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THE UNIVERSITY OF ALBERTA

ADAPTED PHYSIOLOGICAL TESTS FOR MALE COMPETITIVE CYCLISTS

BY

KATHY ANN SOMERVILLE

A THESIS
SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH
IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE
OF DOCTOR OF PHILOSOPHY

DEPARTMENT OF PHYSICAL EDUCATION
AND SPORT STUDIES

EDMONTON, ALBERTA
FALL, 1989

I hereby permit Kathy Somerville to submit the following paper(s) co-authored by myself to the Faculty of Graduate Studies at the University of Alberta as part of her Ph. D dissertation:

Somerville, K. A. & Quinney, H. A. A modified cycle ergometer. *Can. J. Appl. Sport Sci.*, 12(4), 1987, 225-228.

Somerville, K. A., Gervais, P. & Quinney, H. A. Angular velocity of the knee in cycling. *Can. J. Appl. Sports Sci.*, 10(4), 1985, 31P.

Quinney

THE UNIVERSITY OF ALBERTA

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THE UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled "Adapted Physiological Tests for Male Competitive Cyclists" submitted by Kathy Ann Somerville in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Physical Education.

Supervisor

Jean Wessel

Date: September 14, 1989

For my mother
who made me want to learn
and for my father
who has always made me feel that
I can do anything

ABSTRACT

This series of six studies was designed to examine various factors in the physiological testing of male competitive cyclists with the intention of creating sport-specific tests. A Monark cycle ergometer was modified in order to precisely replicate the cyclist's own bicycle for testing. When cyclists completed both 30 second and aerobic power tests on both the modified and standard ergometers, no significant differences in results occurred. It appears that in this case there was a limit to the effect of equipment specificity on test results. A dynamic torquemeter was employed to dynamically calibrate Monark cycle ergometers; it was found that changes in chain lubrication and tension did not create a significant difference in measured and scale values, and that drivetrain friction created a discrepancy between scale and measured values. The angular velocity of the knee was measured during cycling at four cadences and found to range between 176.7 ± 30.1 and 396.0 ± 66.7 degrees/second; the values obtained should enable sport-specific testing and training of competitive cyclists. Cyclists completed 30 second power tests using both a dynamic and static start; a significant increase in peak but not mean power output was found with the dynamic start. The dynamic start is therefore recommended in terms of results and cyclist preference. When a group of 30 competitive road cyclists (15 novice, 15 experienced) underwent both a 30 second power test and an aerobic power test, group membership could be predicted only with the results of the aerobic power test. This finding reflects the fact that testing must be sport and event-specific, and confirms the notion that many factors are involved in group prediction. These studies demonstrated the value of sport-specific adaptations to physiological tests for male competitive cyclists and provided an indication that limitations do exist to the extent to which specificity must be pursued.

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Chapter I

INTRODUCTION

The following series of six papers constitutes an examination of several interrelated facets of the physiological testing of competitive cyclists. Each paper has been designed to fill a gap in the considerable body of knowledge in the area of physiological testing, and therefore each paper has a relatively narrow focus. The final study in the series is an attempt to collate and apply the findings of the first five studies in the form of two testing protocols which are designed to distinguish among cyclists on a physiological basis.

It has become increasingly clear in recent years that the training and testing of athletes must be sport specific. In early studies directed at determining the testing equipment best used to elicit maximal test results, no consideration was given to specificity of equipment. It therefore seemed that aerobic power tests conducted on the treadmill gave the highest test results (Hermansen & Saltin, 1969). Later researchers realized that higher results were realized on tests of aerobic power when cyclists were tested on cycle ergometers and runners on treadmills (Hagberg et al., 1978; Verstappen et al., 1983). Recently researchers have begun to examine the viability of testing cyclists on their own bicycles while attached to windload simulators (Burke, 1982) and in a sport-specific setting such as a velodrome as opposed to an ergometer or treadmill (Ricci & Leger, 1983).

