Effect of short crank use on delta efficiency in recumbent cycling

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ABSTRACT

The purpose of this study was to determine the effect bicycle crank length has on delta efficiency in recumbent vehicles with high bottom brackets. Crank lengths of 170mm, 140mm and 115mm were used in this study. Focus was placed on cranks that are shorter than the typical 170mm cranks. Cranks shorter than 170mm tend to allow a higher cadence which is preferred by many experienced riders. Shorter cranks also allow for a more aerodynamic vehicle profile and may offer improved knee and hip movement over longer crank arms. For this study a volunteer group of 12 males and 9 females n = 21, [mean (SD)] age [27.5 (14.6)], and xseam [102.8 cm (5.6 cm)] were selected to ride on a recumbent cycling ergometer with a typical hip angle of approximately 11°. To determine delta efficiency (DE), cycling power and metabolic power output was measured for each subject at 3 power levels for each of the three cranks being tested. The mean DE for the 115mm, 140mm and 170mm cranks was 0.30±0.067%, 0.32±0.081% and 0.31±0.084% respectively. It was found that there is no statistically significant effect of crank length on DE at the α =.05 level of significance (p = 0.37) for the crank lengths tested. For this reason the length of crank used by recumbent riders should be chosen based on factors other than an effect on DE.

INTRODUCTION

The length of crank used on recumbent vehicles as it relates to delta efficiency (DE) has not yet been addressed in the literature. Cyclists have given special interest to crank lengths that are shorter than conventional cranks because they may offer distinct advantages to recumbent vehicles. Substantial anecdotal evidence provided through testimonies in bike forums and periodicals speaks on behalf of shorter crank use in recumbent vehicles. Some experienced cyclists including the authors prefer shorter cranks in recumbent bicycles but there are not yet data to indicate what affect crank length has on DE. This study investigates the effect of crank length on DE in recumbent cycles with high bottom brackets.

An advantage recumbent cycles offer over upright bicycles is the more aerodynamic profile (Gross, Kyle, & Malewicki, 1983). Recumbent bike manufacturer Ian Sims noted that shorter crank arm in a faired recumbent would allow for a lower fairing, thus giving the vehicle a lower profile and improved aerodynamics (Burrows & Sims, 2004). Another benefit of shorter cranks is the smaller change in joint angle required of the legs and foot joints to pedal. Some individuals with knee problems have reported that the movement of smaller cranks makes pedaling more enjoyable because of decreased stress on the knees. Longer crank arms increase forces on tendons in the knee which can cause knee pain and injury (Asplund & Pierre, 2004). The angle of the knees, hips and ankles while pedaling is determined by the crank size and seat position in relation to the bottom bracket (Too & Landwer, 2004). With smaller cranks the legs move the pedals throughout a smaller circle. A larger crank means that the muscles in the legs exert a force on the joints throughout a larger angle for each pedaling cycle and the knees must bend to a lesser angle (Too & Landwer, 2000). However the benefits of shorter cranks concerning aerodynamics and knee stress will not be evaluated in this study.

Table 1. ANOVA analysis of variance

Source	Sum Sq.	d.f.	Mean Sq.	F	Prob>F
ID	0.15237	20	0.00762	1.76	0.0352
LEN	0.00869	2	0.00435	1.01	0.3691
CAD	0.01483	1	0.01483	3.44	0.0668
LEN*CAD	0.01798	2	0.00899	2.08	0.13
ERROR	0.43169	100	0.00432		
TOTAL	0.74262	125			

