The Oxygen Cost of Cycling - Upright versus Recumbent Position

By

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Abstract

Objective: This study investigated the effect of cycling position (upright vs. recumbent) and seat position on the oxygen cost of cycling.

Experimental design: A two-factor ANOVA with repeated measures was used to examine the effect of cycling position (Monark 814E, Lifecycle 9100 R, and Lifecycle 9500 RHR ergometers) and seat position (optimum and ± 1 setting) on VO_2 and HR.

Participants: Subjects were 10 male physical education students (age = 24 ± 2.1 years, height = 178.8 ± 4.8 cm, weight = 76.2 ± 7.8 kg).

Interventions: Each subject was tested at three 5-minute workloads (55, 137, and 186 Watts) in a random order on the three ergometers. These workloads corresponded with manual settings of 1, 3, and 5 on the Lifecycle ergometers. The cycling protocols for the Lifecycle ergometers were performed with the seat set at 107% of the symphysis pubis measurement and at seat positions of ± 1 setting from the so-called "optimum" setting.

Measures: Physiological response was assessed by continuously monitoring VO_2 and HR.

Results: At the optimum seat setting, the VO_2 was significantly higher at the three workloads on the Monark compared to both Lifecycle ergometers. Seat positions of ± 1 setting from the recommended setting did not affect VO_2. The HR response was non-significant for cycling position and seat position.

Conclusions: The results indicate that the Lifecycle ergometers (9100 R and 9500 RHR) underestimate oxygen consumption and indirectly underestimate energy expenditure. Seat positions of ± 1 setting from the recommended setting on the Lifecycle ergometers did not affect the VO_2.

Résumé

Objectifs: Les objectifs de cette étude sont de découvrir si différentes positions pour pédaler (droit vs. coucher) ainsi que différents réglages du siège, ont des effets sur la consommation d'oxygène.

Design experimental: Une analyse de variance 2x2 avec mesures répétées a été utilisée pour étudier les effets de position pour pédaler (bicyclettes sur place de marques Monark 814E, Lifecycle 9100 R, et Lifecycle 9500 RHR) à différents réglages du siège (optimum et ± 1 du réglage optimum) sur le VO_2 et les pulsations cardiaques.

Participants: Les sujets étaient 10 étudiants en éducation physique de sexe masculin (âge = 24 ± 2.1 ans, grandeur = 178.8 ± 4.8 cm, poids = 76.2 ± 7.8 kg).

Traitement: Chaque personne a été testée à trois charges de travail différentes (55, 137, et 186 Watts) pendant 5 minutes pour chaque charge, dans un ordre aléatoire, sur les trois bicyclettes. Ces charges correspondent au réglage manuel de 1, 3, et 5 sur les bicyclettes Lifecycle. Le protocole pour les bicyclettes Lifecycle a été effectué avec le siège placé à 107% de la mesure de la symphyse pubienne ainsi qu'à des positions de ± 1 de ce placement appelé "optimum".

Measure: Les réponses physiologiques ont été établies en surveillant continuellement le VO_2 et les pulsations cardiaques.

Resultat: Au réglage "optimum" du siège, le VO_2 était significativement plus élevé aux trois charges de travail sur le Monark camparativement aux deux bicyclettes Lifecycle. Les positions assises de ± 1 du réglage optimum n'ont pas eu d'effets sur le VO_2. Le nombre de pulsations cardiaques n'a pas été significativement différent pour les différentes positions de pédalage et de réglage du siège.

Conclusion: Les résultats indiquent que les bicyclettes Lifecycle (9100 R and 9500 RHR) sous-estiment la consommation d'oxygène et indirectement sous-estiment la dépense d'énergie. Les positions assises de ± 1 du réglage optimum sur les bicyclettes Lifecycle n'ont pas d'effets sur le VO_2.

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Experimental Study

Comparison of the Oxygen Cost of Cycling using Upright and Recumbent Lifecycle™ Ergometers

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Introduction

Factors that affect the oxygen cost of bicycling include, wind resistance, rolling resistance, seat adjustment, pedal rate and body position (1). At speeds greater than 25 km/h, the major factor determining energy expenditure is wind resistance (2,3). In contrast to bicycling, fewer variables affect the oxygen cost of stationary cycling. Wind resistance is not a factor during stationary cycling. The relationship between workload and oxygen cost of stationary cycling is linear. This linear relationship is described by the American College of Sports Medicine equation (4):

$$VO_2 \text{ ml/min} = 2 \times \text{Workload (kpm)} + \text{Resting Metabolic Rate } (VO_2 \text{ ml/min})$$

The equation was developed from data collected using the Monark ergometer, a friction type resistance ergometer (5).

Today, numerous types of cycle ergometers are used in fitness and clinical settings. The LifeFitness Lifecycle ergometer is one popular choice. LifeFitness has two basic models, the upright 9100 R and the recumbent 9500 RHR. Each of these ergometers has a similar digital display panel which provides feedback for the cyclist. Energy expenditure (kcal and kcal/h) is predicted based on estimations of VO_2 and then converted to kcal using the relationship 1 L of $VO_2 = 5$ kcal. When the same program, pedal rate, and difficulty level are selected, the estimations are identical for the upright and recumbent Lifecycle ergometers even though body position is different.

Hence, the purpose of this study was to investigate the effect of cycling position (upright vs. recumbent) on the oxygen cost of cycling. Additionally, the effect of seat adjustment on the oxygen cost of cycling in the upright and recumbent positions was examined.

Methods

Subjects

Subjects were 10 male physical education students, ranging in age from 20 to 27 years. The physical characteristics of the subjects are described in Table 1. All participants were healthy and not taking any medications. Written informed consent was obtained prior to testing. A university Research Ethics Committee approved the procedures employed in the study.

Each subject completed two visits to the lab with the visits separated by at least 24 hours. Subjects wore appropriate cycling clothes and footwear for the tests.

Anthropometry

Previous research has determined that the most efficient saddle height for cycling is 107% of symphysis pubis measurement (6). On the first visit, height, weight, and leg length were measured. The symphysis pubis measurement was taken as the distance between the symphysis pubis to the floor, with the subject standing in the upright position, legs straight, and feet approximately shoulder width apart. For the cycling tests on the Monark and Lifecycle ergometers, seat height was set at 107% of the symphysis pubis measurement. This measurement was from the seat surface to the base of the pedal, in a straight line with the seat post and crank arm, and the pedal at the bottom of the pedal stroke.

Cycle Ergometers

After the anthropometric measures were recorded, subjects stretched for 5–10 minutes. Each subject was tested in a random order on Monark (model 810E), Lifecycle

(9100 R) and Lifecycle (9500 RHR) ergometers The 9100 R is the standard sitting model with the legs in a vertical position. The 9500 RHR is a recumbent ergometer with the legs in a horizontal position and the back supported. On the Lifecycle ergometers, the control panel provides feedback on velocity, distance, power output and energy expenditure as a function of workload setting in the manual mode. For example, levels 1,3,5,7 and 9 correspond to 55, 137, 186, 236 and 283 Watts, respectively. Both the 9100 R and 9500 RHR estimate energy expenditure using the same prediction equation even though the muscle mass recruited for the effort varies.

$$\mathbf{VO_2\ (ml/min) = 2\ X\ Workload\ (kpm) + Resting\ VO_2\ (ml/min)}$$

The cycling protocol for the Monark ergometer consisted of three 5-minute workloads with the seat set at 107% of the symphysis pubis measurement. Subjects pedalled at 70 rpm. The three workloads were performed at 55, 137, and 186 Watts. These workloads were selected to correspond with manual settings of 1, 3, and 5 on the Lifecycle ergometers.

The cycling protocol for the Lifecycle ergometers was performed with the seat set at 107% of the symphysis pubis measurement and at seat settings of ± 1 (one whole adjustment up the seat post +1 or one whole number down the seat post –1) from the so-called "optimum" setting. The upright 9100 R has a numbered hole and peg system to adjust the seat height setting to best fit the rider. The recumbent 9500 RHR uses a similar system only the seat travels along a rail on a slight incline. When the seat of either Lifecycle ergometer is in the appropriate position the peg slides into a hole locking the seat in place. Three workloads (levels 1, 3, and 5) were performed at the optimum setting. The control display suggested that these workloads were 55, 137, and 186 Watts.

For seat settings of ± 1, two 5-minute workloads were performed at 55, and 186 Watts. On the Lifecycle ergometers, resistance varies depending upon pedalling velocity. Subjects pedalled at approximately 70 rpm.

Physiological Responses

Heart rate (HR) and oxygen uptake (VO_2) were continuously measured. Subjects were connected to a Sensor Medics 2900 Metabolic cart. Expired air was analysed and V_E, VO_2, and RER were averaged every 20 s using standard equations. The gas analysers were calibrated before each test with gases of known concentrations. The values during the last minute of each 5-minute workload were averaged and represented the steady state for each workload. Resting oxygen consumption was recorded for 5-minutes in a seated position prior to cycling.

A Vantage XL Polar heart rate monitor was used to continuously record HR. The values during the last minute of each 5-minute workload were averaged and represented the steady state HR for each workload.

Statistical Analysis

Results were expressed as means ± S.D. A two-factor analysis of variance (ANOVA) with repeated measures was used to examine the effect of seat position (optimum and ± 1 setting) and type of ergometer (Monark, Lifecycle 9100 R, and Lifecycle 9500 RHR) on VO_2 and HR. Data were analysed using SYSTAT statistical software. When a significant F-ratio was obtained, a post-hoc student t-test was used to identify significant differences. A p-value of < 0.05 was considered statistically significant.