As more research was undertaken involving the cycle ergometer and as more cyclists were used as subjects, some researchers began to focus on modifications to the cycle ergometer and to refinements in testing protocols specific to the sport of cycling. Brodowicz et al. (1982) found that the use of toe clips led to an increase in the VO_2 max and anaerobic threshold of competitive, but not non-competitive cyclists. LaVoie et al (1984) found that the use of toe clips increased peak and mean 30 second power outputs by as much as five to twelve per cent. Davis and Hull (1983) allowed further specificity in research on cyclists by examining the use of cleated shoes; cycling efficiency was increased more than when only toe clips and straps were used.

The importance of crank length on aerobic power and peak 30 second power test results was studied (Conrad & Thomas, 1983; Inbar, 1983) and found to be minimal. The use of dropped handlebars was also examined; Faria et al. (1978) found that cycling with the hands on the drops led to an increased VO_2 max.

The protocols used in testing were also refined; while the original Wingate 30 second power test employed a resistance of 0.075 kiloponds per kilogram of body weight (kp/kg)(Ayalon et al., 1974), later studies explored the use of different relative loads (Evans & Quinney, 1981; Dotan & Bar-Or, 1983; Patton et al., 1985 and Bar-Or, 1987). Optimal velocity in the 30 second power test has also been the subject of some research (Simoneau et al., 1983; Davies et al., 1984; McCartney et al., 1985 and Vandewalle et al., 1987). The application of both optimal load and velocity for cyclists that has resulted from the above research certainly represents an improvement over the original broad equations used by the Wingate group.

The pedalling rate used in aerobic power tests was evaluated; while Astrand (undated) originally recommended 50 revolutions per minute (rpm) as the ideal testing cadence, further work with cyclists has identified a much higher optimal cadence (Gueli & Shephard, 1976; Faria et al., 1982; Thoden et al., 1982).

Optimal seat height for the aerobic power test was examined (Hamley & Thomas, 1967; Shennum & de Vries, 1976 and Nordeen-Snyder, 1977). Some researchers have since contended that the optimal saddle height is that which is normally used by the cyclist (Kroon, 1983 and McCullagh, 1984).

A large number of studies now exist which have employed a wide array of protocols for testing aerobic and 30 second power tests. Unfortunately, researchers have used such a variety of testing protocols that it is difficult to know which protocol is best used in any given situation. In many cases, details of the test protocol are not given in sufficient detail to precisely replicate the experiment. Although some description of the protocol is usually present, most authors do not address such issues as seat height, load optimization, hand position, ergometer modifications and starting technique even though research exists that demonstrates that these are all important considerations (Nordeen-Snyder, 1977; Dotan & Bar-Or, 1983; Kolin, 1984; LaVoie et al., 1984). This series of studies is an attempt to determine whether slight differences in test protocols affect the outcome of the tests.

A further complication arises in the form of subject selection. Many researchers have examined testing protocols and techniques without regard for the type of subject recruited. As is evident from the studies outlined above, the training and testing of athletes must be sport specific in order for the tests to be valid. Because of this, much of the research concerning anaerobic and aerobic power tests is not suitable for the competitive cyclist, since the protocols were developed for a more general population.

This brief description of research topics indicates that the physiological testing of cyclists is becoming more sport specific, with consideration being given to the configuration of the cycle ergometer, saddle height, cadence, load optimization and body position. Further specificity in testing equipment and protocols may yield even better results in aerobic and 30 second power tests. The present series of papers has been designed to examine several of the areas in which existing protocols and equipment may be further adapted to better suit the needs of competitive cyclists. These areas include: the modification of the cycle ergometer, the effect of maintenance and adjustment on cycle ergometer calibration, the angular velocity of the knee in cycling, and starting techniques for the 30 second power test. In an attempt to facilitate comparisons among studies, and to allow the most valid test results possible, the final paper will examine the most appropriate protocols for 30 second and aerobic power tests for competitive cyclists. This series of studies, therefore, was designed for the purpose of creating a protocol for the testing of competitive cyclists that will assess their training progress, evaluate their abilities and to provide information that can be related back to their training techniques.

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Chapter II

The Effect of Chain Maintenance and Adjustment upon the Mechanical Efficiency of Monark Cycle Ergometers

INTRODUCTION

Almost every physiological testing laboratory uses one or more cycle ergometers in order to test aerobic and 30 second power as well as anaerobic capacity. These cycle ergometers must be calibrated regularly in order to ensure that the researcher knows the precise resistance against which the cyclist is pedalling.