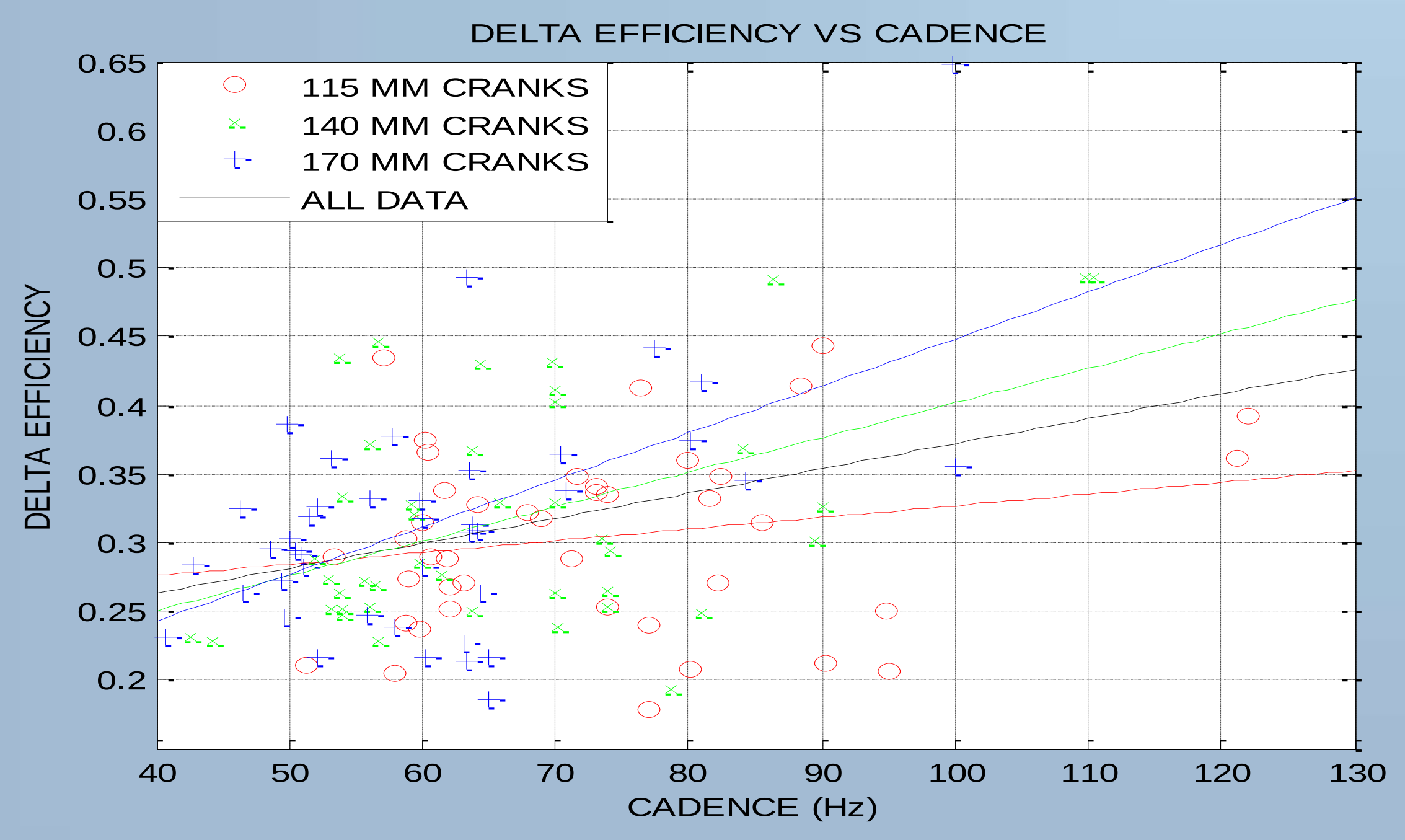

Figure 1. Delta Efficiency vs. Cadence

MATERIALS AND METHODS

A volunteer group of 12 males and 9 females n = 21, [mean (SD)] age [27.5 (14.6)], and xseam [102.8 cm (5.6 cm)] were selected to participate in the study. The subjects were intentionally selected to provide a diverse range of age, fitness level, and cycling experience. Subject xseam was measured by having an individual sit on a bench lengthwise with their legs extended flat on the bench and their back resting against the back of the chair 60 degrees from vertical. The distance from the bottom of the back of the bench to the ball of their foot with their toes pointed vertically was measured. Subject cycling experience was self rated on a scale of 1, 2, or 3 corresponding to seldom, weekly or daily bicycle riding.

