**84.4**	**65.8**	**89.6**

DI

Distance (m)	WR		NWR	
	Splits	Strk Rate	Splits	Strk Rate
250	67.5	72	66.8	78.0
500	64.4	78	65.6	78.0
750	68.0	72	66.1	78.0
1000	64.5	70	67.6	80.0
1250	67.4	72	64.8	80.0
1500	67.4	74	68.4	80.0
1750	64.3	72	63.8	82.0
2000	66.0		64.7	
MEAN - Mid 1 km	**66.4**	**73.2**	**66.5**	**79.7**

Split times (sec) and Stroke Rates (spm)

LJ

Distance (m)	WR		NWR	
	Splits	Strk Rate	Splits	Strk Rate
250	66.9	88	65.1	84
500	64.8	86	69.0	84
750	65.1	84	67.5	86
1000	66.2	84	68.6	86
1250	66.4	84	68.7	90
1500	65.1	84	63.7	90
1750	66.9	84	65.2	90
2000	63.3	84	64.2	90
MEAN - Mid 1 km	**65.5**	**84.4**	**67.5**	**88**

SK

Distance (m)	WR		NWR	
	Splits	Strk Rate	Splits	Strk Rate
250	58.7	96	62.8	92
500	60.8	88	64.5	88
750	64.2	88	67.6	88
1000	66.3	91	67.1	88
1250	66.2	89	66.4	90
1500	65.4	90	65.3	88
1750	66.7	86	67.6	92
2000	66.0		65.8	
MEAN - Mid 1 km	**64.6**	**89.2**	**66.2**	**89**

Split Times (sec) and Stroke Rates (spm)

IM

Distance (m)	**WR** Splits	**WR** Strk Rate	**NWR** Splits	**NWR** Strk Rate
250	65.3	96	64.8	92
500	62.9	90	65.0	96
750	66.1	86	65.2	84
1000	64.9	90	68.0	90
1250	66.5	86	67.9	88
1500	63.8	92	67.4	90
1750	67.3	84	65.9	90
2000	67.3	82	64.0	96
MEAN - Mid 1 km	**64.8**	**88.8**	**66.7**	**90.6**

KP

Distance (m)	**WR** Splits	**WR** Strk Rate	**NWR** Splits	**NWR** Strk Rate
250	62.1	96	62.8	88
500	62.1	96	63.1	88
750	63.2	96	66.0	94
1000	66.0	94	68.0	90
1250	64.5	90	65.3	90
1500	62.8	96	65.6	90
1750	62.2		66.4	94
2000	62.2	96	63.8	90
MEAN - Mid 1 km	**63.7**	**94.4**	**65.6**	**90.9**

Split Times (sec) and Stroke Rates (spm)

JR

Distance (m)	WR		NWR	
	Splits	Strk Rate	Splits	Strk Rate
250	65.4	88	63.0	90
500	63.1	84	66.3	84
750	65.7	84	65.7	78
1000	66.6	80	67.9	84
1250	65.2	80	67.5	84
1500	65.6		66.8	84
1750	65.3	84	65.9	84
2000	65.0	82	65.1	84
MEAN - Mid 1 km	**65.2**	**82**	**66.8**	**83.1**

CS

Distance (m)	WR		NWR	
	Splits	Strk Rate	Splits	Strk Rate
250	64.8	88	67.4	86
500	61.3	84	66.9	86
750	67.8	86		84
1000	64.1	87	66.4	84
1250	67.4	88	70.7	85
1500	66.0	89	72.7	84
1750	65.9	91	70.6	85
2000	68.1		68.9	
MEAN - Mid 1 km	**65.3**	**86.8**	**69.2**	**84.7**