The resistance is measured through the use of a pendulum scale, which measures the difference in force at the two ends of the belt which stretches around the circumference of the flywheel. As the belt is tightened against the wheel, the pendulum is moved and the deflection of the pendulum on the scale indicates the braking force being applied to the flywheel. It is important to realize that the braking force (in kiloponds or Newton metres) which appears on the scale indicates only the braking force being applied directly to the flywheel by the belt. Friction and other mechanical factors inherent in the drive mechanism of the cycle ergometer do not contribute to the deflection of the pendulum, and so are not included in the kilopond (kp) or Newton metre (Nm) values used to reflect the power input of the subject.

Astrand (undated) noted in his original manual for the Monark cycle ergometer that friction from the transmission "increases the work load by about 9% above the one calculated from braking force and distance moved" (p. 14). To compensate for this, Astrand adjusted the values given in his widely-used oxygen uptake prediction table to account for this additional braking force. Astrand explained that the resistances given in the table are therefore actually nine per cent lower than stated; a resistance of 600 kilopond metres (kpm) is actually 650 kpm, 1200 kpm is actually 1300 kpm, and so on. It is obvious (but often overlooked) that if an electronically braked cycle ergometer or other ergometric device is used, the values given in Astrand's oxygen uptake table must be modified.

The value of nine per cent given by Astrand, however, assumes that the cycle ergometer is perfectly adjusted and maintained. While the author stated that most transmission friction involves the chain, it should be noted that other parts of the drive mechanism (the pedal bearings, the wheel hub bearings and the bottom bracket bearings) may also contribute to drive train friction. Whitt and Wilson (1982) stated that a clean, new and lubricated bicycle chain transmission has an efficiency rate of 98.5%, which contradicts the 91% efficiency rate given by Astrand. This might be due to the fact that Whitt and Wilson were giving efficiency values for the chain only, while Astrand was estimating total drive train losses in efficiency. Kyle (1986) reported that losses due to the gear train and bearings were in the order of three to five per cent when the chain was well-oiled. It is possible that the chain transmission used in the Monark cycle ergometer has a lower efficiency than that cited in the work by Whitt and Wilson (1982) and Kyle (1986) due to the design of the tooth form, the difference between the pitches of the chain and the sprockets even when both are new or the construction of the chain itself. The fact that Whitt and Wilson (1982) and Kyle (1986) were considering primarily racing bicycles which likely employ gear trains designed to minimize friction makes this a strong possibility. None of the authors explained how the efficiency values were derived, making speculation difficult.