Results

Mean and S.D. values for VO_2 and HR are included in Tables 2 and 3, respectively. At the optimum seat setting, the VO_2 on the Monark ergometer was significantly higher at 55, 137, and 186 watts than the VO_2 measured using both Lifecycle ergometers. At 55 Watts, VO_2 was 17% lower on the Lifecycle ergometers. At 137 Watts the VO_2 was 8-10% lower on the Lifecycle ergometers. At 186 Watts, VO_2 (L/min) was 2.58 using the Monark ergometer, 2.34 using the Lifecycle (9100 R), and 2.39 using the Lifecycle (9500 RHR).

On the Lifecycle ergometers, it is possible to adjust seat distance using 12 settings. Seat settings of ± 1 from the recommended setting did not affect the VO_2 values (Table 2). There was a significant difference found between -1 seat setting and $+1$ seat setting on the upright Lifecycle (9100R) at a workload of 55 Watts, but these differences were not significant from the optimal seat setting. The heart rate responses to the cycling protocols are presented in Table 3. The repeated measures ANOVA indicated that the HR response was non-significant for seat position (optimum and $\pm$ 1 setting) and type of ergometer (Monark, Lifecycle 9100 R, and Lifecycle 9500 RHR).

Discussion and Conclusion

Jones et al. (7) present normal standards based on height categories for power outputs of 300 and 600 kpm/min (49 and 98 Watts). For subjects 175-180 cm in height, the mean VO_2 was 0.91 ± 0.066 L/min at 49 Watts and 1.51 ± 0.145 L/min at 98 Watts. The corresponding values for HR were 94 ± 17 bpm and 114 ± 21.7 at 49 and 98 Watts, respectively. Our mean VO_2 and HR results for the upright and recumbent Lifecycle tests are in agreement with the standards suggested by Jones et al. (7).

A pedal rate of 60-80 rpm has been recommended for power outputs less than 300 Watts (8). A pedal rate of 70 rpm was used in this study. Several groups (9, 10, 11) have noted that the optimal pedal rate increases as a function of power output.

Previous research has established the importance of cycling position. Aerodynamic handlebars lower VO_2 at a constant cycling velocity by 1-2% compared with normal handlebars (3, 12) with even greater benefits at competitive cycling speeds (13, 14). The aerodynamic handlebars are effective since the body is re-positioned to reduce wind resistance. Wind tunnel tests at speeds 50 km/h have shown a 15% reduction in aerodynamic drag when cyclists assume an aero cycling posture compared to the traditional cycling posture (15). Time trial bicycles are modified (smaller front wheel, front and rear disc wheels, and a sloping top tube) to enhance performance (3).

The effect of body position on the physiological responses to cycle ergometer exercise has been examined (16, 17). Both VO_2 max and maximal workload are significantly higher during cycling in an upright position compared to supine cycling with the legs in the horizontal position. VO_2 max during cycling in the supine position is 10-20% lower compared to VO_2 max measured during cycling in the upright position (17,18).

Upright and supine cycling have been compared using an electrically braked ergometer (Lode, Groningen, The Netherlands) at a cycling rate of 60 rpm and a power output of 180 Watts (16). VO_2 was 0.13 L/min higher in the "upright position" compared to the "supine position". In contrast, we found similar VO_2 values at a power output of 187 Watts using the upright and recumbent Lifecycle models. It has been shown that mechanical efficiency during submaximal cycling in the two positions is similar (16).

Mechanical efficiency was calculated as power output (Watts) divided by energy input (Watts).

For our subjects, the ACSM equation to predict oxygen consumption during stationary cycling estimates VO_2 values of 0.94, 1.94, and 2.54 L/min at power outputs of 55, 137, and 186 Watts. At 55 Watts both the upright and recumbent Lifecycle ergometers provided good estimates of oxygen consumption. At 137 and 186 Watts, the Lifecycle ergometers underestimated oxygen consumption while the measured and predicted oxygen consumption were similar using the Monark ergometer.

To indicate the magnitude of error in estimating energy expenditure the data for one subject at 137 Watts will be used. At level 3 (137 Watts) on the 9100 R Lifecycle, energy expenditure is estimated to be 583 kcal/h (1.944 L/min X 5 kcal/L of oxygen X 60 min/h). Our results indicated that energy expenditure was 519 kcal/h (1.75 L/min X 4.94 kcal/L of oxygen X 60 min/h) since the RER was 0.91. The upright Lifecycle ergometer underestimated energy expenditure by 11% for this subject.

The effect of seat height on oxygen consumption during cycle ergometer work has been previously examined (6, 19). Oxygen consumption has been compared at 131 Watts using three seat heights corresponding to 102, 107, and 112% of symphysis pubis measure (6). VO_2 was lowest with the seat at 107% of the symphysis pubis measure. Examination of the kinematic patterns of the lower limb indicated that the knee was not flexed as much at the higher seat height. Shennum and deVries (19) examined power outputs from 50 to 200 Watts at seat heights of 100, 103, 106, 109, and 112% of inside leg length measured from the ischium to the floor. VO_2 progressively increased as seat height increased. It is necessary to add approximately 5% to their leg length measures to obtain equivalent comparisons. When the data were corrected, the best setting for oxygen economy was 105-108%. In this study, seat positions of ± 1 setting corresponded to 104% and 110% of symphysis pubis measurement, respectively and did not significantly alter VO_2.

In summary, our results indicate that the Lifecycle ergometers (9100 R and 9500 RHR) underestimate oxygen consumption and indirectly underestimate energy expenditure. Seat settings of ± 1 from the recommended setting on the Lifecycle ergometers did not affect the oxygen consumption.

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Table I. Physical characteristics of the subjects (n=10).

Variable	Mean	S.D.	Range
Age (years)	24	2.1	20 – 27
Height (cm)	178.8	4.8	185 – 170
Weight (kg)	76.2	7.8	63 – 88
Leg Length (cm)	85.8	4.6	78.7 – 94.0

Table II. VO_2 (L/min) Results (mean ± 1 S.D.).

Protocol	Seat position	Power (W)		
		55	137	186
Monark	Optimal‡	1.14 ± 0.06	1.91 ± 0.28	2.58 ± 0.18
Lifecycle (9100R)	-1	0.93 ± 0.10		2.33 ± 0.12
	Optimal‡	0.97 ± 0.08*	1.75 ± 0.10*	2.34± 0.10*
	+1	1.03 ± 0.11**		2.38 ± 0.16
Lifecycle (9500RHR)	-1	0.97 ± 0.09		2.35 ± 0.16
	Optimal‡	0.98 ± 0.10*	1.81 ± 0.13*	2.39 ± 0.15*
	+1	1.05 ± 0.12		2.43 ± 0.20

Optimal = 107% of leg measurement
‡ Based on recommendation of Nordeen-Snyder et al. (6)
-1 = one seat setting below optimal seat setting
+1 = one seat setting above optimal seat setting
* Significantly different ($p<0.05$) from Monark
** Significantly different ($p<0.05$) from – 1 seat setting

Table III. Heart Rate (beats/min) results (mean ± 1 S.D.).

Protocol	Seat position	Power (W)		
		55	137	186
Monark	Optimal‡	102 ± 23	135 ± 25	154 ± 26
Lifecycle (9100R)	-1	99 ± 18		149 ± 24
	Optimal‡	98 ± 14	134 ± 19	149 ± 23
	+1	102 ± 17		148 ± 23
Lifecycle (9500RHR)	-1	102 ± 11		152 ± 20
	Optimal‡	97 ± 16	128 ± 20	151 ± 22
	+1	103 ± 15		154 ± 21

Optimal = 107% of leg measurement
‡ Based on recommendation of Nordeen-Snyder et al. (6)
-1 = one seat setting below optimal seat setting
+1 = one seat setting above optimal seat setting

Figure 1. The VO_2 and HR response during cycling on the Monark cycle ergometer, upright Lifecycle (9100R), and the recumbent Lifecycle (9500 RHR).

* significant difference ($p<0.05$) from Monark.

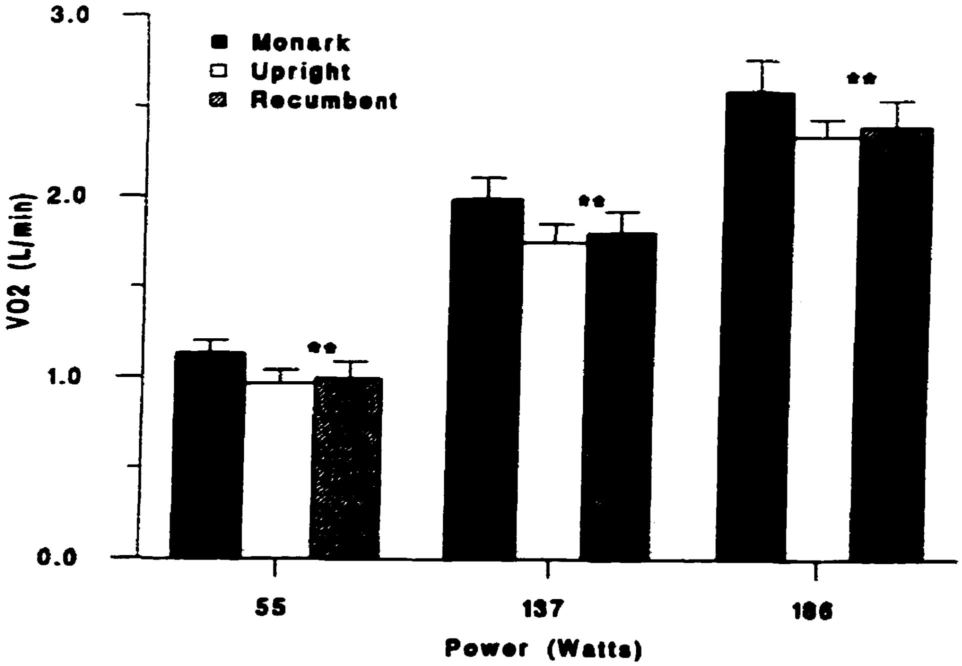
Figure 2. The effect of seat adjustment on VO_2 during cycling on a) the upright Lifecycle (9100R) and b) recumbent Lifecycle (9500 RHR).