Subjects were tested on a custom made high bottom bracket recumbent ergometer with a free motion flywheel that has inertia of 97×10^3 kg s^2 / m^3. Figure 2 shows the ergometer used for this study. The typical hip angle for the ergometer is 11°, the body orientation angle is typically around 140° and the seat back is at an angle of 30° from horizontal. The velocity ratio between the flywheel and sprocket is 2.75. The ergometer power is determined by measuring the flywheel speed and torque. Torque is measured with force transducers (get spec) installed on both the tension and slack sides of the belt. Speed is measured with a magnetic reed switch. The ergometer power is given by:

$$\mathbf{P = (F_{tension} - F_{slack}) \times R \times 2\pi\omega}$$

Both force transducers and the magnetic reed switch were sampled and digitized with an E-DAQ Lite data acquisitions system from Somat, Inc. Sample rate for the force transducers is 20 Hz, and the magnetic reed switch is decimated to 20 Hz.

Fine control of belt tension, and hence ergometer load, is achieved with a hand knob and lever mechanism. The power level is controlled by adjusting the tension on the flywheel belt while viewing a computed power reading. The respiratory exchange ratio (RER), breathing rate, heart rate, VO2 and VCO2 were collected continuously throughout the test using a VO2000 VO2 testing system. Data points were recorded every several breaths depending on the rate of respiration. Metabolic data is calculated from the data acquired by the VO2000 and cycling power output is calculated using data acquired from the ergometer.

All volunteers received an overview of the procedure prior to their participation. Subjects were then asked to wear a heart rate monitor, breathing mask and cycling shoes. Before the test the seat position was set according to the xseam of the individual and the crank to be tested. The seat position was changed with each crank length to ensure a constant distance between the seat and pedal in the farthest position from the rider. This ensures a constant maximum leg angle for each set of cranks tested. All participants used cycling shoes and clipless pedals.

For each crank length the subject self selected a cadence chosen while pedaling at the medium power level before the test began. Subjects were told to pedal at a comfortable pace while the power is gradually increased. They are asked to maintain their chosen cadence for each of the three power levels while using a given crank. A metronome set to the subject's preferred cadence and a digital readout tachometer was provided to help subjects maintain cadence. Cadence was reselected by the subject when the cranks were changed. Subjects were allowed to select a cadence of their choosing but were informed that most people prefer a higher cadence for shorter cranks and a lower cadence for longer cranks. The actual cadence maintained by the subject is measured during the test and later compared to the target cadence.

Subjects were tested using 115mm, 140mm and 170mm long cranks given in randomized order. For each crank a given subject maintained the same 3 power levels given in increasing order. The three ergometer power levels were chosen 30 watts apart based on the subject's age, gender and fitness level. Subjects were tested at one of the following sets of three power levels: {30W 60W and 90W}, {45W 75W and 105W}, {60W 90W and 120W}, {80W 110W and 140W} or {90W 120W and 150W}. Each power level was maintained for 5 minutes total; 3 minutes for the subject to establish equilibrium in bodily systems as measured by respiration and heart rate and 2 minutes of data collection at a constant respiration and heart rate. After the 2 minutes of data collection at the third power level the power is decreased to a minimum amount and the subject is given a brief cool down period. Succeeding the test for each crank length subjects are given a ten minute rest, offered a snack and asked to rate their perceived level of exertion on a scale of 1 to 10 for the crank length just tested.

Prior to the procedure described above (Phase B) a similar testing protocol (Phase A) was used with a different group of 13 subjects. For phase A data was collected for 5 min instead of 2 minutes and two cranks instead of three were tested. The data collection time period was decreased to 2 minutes for phase B after it was observed shortening the data collection to 2 minutes did not change the variability or mean of the data. The conclusions of this study are drawn from Phase B. Phase A serves in confirming the results of phase B.