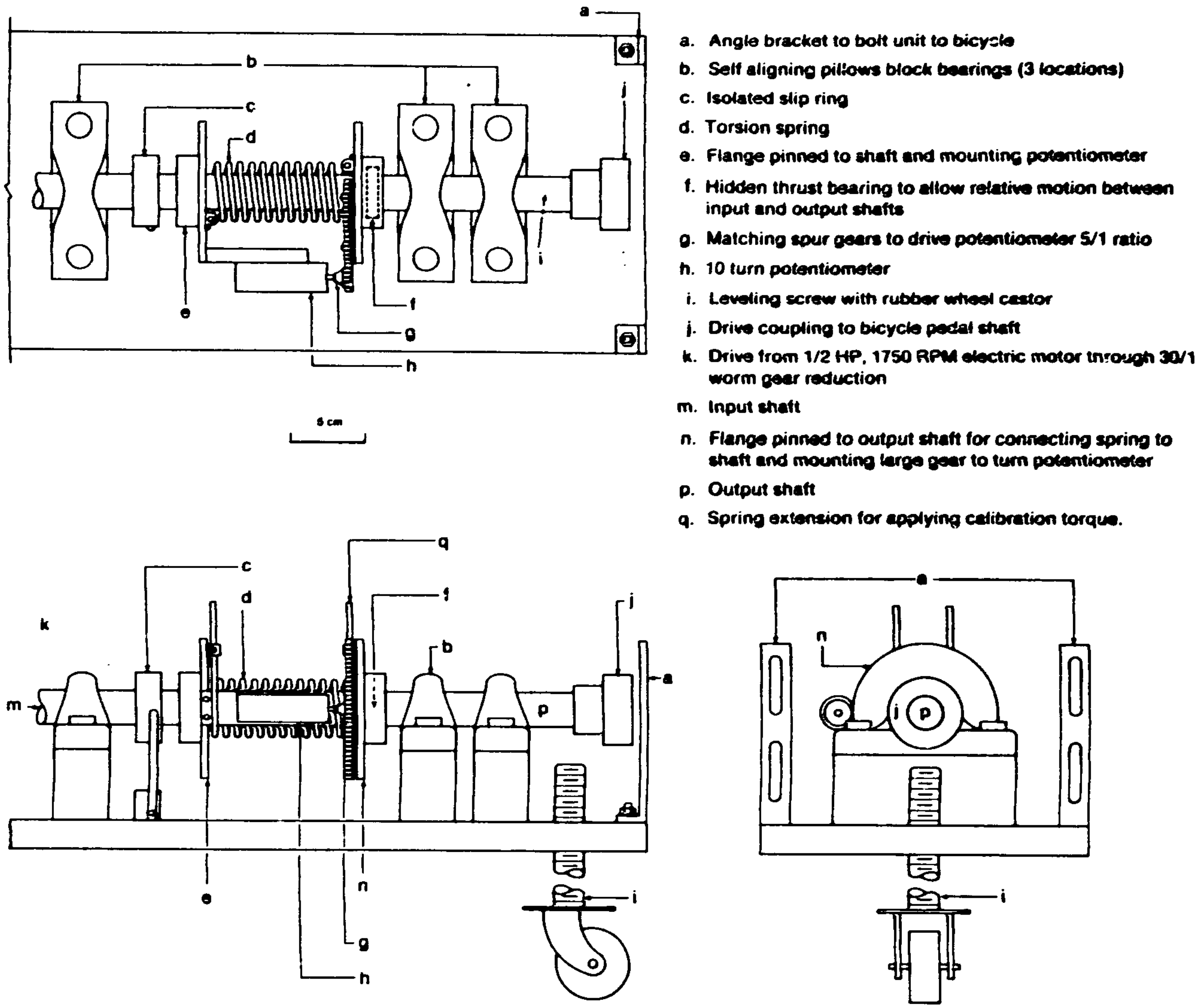
It is generally agreed, however, that the efficiency of the chain drive mechanism decreases as the chain and sprockets become worn, and as lubrication of the components of the transmission becomes less than optimal. Whitt and Wilson (1982) stated that as the chain is subjected to repeated use there is a subsequent loss of lubrication and contamination by dirt and grit. The pitch of the chain becomes larger than that of the cogs as the outside diameter of the pins decreases and/or the inside diameter of the bushings and rollers increases. As noted by Emiliani (1986), even 1/1000th of an inch change in these dimensions can change the overall length of the chain by almost one quarter of an inch. This leads to a situation in which the load applied to the chain is borne by only one or two links (rather than spread evenly among six or seven links), which leads to even more rapid wear of the chain. The lack of fit between the chain and the sprockets decreases the efficiency of the chain drive.

The lubrication and adjustment of the chain and the bearings of the pedal, bottom bracket and freewheel hub also contribute to the loss of efficiency in the chain drive. Friction in all of the bearings increases with decreasing lubrication and with the accumulation of dirt and grit. In addition to this, lack of correct adjustment of the cones and bearings of the bottom bracket, pedals and the flywheel hub will also contribute to a change in the efficiency of the drive mechanism. Whitt and Wilson (1982) state that the amount of efficiency lost due to a worn or dirty drive system is unknown. Finally, the tension at which the chain is maintained (through the movement of the flywheel in its sliding dropouts) may affect the efficiency of the drive transmission.

It is evident that more research is required in order to assess the effects (if any) of improper or inadequate maintenance upon transmission efficiency. The efficiency of the transmission was assessed in this study using the dynamic torquemeter developed by Russell and Dale (1986). This device measures the torque at the bottom bracket axle of the cycle ergometer while driving the axle at 59 revolutions per minute. An illustration of the dynamic torquemeter appears in figure II-1.