Optimal, optimal - 1, and optimal + 1.

* = significant difference ($p<0.05$) from the - 1 seat setting.

Figure 3. The effect of seat adjustment on HR during cycling on a) the upright Lifecycle (9100R) and b) recumbent Lifecycle (9500 RHR).

Optimal, optimal - 1, and optimal + 1.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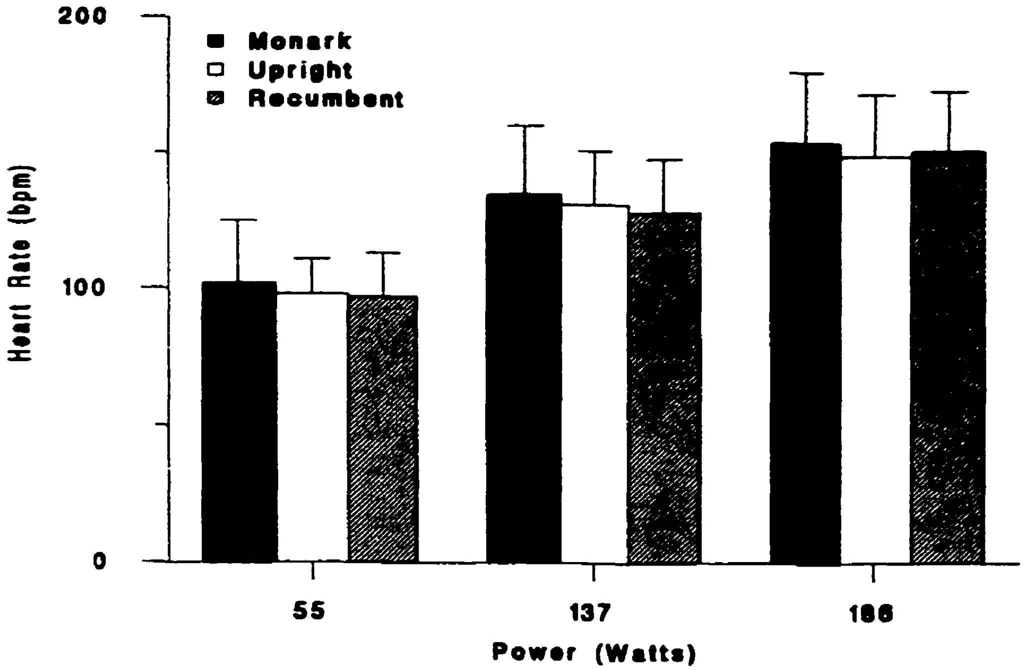
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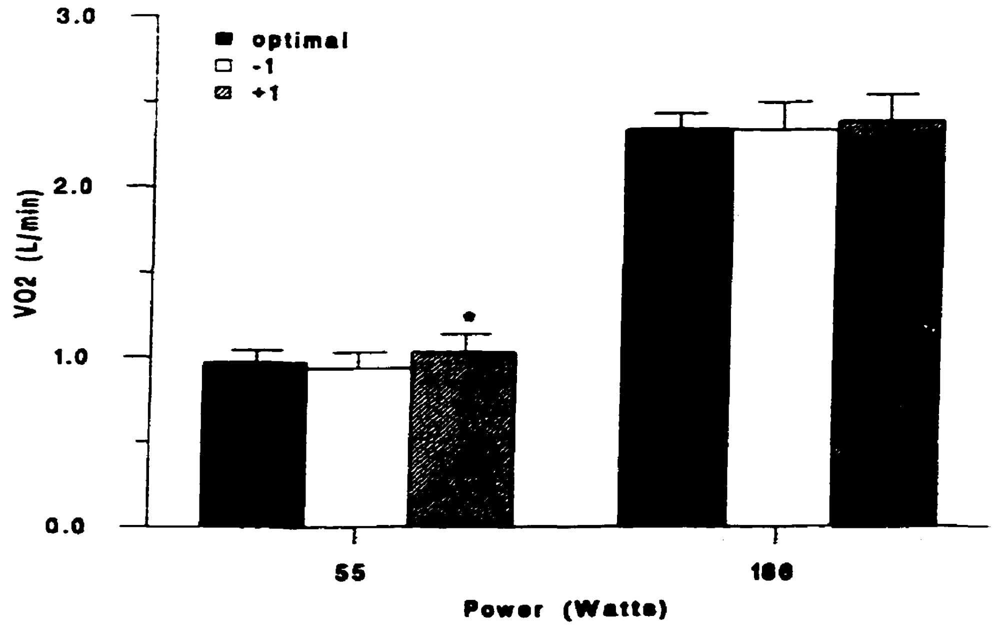
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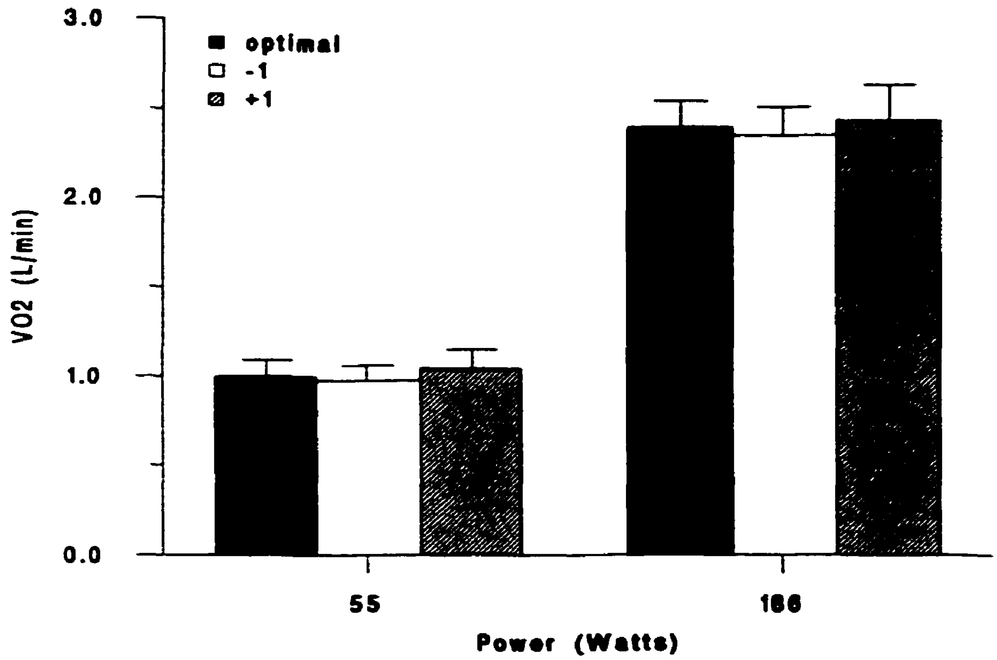
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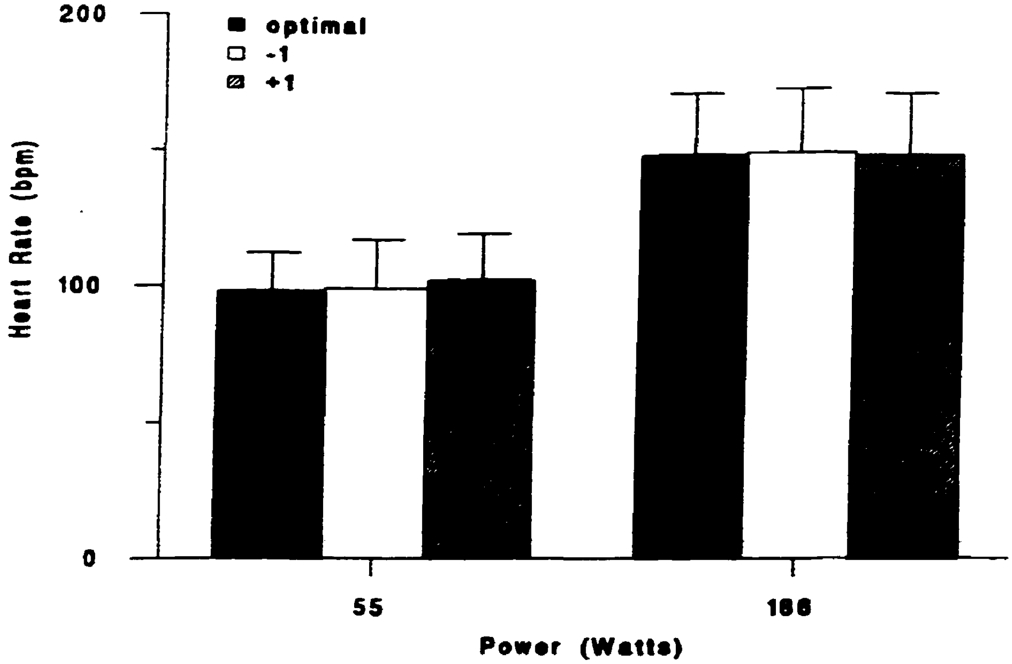
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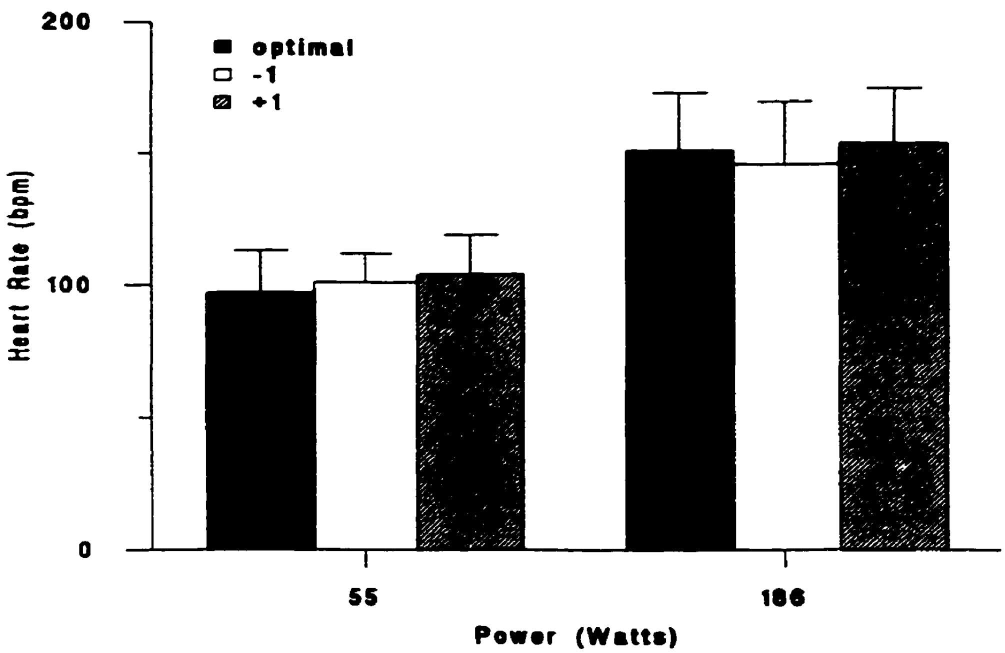
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Power (Watts)