Calculations:

Metabolic power is calculated from the patients RER and VO2 using the following formula:

Power = VO2 * function (RER)

Function (RER) is a value directly dependent on RER that relates the energy produced per liter oxygen consumed to RER. RER is calculated from the ratio of VO2 over VCO2. Power is then converted from cal/min to watts using the following constant:

4.1868 cal/joule * 1min/60seconds = 0.06978

DE is then calculated as the ratio of the change of power output over the change in metabolic power generated. An ANOVA test was used to analyze the data.

RESULTS

This study found no significant difference in delta efficiency between any of the three crank lengths. The mean DE of the 115mm, 140mm and 170mm cranks was 0.30±0.067%, 0.32±0.081% and 0.31±0.084% respectively. It was found that for the lengths of cranks tested there was no statistically significant effect of crank length on DE at the α =.05 level of significance (p = 0.37). Table 1 shows the full results of the ANOVA test. The results of both phase A and B of our study support this result. There was a significant effect on DE due to the subject at the α =.05 level of significance (p = .03). This means that DE varied more based on the subject being tested rather than the crank length being used.

Without considering subject in the ANOVA analysis, there is an effect due to cadence. This effect differs depending on the crank length. Figure 1 shows that the 115mm cranks have a significantly smaller slope than other cranks (p =.02), the 140 mm and 170 mm cranks have increasing slope but are not significantly different from the overall slope (p =.67 and p = .07 respectively). This effect is most likely due to the experienced cyclists (who have a higher delta efficiency due to conditioning) self selected higher cadences. Experienced cyclists did tend to choose higher cadences as documented by an average 9.4 rpm different in cadence between experience levels.

DISCUSSION

The primary finding of this study was that the crank length used on a recumbent bicycle with a high bottom bracket has no observed effect on DE. There is a limited amount of literature that closely applies to the results of this study. J McDaniel and his colleges did a study on an upright ergometer and found that DE increased with increased crank length. However they determined that the result could be attributed more to pedal speed than to crank length. They determined that crank length did not have a large affect on the metabolic cost of cycling.

The variability in the data can be most attributed to the subjects being tested. DE varied most between subjects rather than changes in crank length or other factors. The variability between subjects can be attributed to the diversity of subject age, gender and fitness level.

Subjects' unfamiliarity with the ergometer and respiration mask may contribute to the rather high variability in recorded values of delta efficiency. Five subjects clearly exhibited anomalous values for the initial test. Although the second and third tests for these subjects appear normal, the subjects were not included in the results. In future studies, subjects should be given more familiarization time with the ergometer.

Metabolic and ergometer data are recorded on two independent systems. The test data was synchronized manually after the test. This is a potential source of uncertainty in the data. In phase A we observed there was no difference in the mean or variability of the data if the test had been 2 minutes long instead 5 minutes. For phase B of this study we shortened the data collection to 2 minutes. However because phase B had 2 rather than 5 minutes of data it became more important to accurately match the metabolic and ergometer data. Because phase B has less data the possible error created by manually matching the metabolic data with ergometer data became more significant.

Future studies should be conducted using cranks both shorter than 115mm and longer than 170mm to study the effect for a wider range of crank lengths. It also may be beneficial to conduct a similar study on subjects that are more alike in age, gender and fitness level for example; a group of well trained male cyclists who are close in age. Data variability due to the subject may decrease if the subjects are more similar to one another. If there is an effect on DE due to crank length these test alterations may show it.