The dynamic torquemeter is a vast improvement over other cycle ergometer calibration devices for a number of reasons. Most cycle ergometer calibration takes place while the ergometer is not being pedalled; this is called static calibration. Since we are most concerned with the torque applied while the subject is pedalling, however, it is more desirable to calibrate the ergometer dynamically.

The calibration technique recommended by Astrand in his undated instruction booklet involves hanging a known weight from part of the tension strap and adjusting the



a. Angle bracket to bolt unit to bicycle
b. Self aligning pillows block bearings (3 locations)
c. Isolated slip ring
d. Torsion spring
e. Flange pinned to shaft and mounting potentiometer
f. Hidden thrust bearing to allow relative motion between input and output shafts
g. Matching spur gears to drive potentiometer 5/1 ratio
h. 10 turn potentiometer
i. Leveling screw with rubber wheel castor
j. Drive coupling to bicycle pedal shaft
k. Drive from 1/2 HP, 1750 RPM electric motor through 30/1 worm gear reduction
m. Input shaft
n. Flange pinned to output shaft for connecting spring to shaft and mounting large gear to turn potentiometer
p. Output shaft
q. Spring extension for applying calibration torque.

Figure II-1: Illustration of Dynamic Torquemeter deflection of the pendulum. This is the technique most commonly used in exercise physiology laboratories. A major flaw inherent in this technique is that a weight cannot be directly suspended from the tension strap without interference from the flywheel, which affects the values obtained and thus the calibration of the cycle ergometer. The flywheel may be moved back in the dropouts, but in addition to being an awkward and lengthy process, in some cases the flywheel cannot be moved far enough back to eliminate interference. To alleviate this problem, a new set of calibration weights was constructed, as illustrated in Figure II-2. The weights are hung directly from the tension strap and are added to a frame designed to project on either side of the flywheel. During calibration, weights are added to each side simultaneously to avoid unbalancing the structure and therefore making contact with the flywheel. Because the initial calibration of the cycle ergometers used in this study was crucial to the outcome of the results, this improvement in the static calibration technique was necessary and effective.

As mentioned previously, the static calibration technique does not detect additional resistance which occurs due to losses in mechanical efficiency in the drivetrain. The dynamic torquemeter used in this study did allow the inclusion of some of those factors in the measurement of torque because it was attached to the bottom bracket axle. It should be noted that the attachment of the device to the bottom bracket axle prevents measurement of frictional losses in the pedal bearings and of deflection in the crank. The use of the dynamic torquemeter does allow estimation of energy losses in the bottom bracket, chain and front axle.

The purpose of this study was to re-evaluate Astrand's assertion that there is a 9% loss in efficiency due to energy losses in the transmission, and to evaluate the effect of lubrication and adjustment upon mechanical efficiency levels.