APPENDIX C

Cosmed K2 Validity Study

Appendix C (i)
Cosmed K2 Validity Study - Precis

In the Allan McGavin Laboratory, V02, VE and HR responses were recorded in 10 well trained athletes utulizing the Cosmed K2 and the Medical graphics 2001 exercise system during incremental maximal exercise tests performed on an electronically braked Minhart KEM 3 cycle ergometer. Validity correlation coefficients of 0.95, 0.96 and 0.97 were found for V_E, $V0_2$ and HR, respectively. $V0_2$ and HR measures attained over all six stages of the exercise test showed nonsignificant differences between the two machines (Figures 1 and 3). For $V0_2$, the mean difference of measures was 0.098 with a 95% confidence interval of $0.046 \leq \mu \leq 0.149$. A difference in HR means between the two systems was 4.17 with a 95% confidence interval of $2.156 \leq \mu \leq 6.184$. Although V_E measures of the two systems were highly correlated, V_E was found to be significantly higher with the 2001 system at Stages V and VI of the six stage exercise test (Figure 2). The difference in means of the two measurements of V_E was 7.20 with a 95% confidence interval of $4.716 \leq \mu \leq 9.684$.

Appendix C (ii)

Descriptive Data of the Subjects

SUBJECT	AGE	HEIGHT (cm)	WEIGHT (kg)
1	21	178	65
2	21	170	60
3	21	175	66
4	21	172	68
5	32	164	57
6	25	172	74
7	23	166	61
8	36	170	61
9	25	167	55
10	21	176	69
AVG.	24.6	171	63.6
SD.	± 5.30	± 4.52	± 5.85

Appendix C (iii)
Individual Results for V02, VE and HR During Both Experimental Conditons

a. V02 (l/min) vs. Workload (Watts)

TEST V02 L/MIN	STAGE	s	u	b	j	e	c	t	s			MEAN	STD
		1	2	3	4	5	6	7	8	9	10		
2001	I 40 W	.98	.94	.89	.74	1.07	1.20	1.12	1.14	.99	1.16	1.02	±.142
2001	II 80 W	1.24	1.24	1.15	1.19	1.45	1.44	1.47	1.45	1.31	1.39	1.334	± .122
2001	III 120 W	1.60	1.56	1.495	1.58	1.59	1.74	1.81	1.73	1.71	1.68	1.65	± .098
2001	IV 160 W	2.03	1.90	1.90	2.01	1.72	2.12	2.17	2.05	2.12	2.01	2.00	± 135.
2001	V 200 W	2.47	2.38	2.38	2.41	2.25	2.42	2.62	2.36	2.62	2.47	2.44	± .116
2001	VI 240 W	2.84	2.79	2.90	2.90	3.10	2.79	2.93	2.70	3.14	2.82	2.89	± .137
K2	I 40 W	1.04	.99	.90	.73	1.03	.89	.99	.82	1.02	1.09	.95	± .114
K2	II 80 W	1.28	1.30	1.31	1.00	1.20	1.15	1.32	1.24	1.28	1.32	1.23	± .102
K2	III 120 W	1.66	1.60	1.53	1.31	1.58	1.44	1.63	1.51	1.65	1.58	1.55	± .107
K2	IV 160 W	2.06	2.04	1.92	1.75	1.94	1.68	1.79	1.87	2.04	1.82	1.89	± .133
K2	V 200 W	2.57	2.47	2.46	2.12	2.62	2.14	1.96	2.17	2.60	2.16	2.33	± .242
K2	VI 240 W	3.14	2.93	3.03	2.71	2.90	2.53	2.28	2.71	3.08	2.74	2.80	± .266

b. VE (l/min) vs. Workload (Watts)

