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David R. Bassett Jr., Major Professor

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MEASUREMENT OF EXTERNAL POWER OUTPUT ON THE MONARK 864 WEIGHT ERGOMETER

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Dianne Lee Stephens

December 1990

DEDICATION

To David
My husband & best friend

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Always my sincere appreciation to my husband David. His contributions in seeing this project to its completion are many and without his sacrafice, patience and true concern for my academic goals this degree would not have been possible. I feel truly blessed to be sharing my life with him.

Finally, but not lastly, and in fact above all, I thank my Lord for His steadfast love, direction and many blessings.

ABSTRACT

The Monark model 864 cycle ergometer is widely used for laboratory measurements of power output. The resistance is provided by a weight pan attached to a frictional belt that surrounds the flywheel. It has routinely been assumed that the frictional force between the flywheel and belt (f) is equal to the weight of the pan (F_{weight}). To test this assumption, two load cells were placed in series with the frictional belt, and a direct measurement of f was obtained by subtracting the force recordings. The measurement of f was obtained at various pan weights with pedal cadences ranging from 25-175 rpm. The corrected values for power output were 12-14% lower than the assumed values ($P<.05$). The corrected values for oxygen uptake (VO_2) measurements were 7 and 14% lower for 900 and 1500 kpm/min, respectively.

Since the Monark 864 is the most commonly used ergometer for performing a Wingate Anaerobic Test (WAT) the proposed method was used to correct the power output values for Wingate tests. Significant differences were found ($P<.05$) between corrected and uncorrected power output values at all six 5-s time intervals. Application of the correction factor yielded a 7.6% lower peak power and a 9.8% lower mean power. The corrected fatigue index value was 6% greater than the uncorrected value.

KEY WORDS: cycle, work, Wingate anaerobic test, anaerobic, flywheel, oxygen uptake

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CHAPTER I

INTRODUCTION

Stationary cycle ergometers have been in use for over half a century. They provide a means of measuring external power output, and are widely used in exercise physiology studies dealing with cycling efficiency (4,6,8,12), submaximal prediction of aerobic power (1,15,17), and anaerobic power (2,7,13,16). Early cycle ergometers were usually constructed from modified bicycles (7). A strap passing over the bicycle wheel was connected to a spring scale at the fixed end and to a weight pan at the other end (Figure 1). The frictional force between the rotating wheel and the stationary strap ($\boldsymbol{f}$) is calculated by the following formula:

$$\boldsymbol{f} = F_1 - F_2 \tag{1}$$

where F_1 equals the force exerted by the weights and F_2 equals the residual force measured on the spring scale. External power output is then calculated from the formula:

$$\text{Power (kpm/min)} = \boldsymbol{f}\ \text{(kp)} \times V\ \text{(m/min)} \tag{2}$$

where V is the velocity of a point on the outer perimeter of the flywheel.

Pendulum-style ergometers work on a similar principal. The two ends of the frictional belt exert torques in opposite directions on

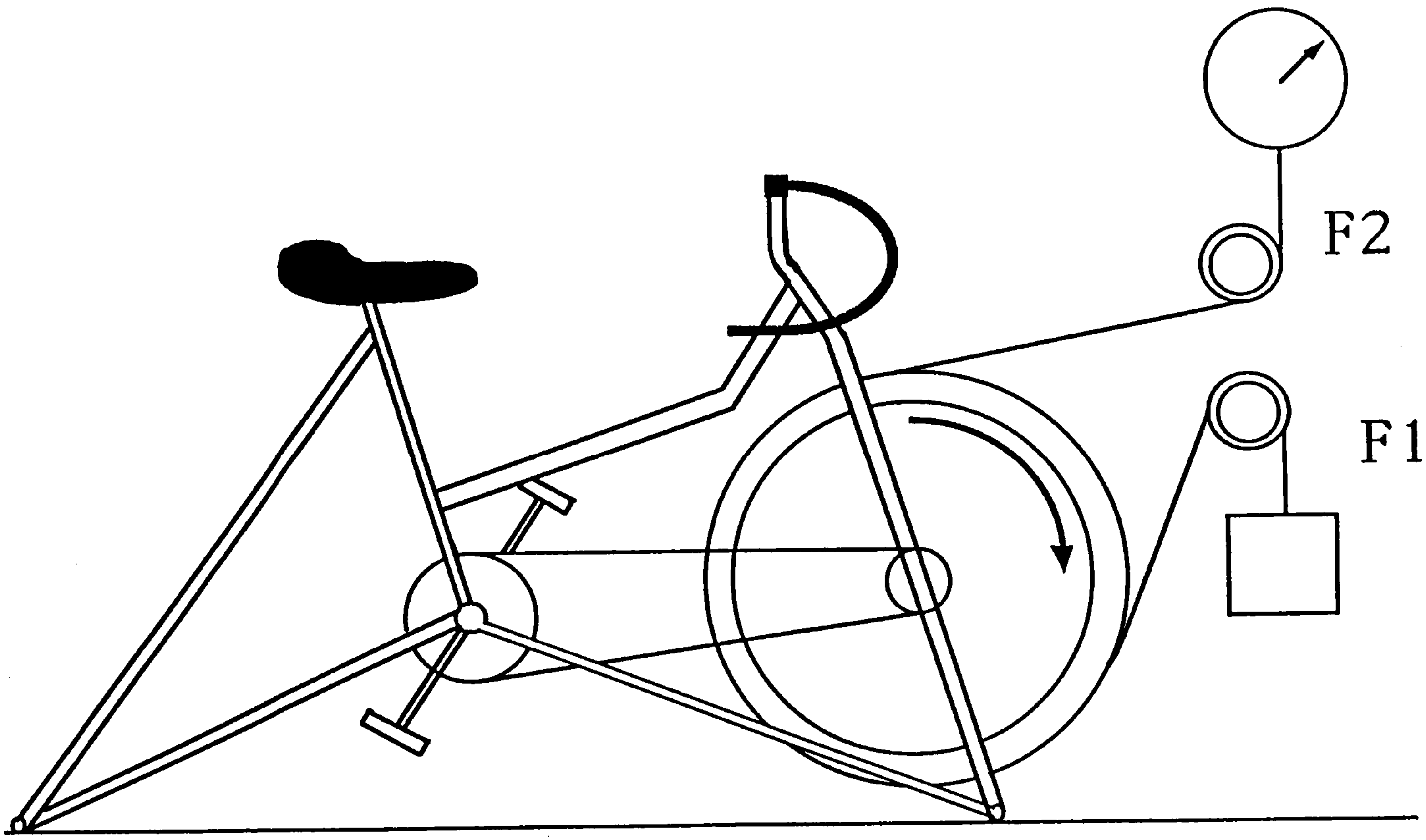

Figure 1. Early Cycle Ergometer

a pendulum arm, which is calibrated to reflect the difference between F_1 and F_2 (Figure 2). Thus, power outputs can be calculated directly from equation 2. These type of ergometers are commonly used in situations where an accurate assessment of steady state power output is needed. Pedal RPM must be held constant in order for both the frictional force ($\mathcal{f}$) and the velocity (V) to remain unchanged.

Weight-loaded cycle ergometers (eg. Monark 864) are primarily used for tests of anaerobic power. One of the advantages of weight-loaded ergometers over conventional friction-type ergometers is that they can be "instantly loaded". This is accomplished by releasing a weight pan attached to the frictional belt (Figure 3). It is assumed that the frictional force ($\mathcal{f}$) is equal to the gravitational force of the weights (F_{weight}), and is therefore independent of changes in flywheel velocity. This assumption allows a simple method of calculating external work and power in situations where flywheel velocity is changing rapidly (eg. the Wingate anaerobic test):

$$\text{Power (kpm/min)} = F_{weight}\ (\text{kp}) \times V\ (\text{m/min}) \tag{3}$$

However, after analyzing the torques exerted on the split-pulley by both ends of the flywheel belt, we questioned the validity of this formula since the pulley radii are two different sizes.