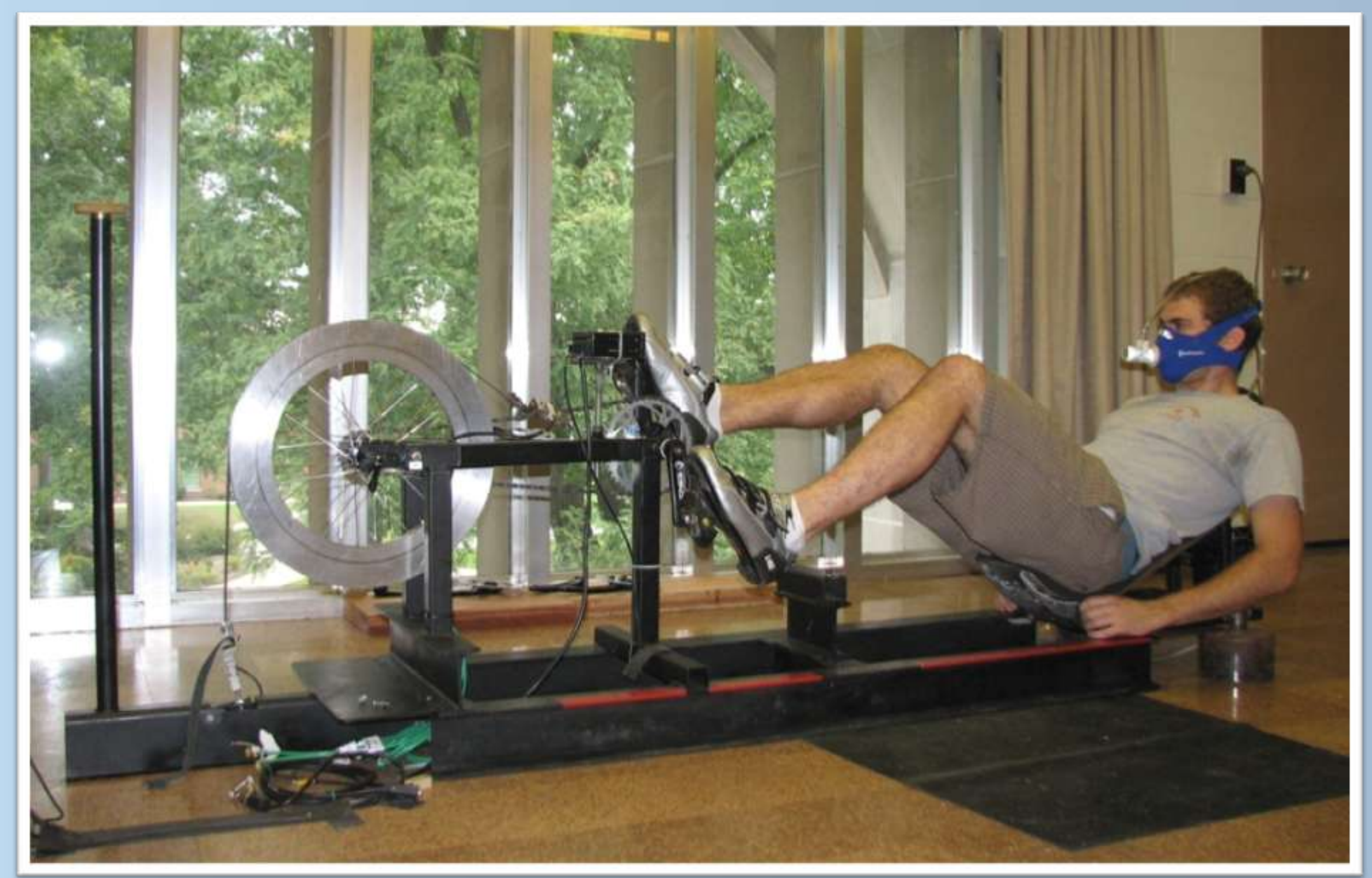

Figure 2. Ergometer with free motion flywheel

CONCLUSIONS

Crank arm length has no observed or statistically significant effect on DE for the lengths of cranks tested for recumbent vehicles with high bottom brackets. This study also indicated that there was no effect on DE due to subject age, subject x-seam, and power level.

Shorter cranks may be preferred by some riders due to some advantages over longer cranks. As mention previously, shorter cranks allow for a tighter fairing which decreases vehicle profile subsequently aerodynamic drag. If shorter cranks became widely used, velomobiles could be designed more aerodynamically. Shorter cranks may also reduce the stress of riding on the knees. Also some riders tend to prefer the higher cadences necessary when shorter cranks are used. Based on the results in this study, recumbent riders may choose their crank length without taking a DE penalty.

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