TEST VE L/MIN	STAGE	S	U	B	J	E	C	T	S			MEAN	STD
		1	2	3	4	5	6	7	8	9	10		
2001	I 40 W	28.48	29.88	24.03	20.88	25.20	40.03	37.53	31.23	26.30	29.13	29.27	± 5.89
2001	II 80 W	34.88	36.43	31.53	29.30	33.13	40.23	45.80	41.00	32.75	32.60	35.76	± 5.11
2001	III 120 W	43.85	46.70	41.03	39.55	43.05	49.03	55.33	51.83	44.13	38.45	45.29	± 5.43
2001	IV 160 W	55.68	59.78	52.23	52.83	49.03	64.60	67.45	66.68	55.05	48.80	57.21	± 7.03
2001	V 200 W	73.68	85.95	72.05	75.30	81.83	81.33	83.83	85.40	83.03	60.93	78.33 *	± 7.85
2001	VI 240 W	93.90	123.20	114.40	114.35	122.00	117.30	104.45	114.68	105.03	100.63	110.99 *	± 9.57
K2	I 40 W	29.93	31.63	26.25	18.58	28.45	28.23	28.85	26.40	26.67	28.93	27.39	± 3.51
K2	II 80 W	34.38	41.13	32.95	24.40	33.53	36.95	38.80	35.73	33.05	33.43	34.43	± 4.45
K2	III 120 W	43.45	49.48	41.75	31.28	42.88	45.80	49.00	44.28	41.25	38.20	42.74	± 5.29
K2	IV 160 W	52.68	61.65	54.78	40.10	54.13	53.20	53.08	56.68	49.15	43.53	51.90	± 6.25
K2	V 200 W	65.30	78.78	74.58	51.43	84.85	73.20	62.33	68.95	65.53	53.13	67.81	± 10.61
K2	VI 240 W	84.10	105.30	102.53	74.08	97.80	101.53	75.08	94.25	85.28	73.88	89.38	± 12.44

c. HR (bpm) vs. Workload (Watts)

TEST HR L/MIN	STAGE	SUBJECTS										MEAN	STD
		1	2	3	4	5	6	7	8	9	10		
2001	I 40 W	137.3	104.0	107.8	96.8	106.0	118.3	124.5	119.3	114.0	116.5	114.5	± 11.6
2001	II 80 W	136.5	118.8	118.5	120.5	118.5	120.5	139.3	135.0	121.3	124.5	125.3	± 8.3
2001	III 120 W	153.3	134.0	131.5	140.5	130.0	132.3	146.8	150.5	137.5	138.0	139.4	± 8.2
2001	IV 160 W	169.5	152.0	147.5	162.3	147.0	149.0	162.0	165.3	151.5	156.3	156.2	± 8.0
2001	V 200 W	187.0	169.3	168.3	180.7	166.8	165.5	178.0	178.8	166.3	179.3	174.0	± 7.6
2001	VI 240 W	197..5	181.3	188.0	194.0	182.0	178.7	188.5	188.3	175.0	198.0	187.1	± 7.9
K2	I 40 W	118.5	101.0	111.0	100.8	107.0	94.3	99.0	111.5	100.3	104.3	104.8	± 7.2
K2	II 80 W	138.8	118.8	126.5	116.5	116.0	107.5	120.5	125.8	112.8	113.8	119.7	± 8.9
K2	III 120 W	154.0	134.3	140.5	133.8	130.0	120.3	142.5	144.0	126.8	125.5	135.2	± 10.2
K2	IV 160 W	171.5	150.3	159.5	155.8	145.8	136.5	162.8	166.0	142.5	148.0	153.9	± 11.1
K2	V 200 W	189.3	165.5	178.3	178.0	164.8	154.0	179.5	179.8	161.3	170.8	172.1	± 10.7
K2	VI 240 W	201.5	180.5	192.8	196.3	177.0	170.0	190.0	190.5	173.3	187.5	185.9	± 10.3