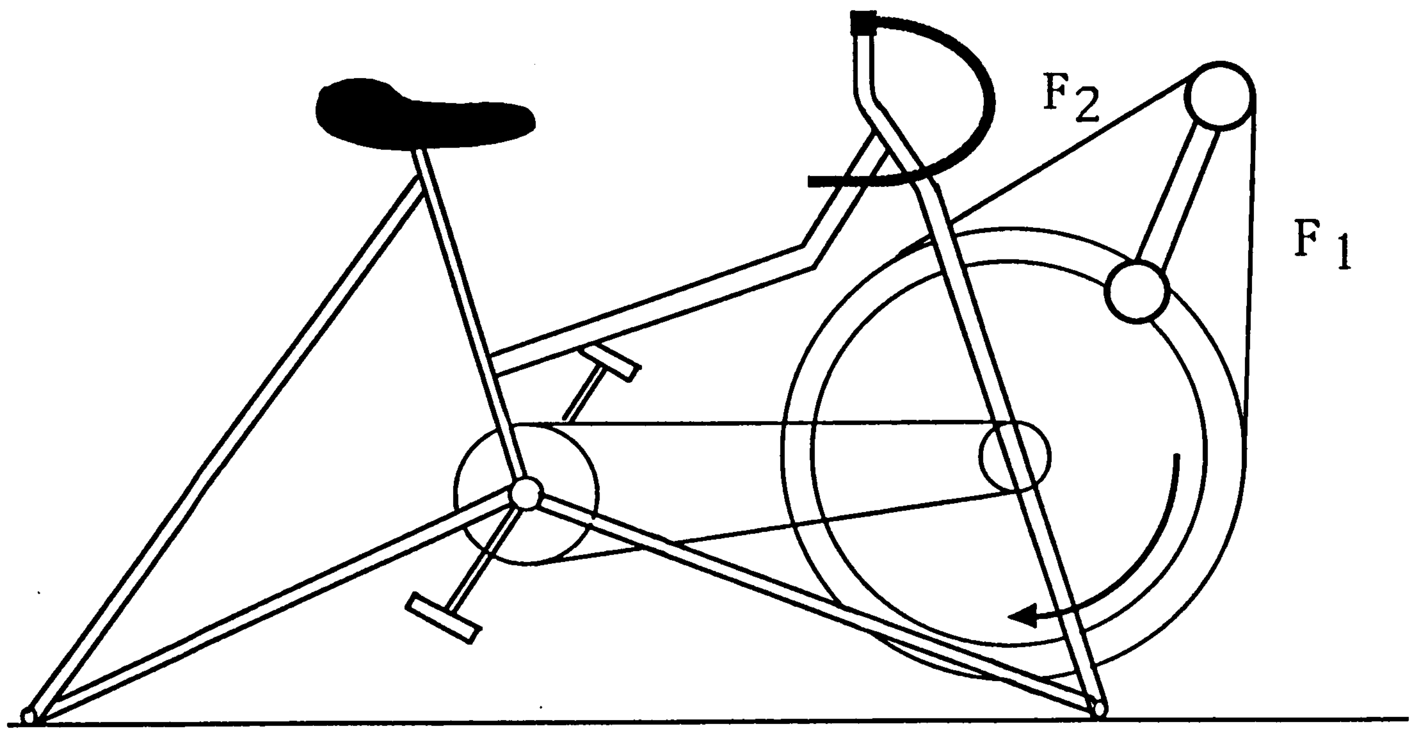

Figure 2. Pendulum-style Ergometer

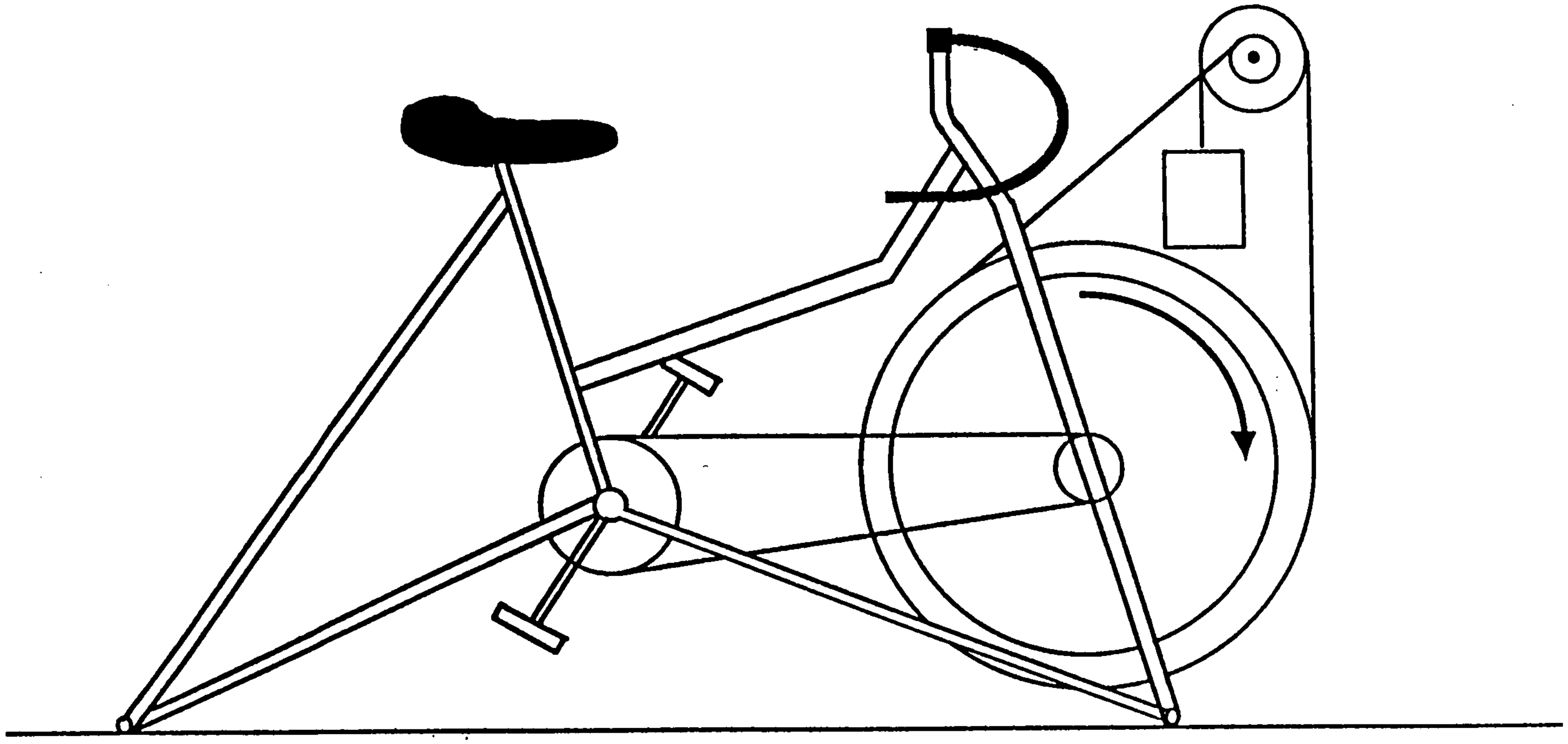

Figure 3. Weight-loaded Ergometer

The present study was designed to examine the accuracy of the Monark 864 ergometer by determining if f is equal to F_{weight}. To accomplish this two load cells were placed at opposite ends of the frictional belt surrounding the flywheel, permitting measurement of f. The accuracy of the Monark 864 was further examined by comparing oxygen uptake (VO_2) responses for the 864 cycle vs. those obtained on the pendulum-style ergometer.

CHAPTER II

METHODS

I. SELECTION OF SUBJECTS

Subjects:

Nine active males volunteered to serve as subjects. Before participating in the study, all subjects were informed of the risks, an informed consent form (see Appendix A) was signed, and a completed health questionnaire (see Appendix B) was obtained in accordance with the University of Tennessee Committee on Research Participation. The criteria for exclusion from the study as defined by the American College of Sports Medicine as one or more contraindications (either relative or absolute) to exercise testing (Appendix C). The physical characteristics of the subjects are given in Table 1.

Table 1. Physical Characteristics of the Subjects (Mean $\pm$ SD, N=9).

	Age (yrs)	Height (cm)	Weight (kg)	VO2 max (l/min)
Mean	26.78	176.53	73.38	4.19
SD	3.11	6.40	11.00	.26

Initially, each subject performed a maximum oxygen uptake test on the Monark 868 pendulum ergometer. The testing consisted of a progressive cycle test to exhaustion. Subjects pedaled at 80 RPM and the resistance was increased by one Kp (9.8 N) every two minutes until exhaustion. In determining maximal oxygen uptake the usual criterion of a plateau in oxygen uptake with an increase in work intensity and/or a respiratory quotient of 1.10 or greater was applied (10,14). Minute ventilations and gas exchange variables were measured using a data acquisition system (Rayfield Equipment, Waitsfield, VT) interfaced to a microcomputer. Expired gases were analyzed with an Applied Electrochemistry S3-A oxygen analyzer and CD-3A carbon dioxide analyzer. Oxygen uptake was monitored and calculated at 60 second intervals. Both analyzers were calibrated with standardized gases analyzed by the Scholander technique (11).