Appendices

Appendix 1 - Review of Literature

Historical Perspective

The first type of machines and vehicles introduced to man were human powered vehicles. Up until the 17th century, boats were powered by humans pulling on long ores, inclined treadmills were powered by people to provide pumps, and there was also evidence of a foot propelled carriage used in France in the 1690's (Whitt & Wilson 1982).

The first known vehicle that resembled the modern day bicycle was developed in France in 1791, it was described as a two-wheeled wooden horse that had no steering capability. By the early 19th century this human powered vehicle was transformed into the hobby-horse. This first version resembled the modern day bicycle with no pedals and again lacked any steering ability. The hobby-horse was propelled by the riders feet pushing on the ground, to steer the horse the rider had to lift or drag the front wheel in the desired direction. In the year of 1817 an important breakthrough occurred in cycling history, Charles Baron von Drais invented a Hobby-horse (Dandy-horse) that had steering. This version of the vehicle was called the velocipede (1818) until 1869 when a new term was issued, the **bicycle** (Oliver & Berkebile 1974).

After the Hobby-horse there was a steady development of the bicycle. Some of the early bicycles were the Ordinary, a big wheeled unsafe bicycle with the rider seated over the middle of the driving (front) wheel. Then came the introduction of the 'safety' models, the 'Xtraordinary, with a smaller front driving wheel and the seat situated further back on the bicycle, the Facile, this bicycle had an even smaller front driving wheel with the seat pushed back even further behind the driving wheel, the Kangaroo 1884, and the rear-driving Safety 1885 (Sharp 1977). Bicycles, such as the Ordinary, were considered dangerous because riders were seated high up with their weight balanced well over the front tire resulting in riders going over the handlebars if they hit the smallest of bumps in the road. The bicycle industry was tarnished because of this danger factor, even athletic men would hesitate to ride the bicycle.

In the mid to late 1860's Starley and Sutton introduced what were called the Rover Safety Bicycles. Safety, meaning that the bicycles were much safer to ride. These bicycles didn't gain popularity until the middle of the 1880's. Starley constructed two versions of the Safety Bicycle, one that was front wheel drive and the other rear wheel drive using a chain system. These bicycles contained the diamond frame that is very evident in the bicycle today (Whitt & Wilson 1982).

The next, and maybe most important development in the bicycle was the pneumatic tire. In 1889 John Boyd Dunlop obtained English patents for his tire and one year later obtained an American patent for that same tire. Earlier development of the bicycle was difficult in America because of poor roads and long distances between towns. With the new tire being introduced there was a wider acceptance of the bicycle in America. This acceptance was fuelled by the increased speed and comfort obtained with the new Dunlop tire (Oliver & Berkebile 1974).

The next step in the structure of the bicycle was the introduction of the coaster brake. Up until the late 19th century the only type of braking system involved application of negative pressure to the pedals. By the year 1989 a free-wheeling braking system was introduced and grew quickly in popularity. The final mechanical change made to the bicycle in America was the development of a multiple-speed driving system. This type of system had been introduced earlier but was too expensive for the average American

(Oliver & Berkebile, 1974).

In the late 1890's the bicycle boom took off. By 1899 there were very few automobiles in America and the bicycle had become the predominant form of transportation for the businessman, and every day man and woman. The bicycle was used for business, pleasure, and sport. It drew people together to form leagues and sporting events grew in popularity. With the sporting aspect of cycling being so popular the development of the bicycle did not stop (Oliver & Berkebile 1974). The goal of making the human powered vehicle faster and more energy efficient is still going today.

The movement of cycling results from the transfer of biochemical energy to mechanical energy. Biomechanical energy primarily results from the oxidation of substrates within the skeletal muscle cells. The energy cost of cycling is thus directly related to the oxygen consumption of the muscles.

1.0 The Oxygen Cost of Cycling:

1.1 Road Cycling:

There are many different types of bicycles on the market that are developed for a wide variety of consumers. The bicycle has become a common and convenient mode of transportation as well as an excellent vehicle for improving cardiovascular fitness. As mentioned earlier the concern with cycling is the energy required by the cyclist to perform the action. One way to evaluate the energy cost of cycling is to measure the oxygen consumed by the cyclist.

Table 1 contains a sample of the literature pertaining to the oxygen cost of road cycling. Selected studies between 1987 and 1996 are listed. The data in these studies were obtained using subjects with a wide range of abilities from no experience in cycling to elite levels of cyclists. The bicycles in these studies were of the racing style and all of the cyclers road in a racing or tuck position. The surfaces rode on by the cyclers varied in shape from straight and flat, to oval and flat, but were all of hard material with one of the surfaces being indoor tracks. Wind speed also varied between studies ranging from 6.5 km/h to calm. The goal of each protocol was for the cyclist to obtain and maintain a steady state at a set speed so that physiological measurements could be taken. Steady state was defined as the body meeting the demands placed on it, and was identified by a levelling off of heart rate and oxygen cost for a given workload. As listed in table 1 the speed of the cyclers ranged from 16 to 40 km/h, while the oxygen consumption ranged from 0.75 to 4.34 L/min. The relationship between speed and VO_2 is not strictly a linear relationship. Baak & Binkhorst (1981) collected data from subjects of both genders in the age groups of 20-30 yrs., and 50-60 yrs., and found the relationship to be linear until approximately 5 m/s or 18 km/h. As the speed of the cyclists increased, the relationship became hyperbolic in nature.

Clearly, the results of the studies concerning the oxygen cost of road cycling are not consistent. At a speed of 40 km/h McCole et al. (1990) found the oxygen cost of cycling to be 4.03 L/min whereas Richardson & Johnson (1994) found the oxygen cost to be 4.34 L/min at the same speed. These differences could be attributed to differences in wind speed and direction as diPrampero et al. (1979) found that factors such as air resistance, wind speed and direction, rolling resistance, body position and body surface area effect the oxygen cost of road cycling.

Similarly, McCole et al. (1990) found the oxygen cost of cycling at 32 km/h to be

2.59 L/min while Swain et al. (1987) found the oxygen cost of cycling at that same speed to be 2.97 L/min. The difference in results between these two studies could be attributed to the fact that Swain et al. (1987) used two groups of subjects, one large (84.4 kg) and one small (59.4 kg) group. Because the mass of the rider has a direct effect on body surface area (BSA), a difference in body surface area could, in turn effect air resistance, and thus oxygen consumption. Additionally, increased load requires increased oxygen consumption. Other factors that may have contributed to these differences are cycling efficiency, the calibration of the ergometer and the equipment used for measurement of VO_2.

1.2 Cycle Ergometers:

As the bicycle has changed with technological advancement so has the cycle ergometer. With the advent of exercise science, and/or the emphasis on fitness for health-related reasons, the cycle ergometer has become an important tool for both assessment and conditioning purposes. Currently, there are a wide variety of ergometers on the market differing in structure, and type of resistance (air, mechanical and electric). Of the ergometers using mechanical resistance, the Monark ergometer is typically considered the standard in research laboratories.