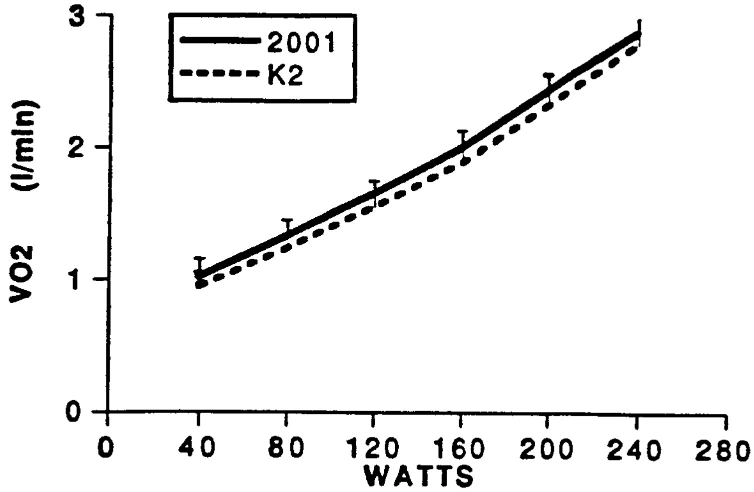

Figure 2 VO2 vs. workload during a 4-minute step incremental test on cycle ergometer.

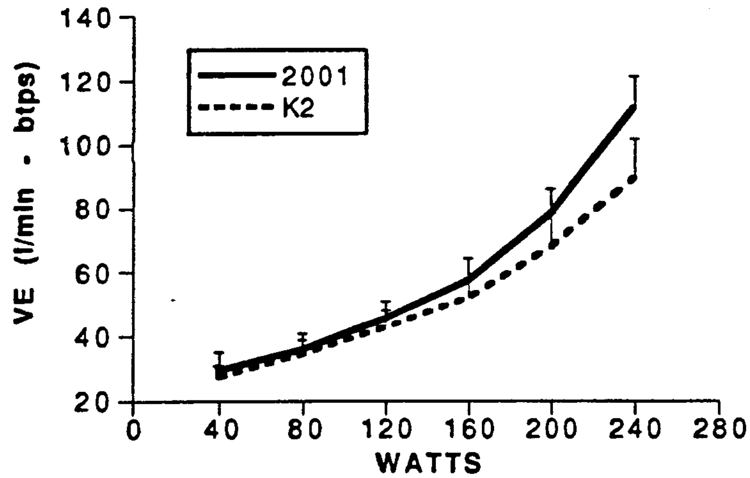

Figure 3 VE vs. workload during a 4-minute step incremental test on cycle ergometer.

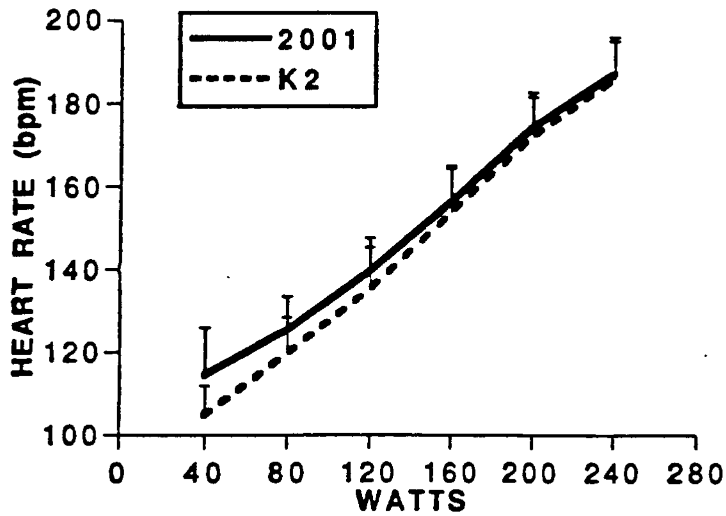

Figure 4 HR vs. workload during a 4- minute step incremental test on cycle ergometer.

APPENDIX D

Kayak Velocity -Raw Data

Appendix D

Kayak Velocity During the Two Experimental Conditions

Subject	**Wash Riding**	**Non-Wash Riding**
MA	3.85	3.75
RJC	3.93	3.89
PG	3.84	3.80
DI	3.76	3.76
LJ	3.81	3.70
SK	3.87	3.77
IM	3.85	3.74
KP	3.92	3.81
JR	3.83	3.74
CS	3.82	3.61
MEAN	3.85	3.76
SD	0.05	0.07