II. PROCEDURES AND TECHNIQUES OF MEASUREMENT

Measurement of f friction:

As in the case of other friction ergometers, the frictional force between the belt and the flywheel (f) is equal to the difference between F_1 and F_2. By attaching two load cells, an MLP-50 and MLP-25 (Transducer Techniques, Rancho California) in series with the frictional belt we were able to obtain direct measures of F_1 and

F_2. The voltage output from each load cell was instantaneously transcribed to a Physiograph recorder (Narco Bio-Systems, Houston, Tx). Both load cells had been previously calibrated from 0-10 kp by suspending weights from them, and were found to be linear. With the ergometer in motion f, was measured at load settings of 2, 4, 6, 8 and 10 kp. At each resistance the pedal cadence was varied from 25 to 175 rpm (increasing in 25 rpm increments).

Maximal aerobic testing:

Initially, each subject performed a maximum oxygen uptake test on the Monark 868 pendulum ergometer. The testing consisted of a progressive cycle test to exhaustion. Subjects pedaled at 80 rpm and the resistance was increased by one kp (9.8 N) every two minutes until exhaustion. In determining maximal oxygen uptake the usual criterion of a plateau in oxygen uptake with an increase in work intensity and/or a respiratory quotient of 1.10 or greater was applied (10,14). Minute ventilations and gas exchange variables were measured using a data acquisition system (Rayfield Equipment, Waitsfield, VT) interfaced to a microcomputer. Expired gases were analyzed with an Applied Electrochemistry S3-A oxygen analyzer and CD-3A carbon dioxide analyzer. Oxygen uptake was monitored and calculated at 60-s intervals. Both analyzers were calibrated with standardized gases analyzed by the Scholander technique (11).

Submaximal aerobic testing:

To establish the energy cost of cycling on the Monark 864 (weight) vs. the Monark 868 (pendulum) ergometers, subjects performed a 15 minute cycling test (five minutes at each workload of 300, 900, 1500 kpm/min) on each cycle ergometer. A metronome was used to keep pedal cadence at 50 rpm. Both ergometers were equipped with toe clips, and the saddle was adjusted to the same height on both cycles. Oxygen uptake was measured continuously, as previously described.

A counter-balanced design was used to minimize the possibility of an order effect. Six of the subjects performed both tests on the same day, with a 45-minute rest period between tests. Three of the subjects performed the tests on different days with a maximum of seven days between tests.

Statistical analysis:

The oxygen uptake and power output data at 300, 900, and 1500 kpm/min were analyzed using a two-way repeated measures ANOVA (ergometer model vs. work rate). A Tukey post-hoc test was used to determine at which work rates there was a significant difference in power output and oxygen uptake between the Monark 864 and 868 ergometers. The statistical software used was CLR ANOVA (5). The significance level was set at P=.05.

CHAPTER III

RESULTS

The effect of pedal cadence and pan weight on the frictional force between the belt and the flywheel ($\mathcal{F}$) is illustrated in Figure 4. At all resistance settings, $\mathcal{F}$ was found to be lower than F_{weight}. This discrepancy between $\mathcal{F}$ and F_{weight} was greatest at the lower pedal rpm's. However, even at the higher pedal cadences there was still a 10% difference between the two measures.

Oxygen uptake values for the Monark 864 (weight) ergometer vs. the 868 (pendulum) ergometer are shown in Figure 5. VO_2 for the 864 weight ergometer was 7 and 14% lower than on the 868 pendulum ergometer at 900 and 1500 kpm/min, respectively. Significant differences ($P \leq .001$) in VO_2 were seen between the two cycles at uncorrected power outputs of 900 and 1500 kpm/min (Table D-1&2, Appendix D).

The measured power output values on the 864 ergometer (using the load cells) were 14, 13 and 12% lower, respectively, than the assumed values for 300, 900, and 1500 kpm/min (Table 2). Highly significant ($P < .001$) differences in power output were seen between the 864 (weight) and 868 (pendulum) ergometers at all three resistance levels (1, 3 and 5 kp) (Table D-3&4, Appendix D).

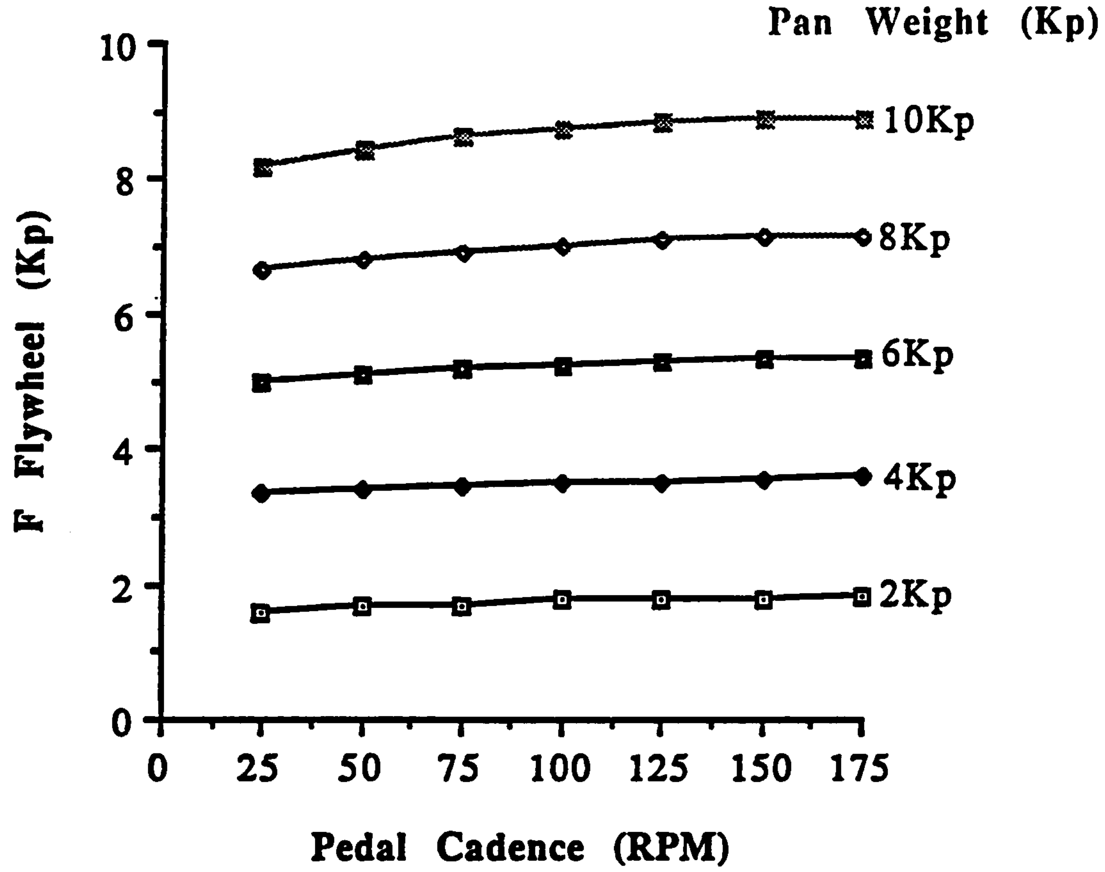

Figure 4. Effect of pedal cadence and pan weight on the frictional force between the flywheel and the belt ($\mathcal{f}$)

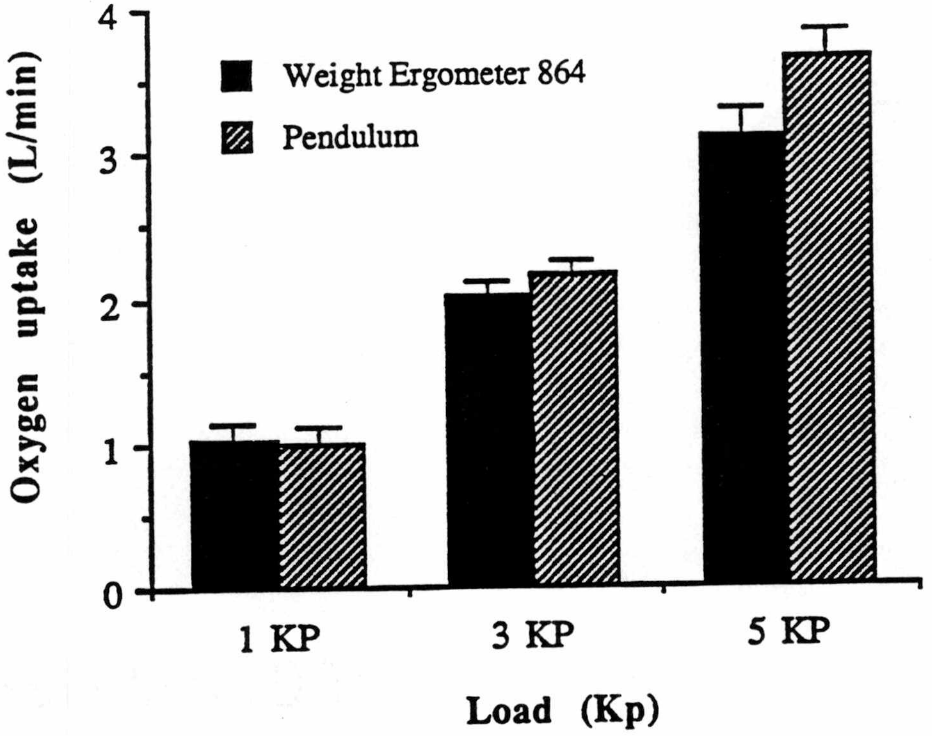

Figure 5. O_2 uptake values for the Monark 864 & 868 ergometers

Table 2. Power Output Measurements on the Monark 864 Weight Ergometer vs. the assumed values (Mean ± SD, N=9) at 1, 3 and 5 kp