The Monark has a basic working principle. The ergometer consists of a frame, one fly wheel, two pedals, a seat, and handlebars. Similar to a road cycle, the fly-wheel is turned through a chain and sprocket system connected to the pedals and wheel. The resistance is applied through the friction of a brake-lace or brake-strap on the fly-wheel. To adjust the resistance, the tightness of the lace or strap is adjusted, such that the tighter the strap, the greater the friction, and therefore the greater the resistance. With such an easy working principle the Monark qualifies for a number of purposes. Quantifying work on the Monark can be accomplished easily through the following calculations:

Power = *Force x Velocity*

kpm/min = *resistance (kg) x distance (6m/rev) x rpm*

To convert into Watts, the following conversion factor is used:

1 watt = 6.12 kpm/min

With the simplicity of the Monark it is easy to assess the relationship between workload and the cost of cycling on the Monark ergometer.

Table 2 contains a summary of studies that investigated the oxygen cost of cycling on an ergometer. The cycling experience varied from well-trained, competitive cyclists, to active and untrained individuals. The average age, weight, and height, ranged from 17 - 30 years, 71 - 79 kg, and 179 - 184 cm, respectively for these studies. Although protocols varied, each had the common goal of establishing a steady state, identified by a steady heart rate at a given workload. When steady state was achieved, the oxygen cost of cycling at a set rpm and workload was identified.

Workloads listed in Table 2 ranged from 0 watts to 250 watts with protocols using multiples of 25 Watts, with one exception (145 watts). VO_2 ranged from values of 0.64 L/min to a maximum recording of 3.73 L/min. To establish a comparable value among studies the computation of the relative VO_2 / watt showed values that ranged from 11.9 to 20.6 $ml \cdot min^{-1} watt^{-1}$. Some of the variation is attributed to type of ergometer with values highest for electrically braked ergometers and lowest for disc braked ergometers. Theoretically, if the workload was held constant on each ergometer then the oxygen cost of cycling on those ergometers should be relatively the same, however, this was not the case.

The researchers in Table 2 primarily used the Monark ergometer as their testing tool. In contrast, Wilmore et al. (1982) used a variety of ergometers and found that the oxygen cost of cycling on an ergometer varied according to the type of ergometer. More specifically Wilmore et al. (1982) compared the oxygen cost of cycling on four different types of ergometers. The ergometer's resistance's were achieved as follows: 1) a fabric belt on a fly-wheel (similar to the Monark), 2) a disc braked system, 3) an electrically braked system, and 4) a pony braked system. Ten male subjects cycled at 50, 100, and 150 watts on each of the four ergometers. Conflicting results showed that at a workload of 50 watts, the oxygen cost of cycling ranged from a low of 0.84 L/min on the disc braked ergometer to a high of 1.03 L/min cycling on the electrically braked ergometer. At a workload of 150 watts, discrepancies in VO_2 values were also found. The lowest VO_2 value was 1.78 L/min when cycling on the disc braked system and the highest value was 2.04 L/min when cycling on the fabric belt ergometer.

Additionally, when comparing the oxygen cost of cycling on the Monark ergometers to cycling on the electric ergometers there is again, a discrepancy. At a workload of 150 watts Coast and Welch (1985) found the oxygen cost of cycling on the Monark to be 2.25 L/min. Widrick et al. (1992) and Luhtanen et al. (1987) found the oxygen cost of cycling on the Monark to be 2.09 L/min and 2.20 L/min, respectively, at a workload of 145 watts. On the other hand an oxygen cost of 2.00 L/min was noted when cycling on an electrical ergometer at a workload of 150 watts (Shennum & deVries; 1976, Wilmore et al.; 1982). There is a significant difference in the oxygen cost of cycling on different ergometers at the same workload which may be attributed to the different ways in which the resistances were engineered for the different ergometers. Different materials have different friction coefficients and each ergometer has different types of materials creating the resistance. The mechanics of the ergometers may affect the efficiency of the cyclists. Factors such as chain and axle frictions may differ between ergometers, whereas the electrical ergometer is not chain driven. This may explain why the oxygen cost of cycling on an electrical ergometer is lower than the oxygen cost of cycling on the Monark ergometer.

In contrast to the results of Wilmore et al. (1982), studies with Monark ergometers showed more consistent VO_2 (L/min) values, ranging from 0.64 L/min at a workload of 0 watts to 3.73 L/min at a workload of 250 watts. When calculating the relative values of VO_2/watt the Monark results ranged from 13.7 to 15.2 ml/min×W. These values attest to the consistency and reliability of the Monark cycle ergometer. Examining the Wilmore article, the relative values expressed as VO_2/watt show a much wider range of values from 11.9 to 20.6 ml/min×W. The slight differences found in the Monark results could be attributed to calibration of equipment or the efficiencies of the riders. In addition, each study contained a group of subjects that was sampled from a different population than the others, with some groups having more cycling experience while others had limited experience. In general, more experienced cyclists have a greater cycling efficiency than the untrained or less experienced cyclist. This may be a factor contributing to a lower oxygen cost of cycling in the trained cyclist.

Mechanical efficiency is calculated as:

$$\frac{\text{External Work} \times 100}{\text{Energy Expended}} = \frac{\text{Wheel Circ} \times \text{RPM} \times \text{Resistance}}{VO_2 \text{ (l/min)}}$$

Generally cycling efficiency is found to range from 15 to 25%. In support, Coyle et al. (1992) examined cycling efficiency of 15 elite cyclists and found a range from 18.3% to 22.6%.

Table 2 is illustrated in Figure 1. The relationship between oxygen cost and workload is linear. The regression equation representing this relationship is **Y = 0.5125 + 0.0019X**, where Y = VO_2 (L/min), and X represents the workload in kpm/min. This equation resembles the American College of Sports Medicine formula in Table 3 (p. 48), which is commonly found in exercise physiology textbooks.

The formula of:

VO_2 = (kg•m/min x 2 ml/kg•min) + (3.5 ml/kg•min x body weight (kg)

consists of 2 components, the resistive component or first part of the equation and the resting component, or second part of the equation (Heyward, 1991). The slope of the lines of these two equations are similar with a slope of 2.0 for equation 1, while the slope of the line in Figure 1 is 1.98. The difference among the equations is found in the y-intercepts or resting component. The y-intercept of the ACSM formula represents the resting metabolic rate (RMR) of the subjects within their sample. In Figure 1, the y-intercept, is approximately 200 ml/min higher than the average male RMR of 300 ml/min. The resting component of Figure 1 represents the metabolic rate of the subjects while they were pedalling at 60 rpm at a workload of 0 watts. This probably accounts for the difference.

Other equations have been used to represent the relationship between VO_2 and workload. Table 3 includes five studies which predict VO_2. These data were collected from non-athletic populations who were tested on a cycle ergometer. One concern with the prediction of VO_2 (L/min) while measuring external work is the assumption that cycling efficiency is 20%.

Storer et al. (1990) and Fairbarn et al. (1994) constructed VO_2 prediction equations using data collected from subjects of the general population (non-athletic) recruited through advertisements in local newspapers. Both experimenters divided their groups of subjects (29-80 years) into decades (20-29, 30-39, etc.). With the data of 231 males and females, Fairbarn et al. (1994) developed two prediction equations, one for males and one for females, following a structure similar to the ACSM equation (Table 3). Storer et al. (1990) also constructed prediction equations for both males and females using multiple linear regression. These equations used workload (watts), body weight (kg), and age (years) as the independent variables. These equations predict VO_2 within 10% of the measured VO_2. Additionally, Siconolfi et al. (1982) and Jones et al. (1985) constructed similar prediction equations.

In examination of these equations it is obvious that the Jones et al., Fairbarn et al., and the ACSM equations are similar. The slope of the lines range from 0.0021 (Fairbarn et al.; 1994) to 0.0019 (Jones et al.; 1985). The main differences between these equations is found in the resting component or y-intercept which represents the resting metabolic rate of each sample. The resting metabolic rate is dependent on a number of variables such as age, gender, body composition, and activity level.

Fairbarn et al. (1994) identified the RMR as 305 ml/min for males and 258 ml/min for females. The resting metabolic rate of females is generally lower than that of males. Jones et al. (1985) only devised one formula that had a y-intercept of 288 ml/min. This constant should be lower because it accounts for both males and females. The average RMR value for Fairbarn et al. (1994) is 282 ml/min, which is almost the same value as that found by Jones et al. (1985). It is thus clear that the relationship of workload and oxygen consumption on the Monark ergometer is linear and that VO_2 can be predicted by the equation

2 x Workload(kpm) + RMR.

2.0 Factors Influencing the Oxygen Cost of Cycle Ergometry:

2.1 RPM

There are several factors that may affect the oxygen cost of cycling on an ergometer. The rate at which the cyclist pedals has been identified as one of these factors. Table 4 contains studies published from 1977 to 1992. These studies consist of subjects ranging from the competitive cyclist to the untrained individual. Subjects varied from 18 to 25 years of age, and from 71 to 79 kg in weight. All cycling was performed on a Monark ergometer except for the study of Boning et al. (1984), in which a Jaeger Ergotest was used. The focus of each of the studies was to examine the effect of pedal rate on the oxygen cost or efficiency of cycling. A wide range of workloads and pedal rates were used. Workloads ranged from as low as 0 to as high as 375 watts, and pedal frequencies ranged from 20 to 120 rpm.

The trend in Table 4 shows that as workload increases so does the pedal rate of the cyclist to maintain the optimal cycling efficiency. At a low workload of 100 watts, Widrick et al. (1992) and Coast & Welch (1985) found the most efficient pedal rate to be between 40 and 45 rpm. At higher workloads between 300-375 watts, the most efficient pedal rates were between 60 and 75 rpm (Sidossis et al.; 1992, Coast et al.; 1986).