	Assumed Power Output (kpm/min)	864 Weight Erg Power Output (kpm/min)	% Diff
1 kp	300	258.5 ± 19.0	14
3 kp	900	780.0 ± 18.7	13
5 kp	1500	1317.7 ± 21.3	12

CHAPTER IV

DISCUSSION

In cycling it is essential to obtain an accurate measure of the frictional force between the flywheel and the belt to compute power output. This quantity, denoted as f, was formerly assumed to be equal to F_{weight}. In the present study, $f < F_{weight}$; therefore, power output will be overestimated unless a correction is made. Our results are generally consistent with the findings of Skinner and Beld (13). They placed a strain gauge against the chain and found that the Monark 864 ergometer overestimates power output at resistance settings above 9.5 kg. However, they reported an error of 5% for these resistance settings, compared to 12-14% in the present study.

The reason for inaccuracy with the Monark 864 cycle is its use of a split pulley, unlike the pendulum cycle. On both cycles F_1 and F_2 rotate the pulley in opposite directions (Figure 6). However, due to the difference in pulley radii on the Monark 864 cycle, the torque (rather than simply the force) exerted by each end on the stationary belt must be taken into account.

Proof That $f \neq F_{weight}$:

For the pulley to remain stationary, the counter-clockwise (CCW) rotational torques acting upon it must equal the clockwise (CW) rotational torques: by calculating the torques on both the large and small radius of the pulley.

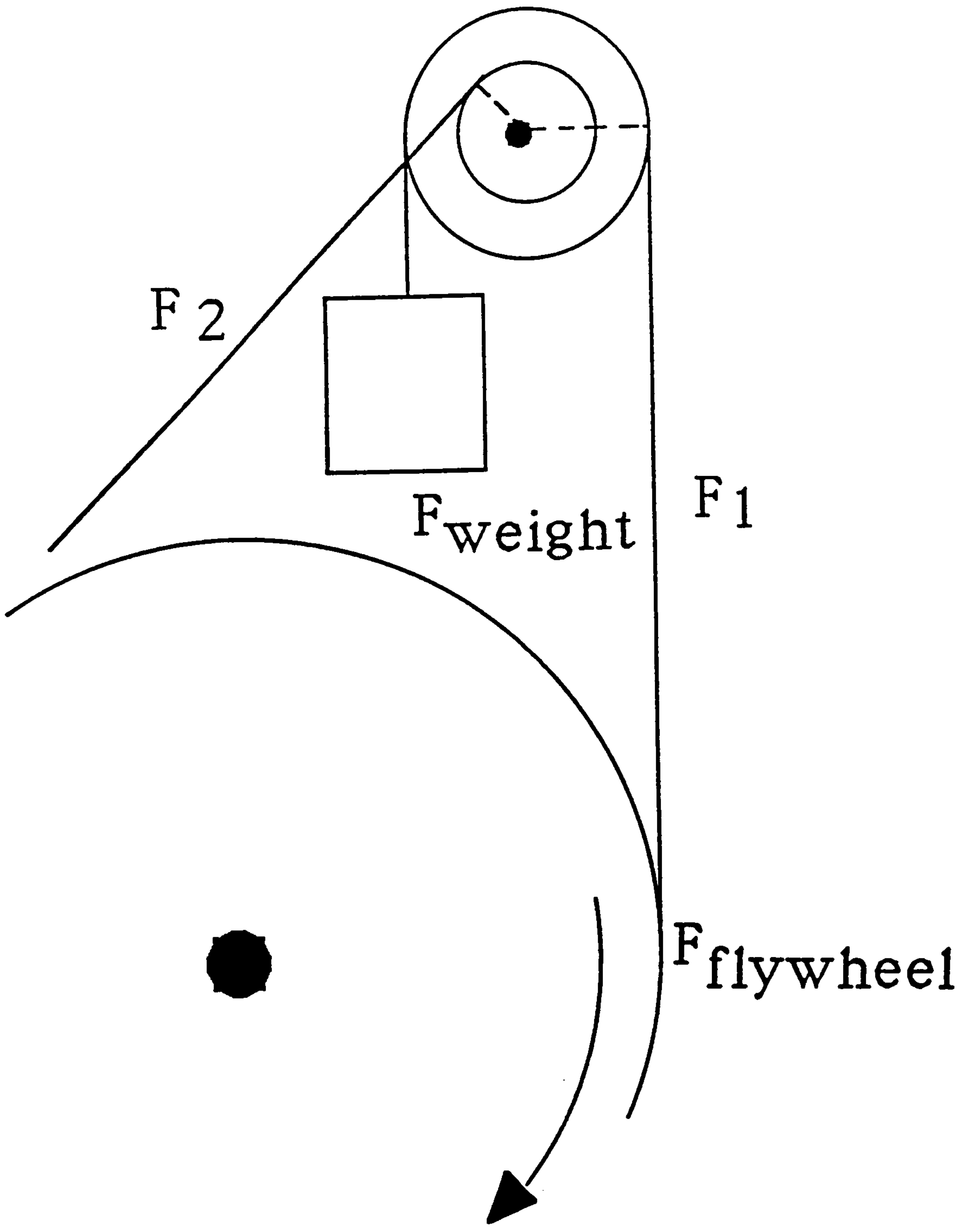

Figure 6. Forces acting upon a Monark 864 weight ergometer

$$T_1 = T_2 + T_{weight} \tag{4}$$

where T_1 is the torque exerted by F_1, T_2 is the torque exerted by F_2, and T_{weight} is the torque exerted by the weight pan. Since the smaller radius of the pulley is 1.6 cm and the larger radius of the pulley is 3.5 cm,

$$F_1 \times 3.5 \text{ cm} = (F_2 \times 1.6 \text{ cm}) + (F_{weight} \times 3.5 \text{ cm}) \tag{5}$$

Solving for F_1:

$$F_1 = \frac{1.6\ (F_2) + 3.5\ (F_{weight})}{3.5} \tag{6}$$

$$F_1 = F_{weight} + .457\ (F_2) \tag{7}$$

Substituting equation 7 into equation 1 yields:

$$f = [\ F_{weight} + .457\ (F_2)] - F_2 \tag{8}$$

$$f = F_{weight} - .543\ (F_2) \tag{9}$$

Thus, $\mathcal{F}$ will always be less than F_{weight}, unless F_2 is equal to zero. Since F_2 is never equal to zero (especially at high work rates), $\mathcal{F}$ will be less than F_{weight}.

Implication for Laboratory Use:

In our study $\mathcal{F}$ was measured by using two load cells to directly measure F_1 and F_2. However, this could also be accomplished by using a single load cell to measure F_2. If one has knowledge of F_{weight} and F_2, $\mathcal{F}$ can be calculated by using equation 9. Once $\mathcal{F}$ is determined, it can be used to compute the instantaneous power output by equation 2 (Power = $\mathcal{F}$ x V). It should be noted that for a given weight, several factors will alter the relationship between $\mathcal{F}$ and F_{weight}, including pedal rpm, heat build-up, etc. For this reason, a constant correction factor cannot be applied, and an electronic load cell is needed.

In summary, the proposed method results in a 12-14% decrease in measured external power output on the Monark 864 weight ergometer. A correction should be used for both steady-state and anaerobic testing, where an accurate assessment of power output is desired. This especially applies to the Wingate anaerobic test (WAT), for which the Monark 864 is often used. Previous research (3) has already demonstrated the need for a 3-6% correction to account for stored kinetic energy in the flywheel. These corrections will have an additive effect and will both cause an overestimation of anaerobic energy production on the WAT.

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APPENDICES

APPENDIX A

STATISTICAL ANALYSIS

Table D-1. Repeated Measures of ANOVA for Oxygen Uptake between the Monark 864 and 868 Ergometers

SOURCE	DF	SUM OF SQUARES	F	P
SUBJECTS	8	.670		
BIKES	1	.629	73.913	.0000
ERROR	8	.068		
WORKLOAD	2	50.880	2526.679	.0000
ERROR	16	.161		
BIKES*WRKLD	2	.722	113.142	.0000
ERROR	16	.051		

* Bikes = Monark 864 weight and 868 pendulum ergometers
Workload = 1, 3 and 5 kp

Table D-2. Tukey Post-Hoc Pairwise Comparison Table for Oxygen Uptake on the Monark 864 and 868 Ergometers

	A	B	C	D	E	F
A. WEIGHT 1 KP	X	_	S	S	S	S
B. PENDULUM 1 KP	_	X	S	S	S	S
C. WEIGHT 3 KP	S	S	X	S	S	S
D. PENDULUM 3 KP	S	S	S	X	S	S
E. WEIGHT 5 KP	S	S	S	S	X	S
F. PENDULUM 5 KP	S	S	S	S	S	X

Table D-3. Repeated Measures ANOVA for Power Output between the Monark 864 and 868 Ergometers

SOURCE	DF	SUM OF SQUARES	F	P
SUBJECTS	8	3761.580		
BIKES	1	179781.660	382.354	.0000
ERROR	8	3761.580		
WORKLOADS	2	11507842.120	42741.781	.0000
ERROR	16	644.960		
BIKE*WRKLD	2	43282.120	536.866	.0000
ERROR	16	644.960		

* Bikes = Monark 864 Weight and 868 Pendulum Ergometers
Workloads = 1, 3 and 5 kp

Table D-4. Tukey Post-Hoc Pairwise Comparison Table for Power Output between the Monark 864 and 868 Ergometers

	A	B	C	D	E	F
A. WEIGHT 1 KP	X	S	S	S	S	S
B. PENDULUM 1 KP	S	X	S	S	S	S
C WEIGHT 3 KP	S	S	X	S	S	S
D. PENDULUM 3 KP	S	S	S	X	S	S
E. WEIGHT 5 KP	S	S	S	S	X	S
F. PENDULUM 5 KP	S	S	S	S	S	X

Part II. CORRECTING WINGATE ANAEROBIC TEST RESULTS ON THE MONARK 864 ERGOMETER USING ELECTRONIC LOAD CELLS

CHAPTER I

INTRODUCTION

A number of laboratory tests have been used to assess an individual's ability to perform high-intensity, short-duration work. These tests include assessment of ATP, CP, muscle glycogen, lactate and oxygen debt. However, in the last decade there has been an increase in the utilization of noninvasive, muscle performance tests (versus the measurement of biochemical or physiological variables) to predict anaerobic performance (1,5,18,20,21,24). The most prevalent is the Wingate Anaerobic Test, an all-out 30-s test based on a prototype by Cummings (8), and modified by Bar-Or and colleagues in the 1970's (2,5,10). Results from the Wingate Test have been shown to be reliable (2,14,15,17,10,13) and valid (1,2,3,9,11,13,15,18,23). Variables indicative of anaerobic performance for the WAT include measures of peak power, mean power and fatigue index. These three indices are assumed to reflect certain metabolic characteristics of anaerobic performance (13,16,17,23).

The ergometer most often used for Wingate testing is the Monark 864 weight-loaded cycle (Figure 1). The primary advantage of this cycle over other friction-type ergometers is that the resistance is "instantaneously" applied by releasing a weight pan attached to the belt. In addition, the amount of resistance which can be applied is greater than that of other friction ergometers (22).

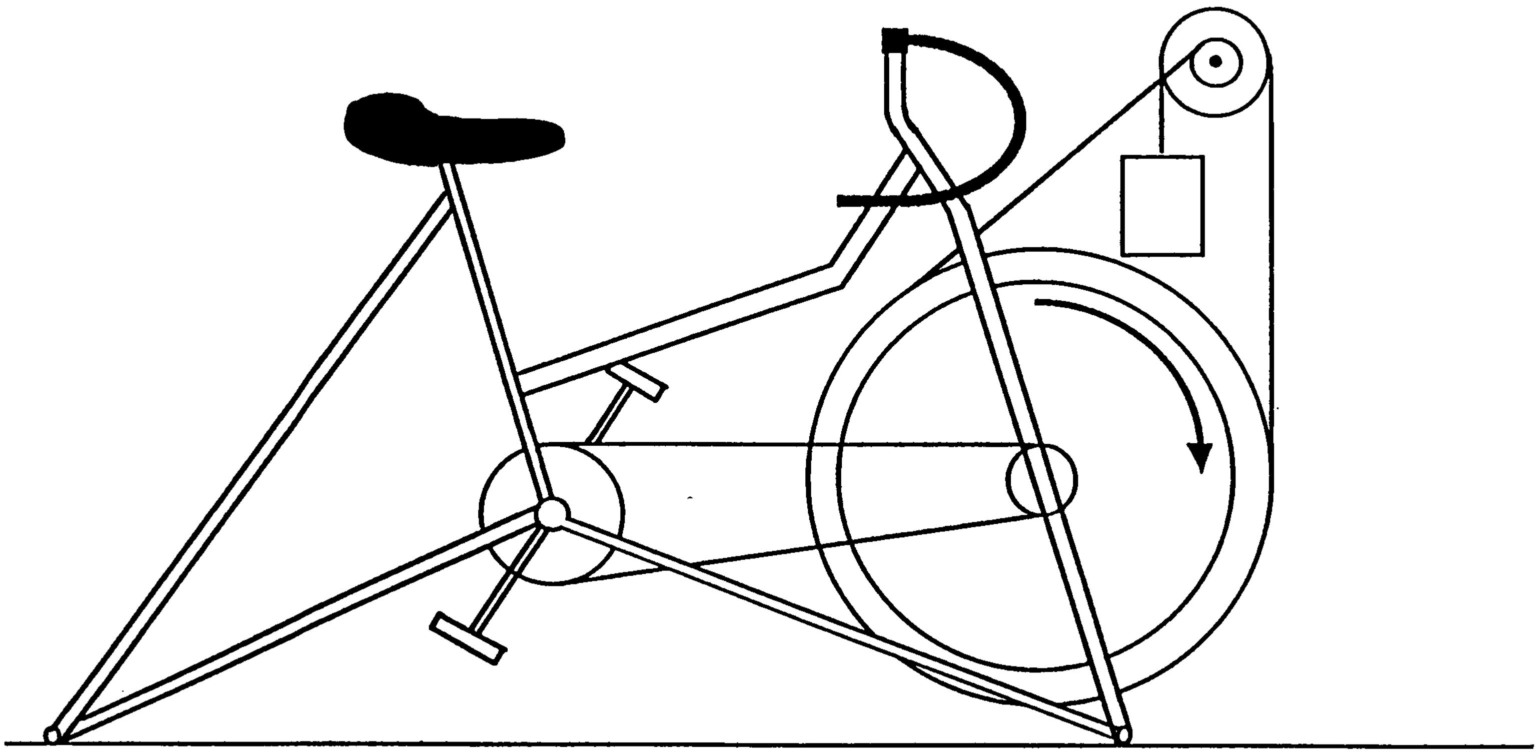

Figure 1. Weight-loaded ergometer

Previously, investigators have assumed that the frictional force between the flywheel and the belt ($\mathscr{f}$) is equal to the gravitational load of the weights in the pan (F_{weight}). Accordingly, external power has been calculated by the equation:

$$\text{Power (kpm/min)} = F_{weight}\ \text{(kp)} \times V\ \text{(m/min)} \qquad (1)$$

where F_{weight} is the force exerted by the weight pan and V is the velocity of a point on the outer perimeter of the wheel. However, a previous study performed in our laboratory demonstrated that this formula is being incorrectly applied since the weight of the pan (F_{weight}) is only approximately equal to the resistance between the belt and the flywheel ($\mathscr{f}$). Furthermore, a study by Skinner et. al. found the Monark 864 ergometer is inaccurate at the higher resistance levels (22). The objective of the present study was to correct the power outputs obtained during a WAT, and to determine the extent of the error between corrected and uncorrected values.

CHAPTER II

METHODS

I. SELECTION OF SUBJECTS

Subjects:

Eight active males, voluntarily participated in this study. All were highly trained power athletes who were presently training and/or competing in track and field. Accordingly, these participants were accustomed to daily sprint training requiring maximal exertion. The physical characteristics of the subjects are given in Table 1.