Table 5 shows a global picture of the relationship between the oxygen cost of cycling and pedal rate. With the exception of three investigations, two which used electric ergometers and one which used a modified fabric belt ergometer, Monark ergometers were used. The number of subjects within each study ranged from 5 to 15, covering a wide variety of individuals from well trained cyclists to untrained, non-athletic individuals. These studies covered a range of pedal rates from 20 to 100 rpm and power ranged from 0 to 300 watts. The oxygen cost of cycling was lowest at a pedal rate of 40 rpm and a power of 0 watts (0.435 L/min), and highest at 100 rpm and power of 300 watts (4.22 L/min).

Pedal rate has a parabolic or quadratic relationship in respect to the oxygen cost of cycling at a set workload (Coast & Welch; 1985). At a given workload, if the pedal frequency is too low or too high the cost to perform that work increases or the efficiency of cycling decreases (Hagberg et al.; 1981). Results obtained by Widrick et al. (1992) best show the parabolic relationship. When cycling at a workload of 145 watts and 40 rpm cyclists consumed 2.18 L of oxygen per minute. At the same workload but differing pedal rates of 60 and 80 rpm, the cyclists consumed 2.09 and 2.19 L of O_2/min, respectively. The most efficient pedal rate at a workload of 145 watts was 60 rpm because the oxygen cost at this pedal rate was the least.

From Table 5 it can be concluded that at lower workloads a lower pedal rate is most cost efficient and that at greater workloads a higher pedal rate is more cost efficient.

It is hard to identify the most cost efficient pedal rate for each workload because there are differences among studies in the nature of subjects and the equipment. Subjects vary in cycling efficiency which may have a considerable effect on the actual oxygen cost of cycling.

A variety of theories have been offered to explain why different pedal rates may affect the oxygen cost of cycling. Seabury et al. (1977) speculated that additional muscle fibers were recruited when workload increased resulting in decreased cycling efficiency if a slow pedal rate was employed. Additionally, Faria (1982) suggested that the recruitment of less economic fast-twitch muscle fibers may affect the efficiency of cycling.

2.2 Seat Height:

Saddle height or seat height is the distance from the surface of the pedal, at the bottom of the pedal stroke, to the surface of the seat. The most common measure of seat height is the symphysis pubis measurement. This measurement is taken with the person standing erect, the legs straight and approximately shoulder width apart. A measuring instrument is used to determine the distance from the symphysis pubis to the floor (Hamley et al.; 1967). This measurement is then transferred to the bicycle from the seat surface to the base of the pedal, in a straight line with the seat post and crank arm, with the pedal at the bottom of the pedal stroke.

Two studies concerning seat height are summarised in Table 6. A study by Nordeen-Snyder (1977) included 10 female subjects with little or no cycling experience with the study by Shennum & deVries (1976) having 5 subjects with experience on a racing style bicycle. In both studies cycling was performed at 60 rpm. Shennum &

deVries (1976) examined the effect of seat height on the cost of cycling using a variety of workloads and seat heights. The subjects cycled at workloads ranging from 50 to 200 watts for three minute intervals with the resistance increasing by 25 watts every 3 min until a workload of 200 watts was achieved. Seat heights ranged from 105% to 114% of symphysis pubis height.

In contrast, Nordeen-Snyder (1977) using only one workload of 130 watts had their subjects cycle for 8-9 minutes. Seat heights ranged from 102% to 112% (symphysis pubis). Each test was performed on the same day with a 10 minute rest period between tests. VO_2 ranged from 0.994 to 2.782 L/min depending on the seat height and workload. Nordeen-Snyder (1977) found the oxygen cost of cycling at 130 watts to be 1.69, 1.61. and 1.74 L/min at saddle heights of 102, 107 and 112%, respectively. It is evident that the most cost efficient position is at a seat height of 107% of symphysis pubis measurement. Shennum & deVries (1976) found similar results with the most cost efficient saddle height between 105 to 108% of symphysis pubis measurement.

These results show that there is a definite effect of seat height on the oxygen cost of cycling. At the higher seat adjustments the movement becomes very awkward with more body rocking motion which increases oxygen consumption. Also, the knee temporarily locks at the higher seat adjustments which effects the fluidity of the movement and the efficiency of the movement. At the lower seat adjustments, the leg does not extend fully which also decreases the efficiency. Variation in seat height may affect the recruitment of the different types of muscle fibers and oxygen cost of cycling.

2.3 Body Position:

Body position has also been suggested to affect the oxygen cost of outdoor bicycling. The tuck position of the cyclist can reduce the BSA of the rider which decreases the air resistance and in turn decreases the oxygen cost of cycling. However, Origenes et al. (1993) found that there was no effect on the oxygen cost of cycling when comparing low tuck racing positions to upright cycling positions on ergometers. At workloads of 100, 200, and 300 watts the oxygen cost of cycling in the aero-posture and upright posture was the same. The only differences were found in heart rate, such that cycling in the low tuck posture contributed to a lower HR, but this difference was not significant.

Begemann-Meijer & Binkhorst (1989) and Diaz et al. (1978) examined the effect of altering the structure of the stationary bicycle on the oxygen cost of cycling. The studies compared (Table 7) the oxygen cost of cycling on a recumbent ergometer and on the traditional upright cycle ergometer using 16 male subjects. The recumbent position was achieved by modification of a standard upright ergometer.

Diaz et al. (1978) had the subjects cycle for 45 minutes at two workloads on an upright ergometer and on a recumbent ergometer for a total of four, 45 minute cycling sessions. The workloads were 60 and 120 watts for the males, 60 and 90 watts for the females. Begemann-Meijer & Binkhorst (1989) used a progressive test with workloads ranging from 30 to 120W and increments of 30W. Each of the intervals was 5 minutes in duration.

Diaz et al. (1978) found VO_2 (L/min) ranged from 0.91 in the females at a workload of 60 watts to 1.90 L/min in the males at a workload of 120 watts. Begemann-

Meijer & Binkhorst (1989) found no significant differences in VO_2 values between upright and recumbent cycling. Similarly, with subjects pedalling at 60 rpm, Diaz et al. (1978) found the oxygen cost of cycling was 1.08 and 1.09 L/min for males and 0.93 and 0.91 L/min for females, in the upright and recumbent cycling positions, respectively, at a workload of 60 watts. At 120 watts Begemann-Meijer & Binkhorst (1989) found the oxygen cost of cycling in the two positions to be approximately 1.75 L/min, while at the same workload Diaz et al. (1978) found the oxygen cost of cycling in the two positions to be 1.85 L/min.

These data suggest that the differences in the oxygen cost of cycling between the upright cycling position and the recumbent cycling position at low workloads is small.

3.0 High-Tech Ergometers

With technological advancements in every industry, many changes have developed within the fitness profession. The bicycle and the cycle ergometer have evolved into more dynamic vehicles. LifeFitness has developed several models of cycle ergometers (Lifecycle), including an upright model (9100 R) and a recumbent model (9500 RHR).

The resistance of the electric ergometer is established via a magnetic field. A solid armature is connected to the pedals through a gearing system and rotates in the magnetic field to create resistance. This system is called an eddy current brake system. Two variables control the current in the field coils of the eddy brake: 1) the tachometer, which generates electrical pulse feedback from the armature shaft when the pedal rate varies, and 2) the voltage of the load selector. These two variables maintain a constant work rate if pedal rate varies. Resistance is increased with a stronger current through the coils of the eddy current brake. A stronger current applies more drag to the armature, which is connected to the pedals, therefore making it harder to pedal. The relationship between the drag force and pedal rate is inverse, therefore, as pedal rate decreases, the drag force increases. The workload set by the load selector also remains constant at any given setting (Clark & Greenleaf, 1971).

The digital display of the Lifecycle ergometer gives the user a choice of 6 programs. Only the manual program will be examined in this study. The display takes the user through a number of steps which prompts the rider to select a level at which to ride. The manual program contains a range of levels from 0-12, with 0 being the least difficult and 12 being the most difficult in terms of resistance. The digital displays of the Lifecycle ergometers provides feedback as energy (kcal and kcal/hour), distance (miles) and velocity (rpm). Energy expenditure is converted to oxygen consumption using the following formula:

5 kcal of energy = 1 L of oxygen

Table 8 shows the Caloric expenditure and VO_2 as displayed by the computer panel for two models of Lifecycle ergometers. The table shows that power output for the upright 9100 Lifecycle ergometer and recumbent 9500 RHR Lifecycle ergometer are the same at each level. Conversion of the power output (watts) into work (kgm) allows for the elaboration of a workload - VO_2 plot using estimated VO_2 from the caloric expenditure and the work output provided. The relationship is illustrated in Figure 2 and is expressed as $Y = 0.002X + 0.300$, where Y = predicted VO_2 (L/min), X = the workload in kpm, and the resting metabolic rate = 0.300(see Figure 2).

The Lifecycle equation to predict oxygen cost or energy expenditure is the same as the ACSM prediction formula for friction type resistive ergometers. However, experimental evidence suggests that the oxygen cost of cycling on an electrically braked ergometer is different from cycling on a Monark ergometer or friction braked ergometer (Wilmore et al.; 1982).

Table 1. Oxygen cost of cycling.