Before data collection began, the study design was approved by the Human Subjects Committee at the University of Tennessee. Prior to participation in the study, all of the subjects were informed of the details and risks of the experimental protocol, and were required to sign an informed consent form (Appendix A). Subjects were screened using a health screening questionnaire (Appendix B) with the criteria for exclusion being defined by American College of Sports Medicine as any one or more contraindications (either relative or absolute) to exercise testing (Appendix C). Following an explanation of the testing procedures each subject was encouraged to ask questions pertaining to any aspects of the study which were unclear.

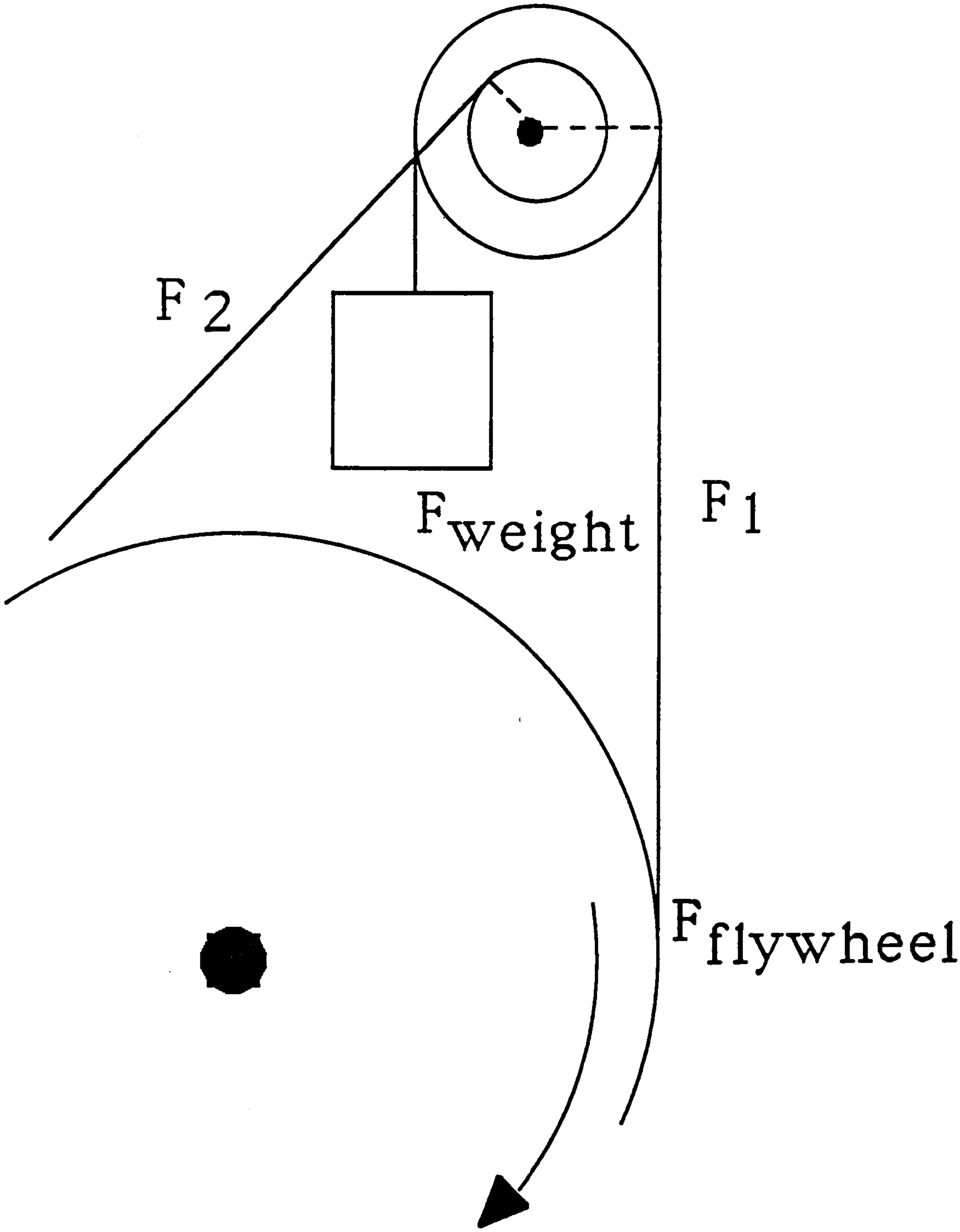

Figure 2. Forces acting upon a Monark 864 weight ergometer

Table 1. Physical Characteristics of the Subjects (Mean $\pm$ SD, N = 8).

	Age (yrs)	Height (cm)	Weight (kg)
Mean	21.37	184.84	88.13
SD	2.97	6.75	16.25

II. PROCEDURES AND TECHNIQUES OF MEASUREMENT

Measurement of f (for correcting power output):

As in the case of the other friction ergometers, f (the frictional force between the belt and the wheel) is equal to the difference between F_1 and F_2 (Figure 2). By attaching two load cells, an MLP-50 and MLP-25 (Transducer Techniques, Rancho California) in series with the frictional belt, we were able to obtain direct measures of the forces exerted on the front and back end on the frictional belt, F_1 and F_2, respectively. The voltage output from each load cell was instantaneously transcribed onto a Physiograph recorder (Narco Bio-Systems, Houston, TX), and an accurate measure of f was obtained by calculating the difference between F_1 and F_2. Before each test both load cells were calibrated from 0-10 kp by suspending known weights from them, and were found to be linear. Corrected external power outputs were calculated by the product of the accurately measured $\mathcal{F}$ and the velocity of the flywheel.

<u>Anaerobic testing:</u>

The Wingate Anaerobic Test, as characterized by Bar-Or and colleagues (2,4), requires a 30-s all-out supramaximal effort against a constant resistance relative to body weight. Tests were performed on a Monark 864 weight-loaded cycle ergometer equipped with toe clips. A ten minute warm-up at a heart rate of approximately 160 bts/min preceded each test. Following the warm-up and a five minute rest period, the subject began pedaling as fast as possible on the unloaded cycle, and after reaching maximal pedal cadence the predetermined resistance (0.090 kp/kg of body mass) was applied. Verbal encouragement to maintain maximal pedal frequency was provided throughout the 30 second test.

The ergometer was instrumented with a magnetic relay which monitored flywheel rpm. The relay was interfaced to an IBM computer via an IBM analog-digital converter, generating an on-line analysis of power output. Throughout the 30-s duration the amount of resistance between the flywheel and the belt ($\mathcal{F}$) was determined by simultaneously measuring F_1 and F_2 using load cells, as previously described. The number of wheel revolutions per 5 second interval and the accurately measured $\mathcal{F}$ were used to compute power output by the following formula:

$$\text{Power} = \mathcal{F} \times \text{flywheel rpm} \times 1.615 \text{ m/flywheel rev.} \qquad (2)$$

Three parameters of power output were calculated: 1) peak power - the highest power output attained for any 5-s interval during the test, 2) mean power - the average power output during the 30 second test, 3) Fatigue index - % decline in power output, (calculated by the difference between the highest and lowest powers outputs, divided by the highest power output).

Statistics analysis:

Power output values at each 5 second interval were analyzed by a two-way repeated measures of analysis of variance (corrected vs. uncorrected), using the statistical software program CLR ANOVA (7). Because there were no significant interaction effects, we tested for simple effects to determine where the significant differences between corrected and uncorrected values were located (ie. at which specific 5 second time intervals). Peak power, mean power and fatigue index were analyzed using a students T-test for paired observations. The significance level was set at P=.05 for all statistical comparisons.

CHAPTER III

RESULTS

Figure 3 depicts an actual graph of the voltage outputs measured by each load cell and transcribed onto the Physiograph recorder (ie. measurements of F_1 and F_2).

The mean and standard deviation for uncorrected and corrected power output measures on the Monark 864 ergometer are represented in Figure 4. Highly significant differences ($P \leq .001$) in power output occured at all six 5-second time intervals when corrected and uncorrected scores were compared (Table D-1&2, Appendix D).

The uncorrected and corrected Wingate scores for peak power, mean power and fatigue index are presented in Table 2. The load cell correction decreased peak power and mean power by 103.1 Watts (7.6%), and 94.4 Watts (9.8%), respectively ($P < .002$). Fatigue index was increased by 6.0% with the load cell correction ($P=.001$).