Authors	Subjects	Surface	Wind Speed	Speed (km/h)	VO_2 (L/min)	Vo_2/Speed (ml/km)	Comments
McCole et al (1990)	28 comp	straight flat track	not listed	32	2.59	4842	rider maintained aero-posture
				37	3.59	5820	
				40	4.03	6048	
Richardson & Johnson (1994)	11 elite male	flat course	3-6.5 km/h	40	4.34	6510	Normal handlebars tuck position
Capelli et al. (1993)	2 amateur	flat course	calm	20	0.75	2250	rode in Velodome (Italy)
				40	3.51	5268	racing posture
Sheel et al. (1996)	6 male 5 female	400m asphalt track	calm	30	1.32	2640	drop-bars racing position
Swain et al. (1987)	10 male	straight flat track	light	16	1.18	4428	Racing position
				25	1.91	4584	Hands on drop bars
				32	2.97	5568	

Table 2. Oxygen cost of cycling on an ergometer at 60 RPM.

Authors	Subjects	Ergometer	Workload (Watts)	VO_2 (L/min)	VO_2/Watt (ml/min×W)
Croisant et al. (1984)	9 male rec & comp cyc 24 yrs, 76 kg, 179 cm	Monark	0	0.64	
			250	3.43	13.7
Sidossis et al. (1992)	15 male trained cyc 24 yrs, 71 kg	Monark	0	0.66	
			175	2.50	14.3
Widrick et al. (1992)	12 male rec 24 yrs, 79 kg, 184 cm	Monark (818E)	100	1.59	15.9
			145	2.09	14.4
Shennum & deVries (1976)	5 cyc 17 yrs, 74 kg, 178 cm	Collins Cycle ergometer	100	1.47	14.7
			150	2.00	13.3
			175	2.35	13.4
Luhtanen et al. (1987)	5 male active 30 yrs, 74 kg, 182 cm	Monark mech braked	145	2.20	15.2
			250	3.73	14.9
Coast et al. (1986)	5 male 26 yrs, 73 kg	Monark adapted race	150	2.25	15.0
Wilmore et al. (1982)	10 male	fab belt on fly-wheel	50	0.97	19.4
			100	1.45	14.5
			150	2.04	13.6
		disc braked	50	0.84	16.8
			100	1.26	12.6
			150	1.78	11.9
		elec braked	50	1.03	20.6
			100	1.47	14.7
			150	2.00	13.3
		Pony/braked system	50	0.92	18.4
			100	1.42	14.2
			150	2.01	13.4

KEY:

cyc - cyclist
mech br - mechanically braked
comp - competitive cyclist
rec - recreational cyclist

Table 3. Equations to predict VO_2 on a cycle ergometer.

Authors	Subjects	Equation
Heyward (1991)	N/A	ACSM VO_2 (ml/min) = 2 x workload (kpm) + RMR (ml/min)
Storer et al. (1990)	sedentary 20-70 yrs	male VO_2 (ml/min) = 10.51(W) + 6.35(kg) - 10.49(yrs) + 519.3 female VO_2 (ml/min) = 9.39(W) + 7.71(kg) - 5.88(yrs) + 136.0
Fairbarn et al. (1994)	sedentary 20-80 yrs	male VO_2 (L/min) = 0.3055 + 0.0021workload(kpm) female VO_2 (L/min) = 0.2579 + 0.0021workload (kpm)
Siconolfi et al. (1982)	20-70 yrs	male VO_2 (L/min) = 0.348(X_1)-0.035(X_2) + 3.011 X_1 = VO_2(L/min) Astrand Nomogram female VO_2 (L/min) = 0.302(X_1) - 0.019(X_2)+1.593 X_2 = age in yrs
Jones et al. (1985)	Non-athletes	VO_2 (L/min) = 0.19(W) + 0.288

Table 4. Effect of pedalling velocity on efficiency of cycling.

Author	Subjects	Ergometer	Power (watts)	Most Efficient RPM
Seabury et al. (1977)	3 male recreational, 20 yrs, 75 kg, 182 cm	Monark	0 80 160 245 325	40 44 55 61 62
Widrick et al. (1992)	12 male recreational, 24 yrs, 79.3 kg	Monark (818E)	50 100 150	40 40 60
Coast et al. (1986)	5 cyclists, 25 yrs, 73 kg	Monark	375	60-80
Coast & Welch (1985)	5 male, 28 yrs, 73 kg	Monark	100 150 200 250 300	45 60 65 70 75
Boning et al. (1984)	9 trained, 18 yrs, 72 kg, 182 cm, 6 untrained, 22 yrs, 81 kg, 186 cm	Jaeger Ergotest	50 200	40 70
Sidossis et al. (1992)	15 cyclists	Monark	175 210 240 275 300	60 60 60 60 60

Table 5. Oxygen cost (L/min) of cycling on an ergometer.

				Velocity (rpm)				
Author	Subjects	Bike	Power(W)	20	40	60	80	100
Gaeser et al. (1975)	12 male	electric braked	0		0.44	0.45	0.58	0.93
Sidossis et al. (1992)	15 cyclists	Monark 819	0			0.66	0.77	1.04
Croisant et al. (1984)	9 male	Monark	0	0.48	0.53	0.64	0.85	1.34
			40	1.04	0.94			
			60	1.32		1.20		
			100					2.06
			200					3.20
			250			3.43		
Nordeen-Snyder (1977)	10 female	Belt resistance	130			1.61		
Widrick et al. (1992)	12 male	Monark 818E	100		1.53	1.59	1.65	1.85
			145		2.18	20.9	2.19	2.30
Miyashita & Kanehisa (1980)	9 male	Monark	60		1.03			1.52
			150		2.09			2.49
Luhtanen et al. (1987)	5 male	Monark	145			2.20		
			225			3.32		
			250			3.73		
Shennum & deVries (1976)	5 cyclists	Collins	100			1.47		
			200			2.71		
Sidossis et al. (1992)	15 cyclists	Monark 819	175			2.50	2.56	2.74
			300			4.10	4.16	4.22
Coast et al. (1986)	5 male	Monark	150			2.25		

Table 6. Effects of seat height on the oxygen cost (L/min) of cycling.

Author	Subjects	Bike	Workload (Watts)	Symphysis Pubis (%)	VO_2 (L/min)
Nordeen-Snyder (1977)	10 male, 18-31 yrs	Modified cycle ergometer	130	102	1.69
				107*	1.61
				112	1.74
Shennum & deVries (1976)	5 subjects, 16-18 yrs, cyclists	Collins	50	105	1.00
				108*	0.99
				111	1.06
				114	1.07
			100	105*	1.40
				108	1.47
				111	1.43
				114	1.46
			150	105*	1.97
				108	2.00
				111	2.05
				114	2.05
			200	105*	2.68
				108	2.71
				111	2.78
				114	2.76

* Optimal symphysis pubis measure (expressed as a percentage)

Table 7. Effects of body position on the oxygen cost (L/min) of cycling.

			Power (W)			
Authors	**Subjects**	**Position**	**60**	**90**	**120**	**Comments**
Begemann-Meijer & Binkhorst (1989)	9 male, 29 yrs, 69 kg, 180 cm	upright	1.20	1.50	1.75	Modified electrically braked ergometer
		recumbent	1.20	1.50	1.75	
Diaz et al. (1978)	7 male, 29 yrs, 74 kg	upright	1.08		1.90	Type of ergometer not stated
		recumbent	1.09		1.80	
	5 female, 29 yrs, 59 kg	upright	0.93	1.29		
		recumbent	0.91	1.26		

Table 8: VO_2 (L/min) for upright and recumbent Lifecycle ergometers.

Level	VO_2 (L/min)	Energy Expenditure (Kcal/hr)	
		Upright 9100	Recumbent 9500 RHR
0	0.84	252	252
1	0.96	288	288
2	1.32	397	397
3	1.94	583	583
4	2.25	674	674
5	2.54	761	761
6	2.83	849	849
7	3.13	940	940
8	3.48	1044	1044
9	3.70	1110	1110
10	4.12	1235	1235
11	4.38	1315	1315
12	4.53	1359	1359

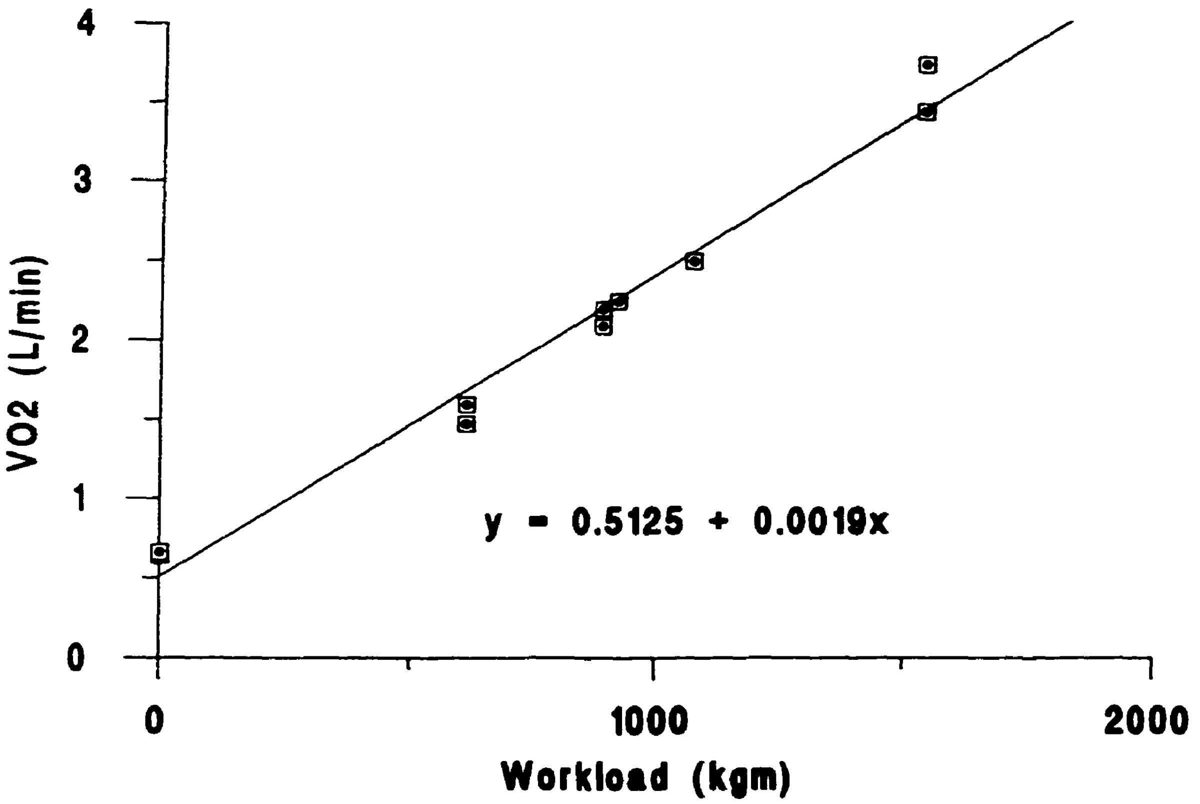

Figure 1. The oxygen cost of cycling at 60 RPM (cycle ergometer).

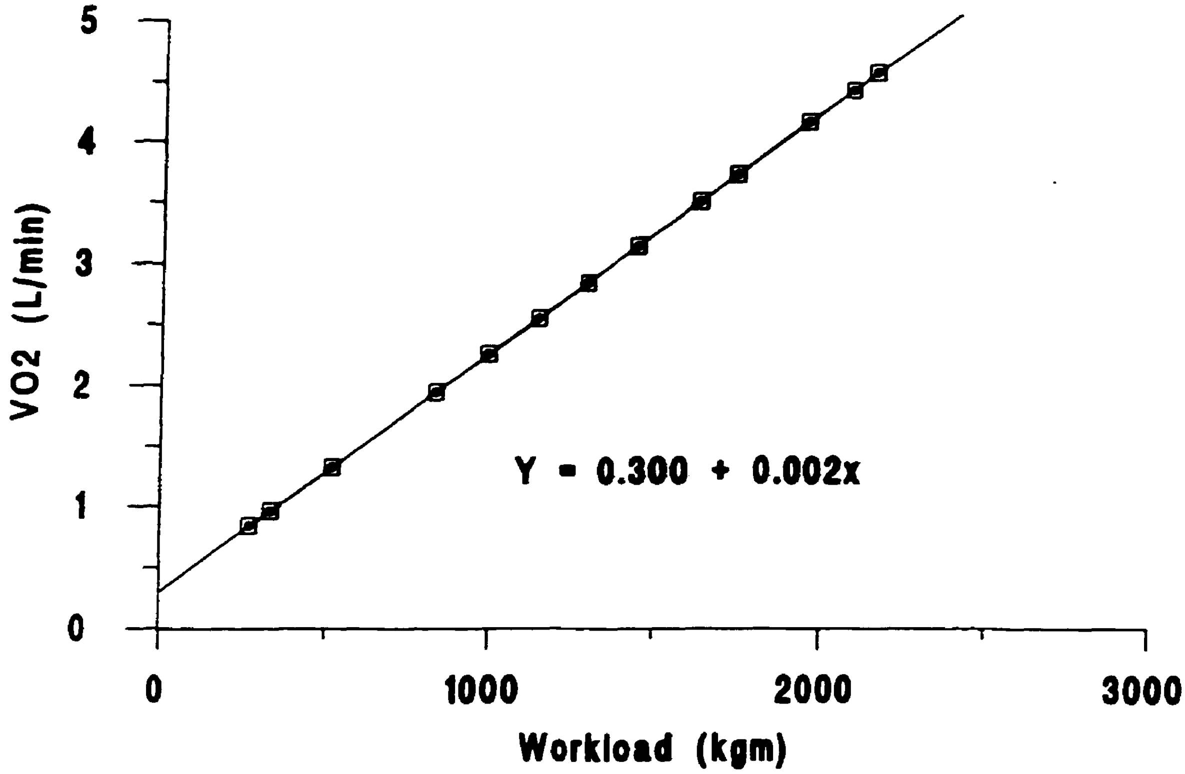

Figure 2. The estimated oxygen cost of cycling on the upright (9100R) and recumbent (9500 RHR) Lifecycle ergometers.

Appendix 2 - References

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CONSENT FORM

Project Title: Comparison in Energy Requirements Between Cycling Position and Type of Ergometer: Lifecycle™ vs. Monark

Name of Subject:_____________________

Date of Testing:_____________________

I, ________________, agree to participate in this study, as explained by _____________________. This research project is under the direction of Helene Perrault, Ph.D., Associate Professor in Exercise Physiology and Co-Director of Seagram's Sport Science Center at McGill University and David Montgomery, Ph.D., Professor in Exercise Physiology and Co-Director of the Seagram's Sport Science Center at McGill University in Montreal, Quebec, Canada.

DESCRIPTION OF THE STUDY:

With the growing concems for health and wellness there has been a vast development in fitness equipment. Lifefitness has become one of the leaders in the development of new computer age fitness equipment. One line of equipment that Lifefitness is most noted for is cycle ergometers. These ergometers are best recognized through their digital display panel, which provides feedback to the rider, and the self adjusting electrical resistance to maintain a consistent power output at different pedal rates. This study concentrates on two of these ergometers, the Lifecycle™ 9100 upright Aerobic Trainer and the Lifecycle 9500 RHR Recumbent ergometer.

The feedback provided by the computer display panel shows the rider the distance cycled in miles, the predicted calories expended per hour, the total calories expended per exercise bout, and the pedal rate at which the rider is cycling. As noted the calories expended per hour are a prediction. This prediction is established through a prediction equation inherent to the computer program of each of the Lifecycle™ ergometers. It has been found that the prediction equation for each of the Lifecycle™ ergometers is the same. Not only is it the same for each Lifecycle™ ergometer, but it is the same equation that was developed through data collected on friction type ergometers, such as the Monark.

This project will examine the oxygen cost of cycling on the Lifecycle™ 9100 Aerobic Trainer, Lifecycle™ 9500 RHR recumbent and Monark. Comparing the oxygen cost of cycling between these ergometers will identify if it is valid to use a prediction equation for one type ergometer on another ergometer of a different type of resistance, as well, it will identify if it is valid to use this same prediction equation when cycling in two different positions, the traditional upright position and recumbent position. Thirdly it will give an indication of how accurate the calories expended per hour feedback are on the two Lifecycles. Additionally, the effect of seat adjustment on oxygen cost will be examined. Oxygen cost will be recorded using the Sensor Medics 2900 metabolic cart.

Heart rate will be monitored using the Vantage XL Polar HR monitor. The Metabolic cart collects all the expired air of the subject through a mouth piece attached to a turbine and hose system. At the same time the subjects nose is pinched close with a nose clip. Heart rate will be transferred directly to the computer printout via an electrical pulse picked up by the sensor strap of the XL heart rate monitor. The sensor strap needs to be attached firmly around the subjects trunk just below the chest and in contact with the skin.

Total duration of the test will be approximately 3 hours broken down into 3 one hour visits separated by at least 24 hours. Measurements will be recorded every 20 seconds under the following conditions: (all workloads are submaximal)

Protocol 1: Performed on Lifecycle™ 9100, 9500 & Monark

a. Resting seated for 5 minutes
b. 5 minutes cycling at workload 1
c. 5 minutes cycling at workload 2
d. 5 minutes cycling at workload 3
e. 5 minutes active recovery, no measurements recorded

Protocol 2: Performed on Lifecycle™ 9100 & 9500 (seat Adjustment)

a. Resting seated for 5 minutes
b. +1 seat adjustment
    i) 5 minutes cycling at workload 1
    ii) 5 minutes cycling at workload 2
    iii) 5 minutes active recovery, no measurements recorded
c. -1 seat adjustment
    i) 5 minutes cycling at workload 1
    ii) 5 minutes cycling at workload 2
    iii) 5 minutes active recovery, no measurements recorded

RISKS AND BENEFITS:

1. **Risks:** The subjects may experience some discomfort from being attached to the metabolic cart. With the mouth piece entirely in the mouth it is hard to swallow and the throat may become dry. Additionally, being attached to the cart may cause some subjects to feel short of breath or claustrophobic. The experimenter will constantly monitor the actions of the subject as well as question how they are feeling. If any problems occur the test will be terminated.

2. **Benefits:** The subject will receive a predicted VO_2 max value which will give them an indication of their fitness level.

COST AND PAYMENT:

There is no cost, nor is there any payment associated with participation in this study.

CONFIDENTIALITY:

I understand that all personal information obtained during the testing procedures will remain strictly confidential. The results of all subjects will be pooled so that only the overall results will be used if presentation in scientific seminars or publication of this study occurs.

THE RIGHT TO WITHDRAW OR REFUSE:

I understand that the participation in this study is purely voluntary, and that I am free to withdraw at any time and that no reason need be provided. A refusal to participate will not result in any penalty or loss of privileges.

VOLUNTARY CONSENT:

I have read this form, I have asked questions for which I have received satisfactory answers, and I consent to participate in this study. I understand that Dr. Helene Perrault and Dr. David Montgomery are principle investigators of this study and will be available to answer any of my questions in regard to this project.

At the signature of this consent form I will receive a copy.

Participant **Date**

Witness **Date**

Investigator **Date**

Responsible for this study are:

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