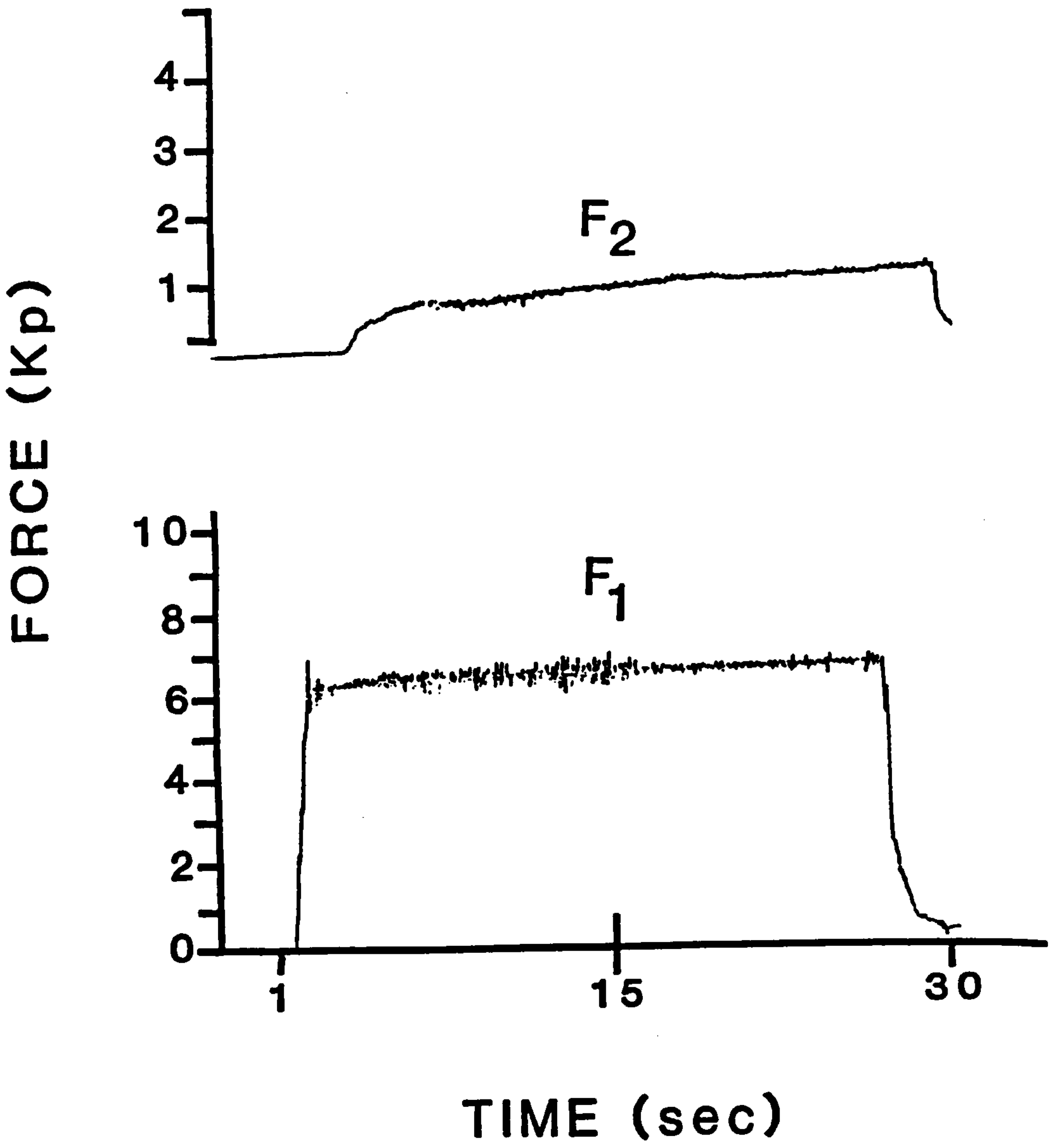

Figure 3. Actual graph of the force between the flywheel and the belt ($\mathcal{F}$) on the Monark 864 weight ergometer using electronic load cells

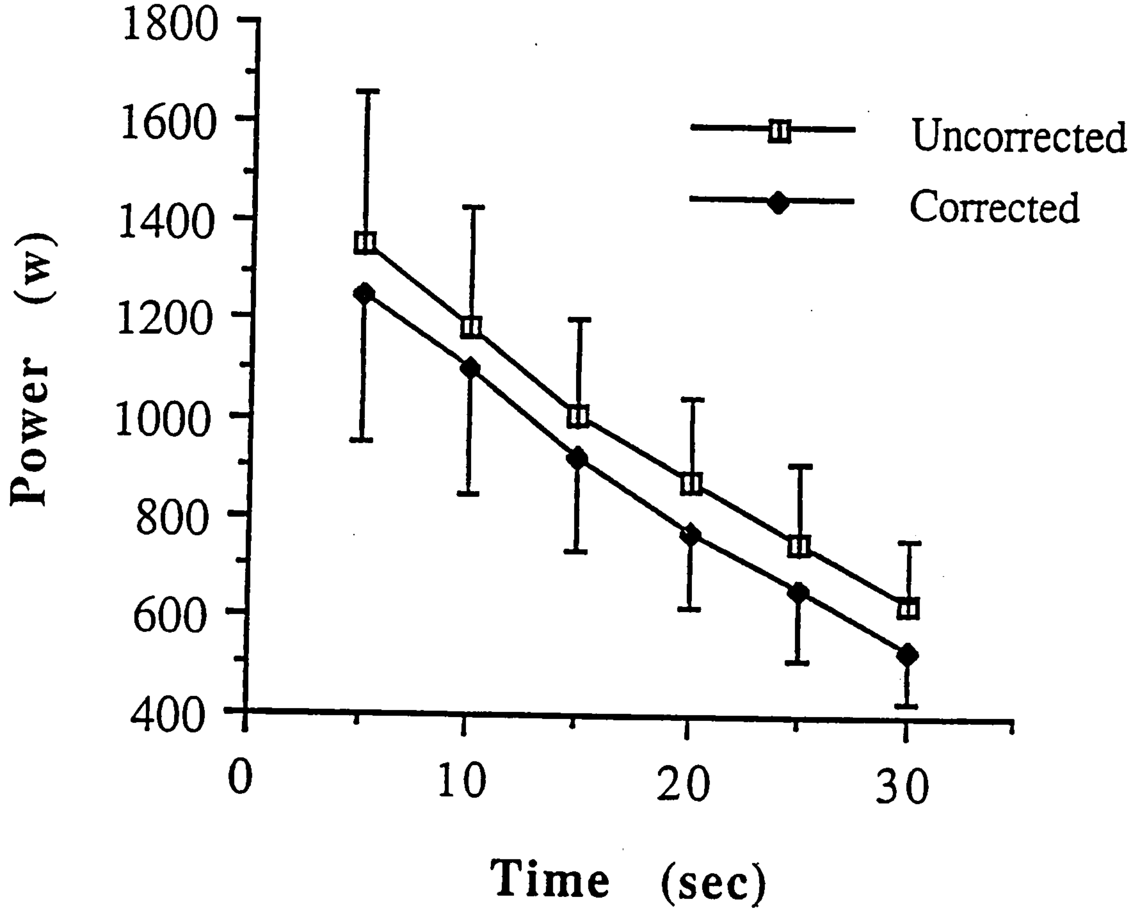

Figure 4. Uncorrected and corrected power output measurements at each 5-s interval

Table 2. Effects of Load Cell Correction on Peak Power, Mean Power and Fatigue Index. (Mean ± SD, N = 8)

	Uncorrected	Corrected	% Diff.
PP (W)	1354.2 ± 301.6	964.6 ± 193.7	+7.6
MP (W)	1251.1 ± 302.5	870.2 ± 180.1	+9.8
FI (%)	53.3 ± 6.8	56.7 ± 7.3	-6.0

CHAPTER IV

DISCUSSION

Standardization of the WAT is still undergoing modifications and refinements. The equation, Power = F_{weight} X Velocity, is an inaccurate method for measuring external power output on the Monark 864 cycle. This error results from assuming that the weight in the pan (F_{weight}) and the resistance between the flywheel and the belt (f) are precisely equal. These results have relevance for tests of anaerobic power (eg. the WAT), since they show that power output is being overestimated.

In the present study we found the absolute difference between corrected and uncorrected power outputs to be fairly constant (103, 91, 93, 107, 93 and 93 Watts) throughout the test duration (Note Figure 4). However the % difference between these two variables was greater at the lower rpm's, increasing from 7.8% at the start of the test to 15% at the end of the test. This finding suggests that pedal rpm will affect the % correction needed for each individual test. Other factors which may alter the % correction are the amount of weight used (22), heat build-up and belt wear. Thus, a constant correction factor can not be used and electronic load cells are required for accurate results.

A study by Bassett (6) found that the measured external power output on the Monark 864 cycle should also be corrected for stored kinetic energy released by the flywheel during the 30 second test duration. This energy contributes to the mechanical work done, and since it was stored prior to the start of the test, the subject should not be credited with this work. The additive effect of this correction will further decrease the measured power output attributable to the exercising subject.

If one were strictly interested in relative power output, field tests such as the 200 meter run would be sufficient for assessing anaerobic performance. However, the advantage of the Wingate test is that it provides an absolute, quantitative measurement of anaerobic power. Quantitative measurements are essential for studies estimating the relative contribution of aerobic, glycolytic, and ATP-CP energy stores in exercise of short duration (11,14,15,18,19). Since errors in the measured total power output enter into calculating the contribution of the respective energy sources, an overestimation of the anaerobic component is likely. This inaccuracy needs to be addressed before valid comparisons between the WAT and other similar anaerobic cycle tests can be made.

The proposed correction for the Monark 864 does not influence the relative validity of the WAT, which has been established by correlating it against anaerobic performance in various sports (1,2,5,10,12,23). However, in light of the present findings, future tests involving the Monark 864 cycle ergometer should incorporate the correction for an accurate assessment of power output.

CHAPTER V

CONCLUSIONS

In conclusion, the equation: Power (kpm/min) = F_{weight} (kp) x V (m/min), which is presently used as a method for measuring power output on the Monark weight-loaded ergometer, is inadequate. This results from the fact that the resistance between the flywheel and the belt (f) are not precisely equal to the weight in the pan (F_{weight}) as has been previously assumed. The proposed method for correcting power output on the Monark weight ergometer requires a load cell modification. The correction will result in a decrease in both the measured power output in steady-state exercise and during a Wingate anaerobic test.

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APPENDICES

APPENDIX A

INFORMED CONSENT FORM

Project Director: Dianne L. Stephens
Faculty Sponsor: David R. Bassett, Jr. Ph.D.

Address:
Dept. of Human Performance & Sports Studies
School of Education
University of Tennessee-Knoxville
1914 Andy Holt Ave./ Knoxville TN 37996

Phone: (615) 974-5111

The object of this research study is to correct the measurement of external power output on the Monark cycle using a load cell modification.

Please initial the appropriate section (either A or B) to define your participation in this test.

Part A will be achieved by performing a 30 second all-out work bout on the Monark cycle ergometer. After a 10 minute warm-up, you will be asked to begin pedaling as fast as possible on the unloaded (no resistance) cycle. Immediately upon reaching maximal speed a predetermined resistance will be applied and you will pedal at a maximal rate for thirty seconds.

Initial________

Part B will require that you pedal at 50 rpms for five minutes at three different exercise loads, one Kg, three Kg and five Kg respectively.

You will do this protocol on both the Monark 864 cycle and the pendulum cycle. Your oxygen uptake will be measured on both cycles by having you breath into a plastic hose connected to a laboratory apparatus.

Initial________

Potential Risks and Discomforts

While the risk of a disorder of the heart beat or a heart attack can occur during this type of test, the risk is minimal. Exercise of this type may produce nausea, light-headedness, acute muscular discomfort, musculoskeletal injury, abnormal blood pressure responses, disorders of the heart and in very rare instances heart attack.

I have read the statement above and understand the risks involved and my role in the experiment I have had the procedures explained and demonstrated to me. In addition, I am aware that:

1) I may withdraw my consent and discontinue participation at any time without penalty or prejudice toward me;
2) I am not suffering from any medical condition that may interfere with my participation in this experiment, using any medication that could prohibit participation in the experiment, or habitually using alcohol or drugs;
3) I understand that in the event of physical injury resulting from the research procedures, financial compensation is not available and

reimbursment for medical treatment is not provided by the University of Tennessee.

4) I understand that my participation is completely voluntary and responses made during this study will be kept strictly confidential.

5) I understand that data from this study may be used in research reports or presentations; however, my name and other identity will not be disclosed.

6) I understand that before signing this form I am entitled to ask questions about any aspects of the study which are unclear to me.

AUTHORIZATION:

I, ______________________________, have read the above and decided to participate in the research project described above. My signature also indicates that I have received a copy of this consent form.

______________________________ ______________

Participant's signature Date

______________________________ ______________

Witness Date

APPENDIX B

PERSONAL HISTORY FORM

Name________________________ Age____________

Date___________________________

Check X if yes:
Past History
Have you ever had?

	Yes	No	Don't Know
Rheumatic fever	( )	( )	( )
Heart murmur	( )	( )	( )
High blood pressure	( )	( )	( )
Any heart problems	( )	( )	( )
Varicose veins	( )	( )	( )
Lung disease	( )	( )	( )
Epilepsy	( )	( )	( )
Irregular heart beat	( )	( )	( )
Chronic bronchitis	( )	( )	( )
Emphysema	( )	( )	( )
Diabetes	( )	( )	( )
Bronchial asthma	( )	( )	( )
Kidney disease	( )	( )	( )
Liver disease	( )	( )	( )
Hay fever	( )	( )	( )

Present Symptoms Review:

Have you ever had?

Chest pain	( )
Shortness of breath	( )
Heart palpitations	( )
Leg or ankle swelling	( )
Coughing of blood	( )
Hypoglycemia	( )
Feel faint or dizzy	( )

Do you smoke? ( )

APPENDIX C

CONTRAINDICATIONS TO EXERCISE TESTING:

1. Recent acute myocardial infarction
2. Unstable angina
3. Uncontrolled ventricular dysrhythmia
4. Uncontrolled atrial dysrhythmia which compromises cardiac function
5. Congestive heart failure
6. Severe aortic stenosis
7. Suspected or known dissecting aneurysm
8. Active or suspected myocarditis
9. Thrombophlebitis or inracardiac thrombi
10. Recent systemic or pulmonary embolus
11. Acute infection
12. Third degree heart block
13. Significant emotional distress (psychosis)
14. A recent significant change in the resting ECG
15. Acut pericarditis

RELATIVE CONTRAINDICATIONS TO EXERCISE TESTING:

1. Resting diastolic blood pressure over120 mm Hg or resting systolic blood pressure over 200 mm Hg
2. Moderate valvular heart disease
3. Digitalis or other drug effect
4. Electrolyte abnormalities
5. Fixed rate artificial pacemaker
6. Frequent or complex ventricular irritability
7. Ventricular aneurysm
8. Cardiomyopathy including hypertrophic cardiomyopathy
9. Uncontrolled metabolic disease (diabetes, thyrotoxicos, myxedema, etc.)
10. Any serious systemic disorder (mononucleosis, hepatitis, etc.)
11. Neuromuscular, musculoskeletal, or rheumatoid disorders which would make exercise difficult

STATISTICAL ANALYSIS

Table D-1. Repeated measures ANOVA for power output between uncorrected and corrected values

SOURCE	DF	SUM OF SQUARES	F	P
SUBJECTS	7	2904548.501		
CONDITION	1	222604.192	53.487	.0002
ERROR	7	29132.975		
INTERVAL	5	5975958.239	71.850	.0000
ERROR	35	582207.308		
COND*INT	5	806.452	.664	.6531
ERROR	35	8500.619		

* Condition = uncorrected and corrected values
Interval = the 5-s time intervals

Table D-2. Simple effects for power output between uncorrected and corrected values

EFFECT	F	P
CONDITION at 5	27.896	.001
CONDITION at 10	32.556	.001
CONDITION at 15	47.994	.000
CONDITION at 20	57.332	.000
CONDITION at 25	61.240	.000
CONDITION at 30	43.034	.000
INTERVALS at UNCORR	78.938	.000
INTERVALS at CORR	64.179	.000

* Condition = uncorrected and corrected values
Intervals = the 5-s time intervals

VITA

Dianne Lee Stephens was born in Riverside, California on September 5, 1963.

She entered the public school system in 1968, attending elementary schools in California, Washington and Virginia. She then moved to San Diego California where she was graduated in 1981 from Serra High School.

In September 1981 Dianne entered Grossmont Jr. College and after receiving her associates degree was admitted to California State University Northridge where she received a Bachelor of Science Degree in Physical Education, option Exercise Physiology, in May 1987.

In January 1989, Dianne entered the Graduate School at the University of Tenessee Knoxville. During this time she was employed as a graduate assistant in the Department of Human Performance and Sport Studies. She received the Master of Science degree in Physical Education, with an emphasis in Exercise Physiology, in December 1990.

The author is a member of the American College of Sports Medicine.

She is married to David Eldon Stephens of Chico California.