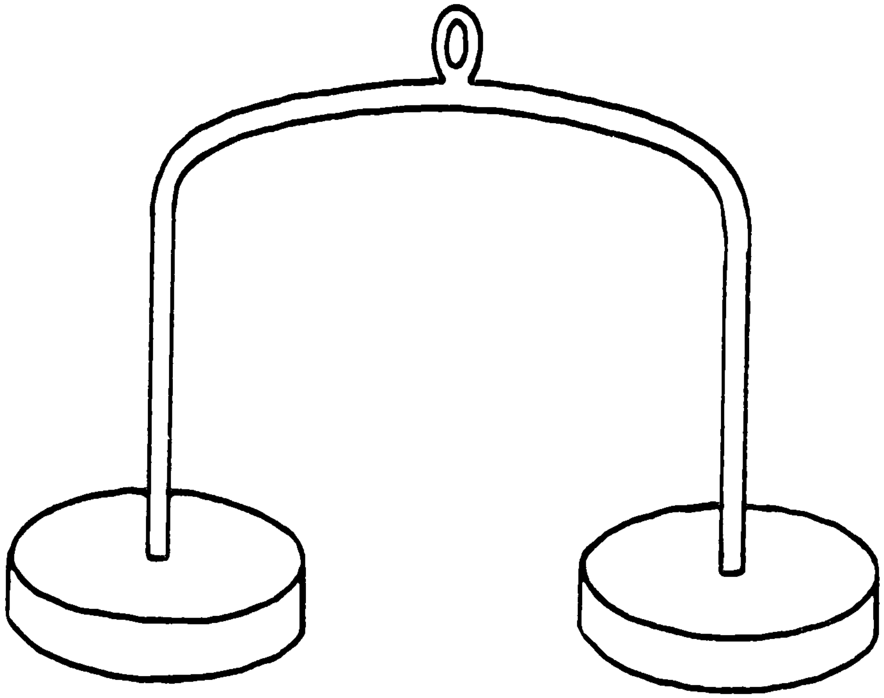


Figure II-2: The weight-hanger for static calibration of the cycle ergometers was constructed such that the weights were suspended on either side of the flywheel.

METHODS

To determine the effects of proper maintenance and adjustment to the chain, the torque was measured on five statically calibrated Monark 868 cycle ergometers at each kilopond setting under the following four conditions: chain unoiled, incorrect tension; chain unoiled, correct tension; chain oiled, incorrect tension; chain oiled, correct tension. The dynamic torquemeter was calibrated as described in Appendix A.

In this study, the chain was cleaned with alcohol in order to attain the "unoiled" status. Ballantine (1982) recommended a maximum of one-half inch up and down play in the chain for correct tensioning. The "correct" tension test condition was therefore considered to be one-half inch of up and down play. The "incorrect" tension test condition utilized a chain tension allowing one inch of up-and-down play since this most closely approximates the condition in which neglected laboratory cycle ergometers are found.

The data was analyzed using an analysis of variance with three factors on the repeated measures for both the raw data and the data expressed in terms of per cent difference between scale and measured values. The latter was included to express the data in values comparable to those found in the literature and to determine if a significant difference existed between per cent scale and measured values.

RESULTS

Intraclass reliability of the dynamic torquemeter was assessed by repeating the measurement of each of the five cycle ergometers tested in the .5 inch tension, oiled condition and was found to be .99.

For each of the conditions and resistances the per cent difference (% diff) between the scale and the measured resistance values was calculated. The % diff over all conditions was 5.3 (SEM=1.7). The mean % diff for the .5 and 1 inch chain conditions were 5.9 (SEM=2.5) and 4.8 (SEM=2.3) respectively. The mean % diff for the dry condition was 4.7 (SEM=2.3) and for the oiled condition was 6.0 (SEM=2.4). The mean % diff for each resistance setting were: 1 kp; -11.4(SEM=6.9)/ 2kp; -1.8(SEM=3.4)/ 3kp; 1.6(SEM=2.5)/ 4kp; 17.7(SEM=2.5)/ 5kp; 10.7(SEM=1.6) and 6kp; 15.4(SEM=1.5). The mean % diff values for the five cycle ergometers were -15.8 (SEM=5.3), 13.6 (SEM=2.0), 8.0 (SEM=3.1), 11.4 (SEM= 2.0) and 9.6 (SEM=2.2). The mean % diff for the five cycle ergometers when the chain was oiled and the tension was .5 inches (an ideal condition) was 7.7 (SEM=3.3). An analysis of variance with three factors on the repeated measures did not detect a significant difference among any of the conditions. The grand mean was significant (p=.002) indicating that the per cent difference between the scale and measured resistance values was significantly different.

An analysis of variance with three factors on the repeated measures was also performed on the raw data collected for each condition. No significant difference was found for any of the main effects or interactions. Figures II-2 through II-5 are graphic representations of the mean measured resistance values for each of the four conditions compared to the scale values. In each condition the graphs are very similar, reflecting the lack of significant difference among the four testing conditions.

DISCUSSION

The fact that no significant difference was found between any of the conditions and resistances implies that there is no discernible effect upon measured resistance, whatever the chain condition and level of resistance. Nonetheless, a noticeable trend is evident when Figures II-3 through II-6 are studied. All four graphs are very similar, and all show an increased diversion from scale values at the 173.6 W (3 kp) level. This finding is similar to the trend noted in Russell and Dale (1986), in which losses in generated power due to friction increased as the load increased. In the present study it appears that when the load was increased above a critical value (173.6 W) the resulting tension generated greater mechanical friction in the bearings and chain. The % diff

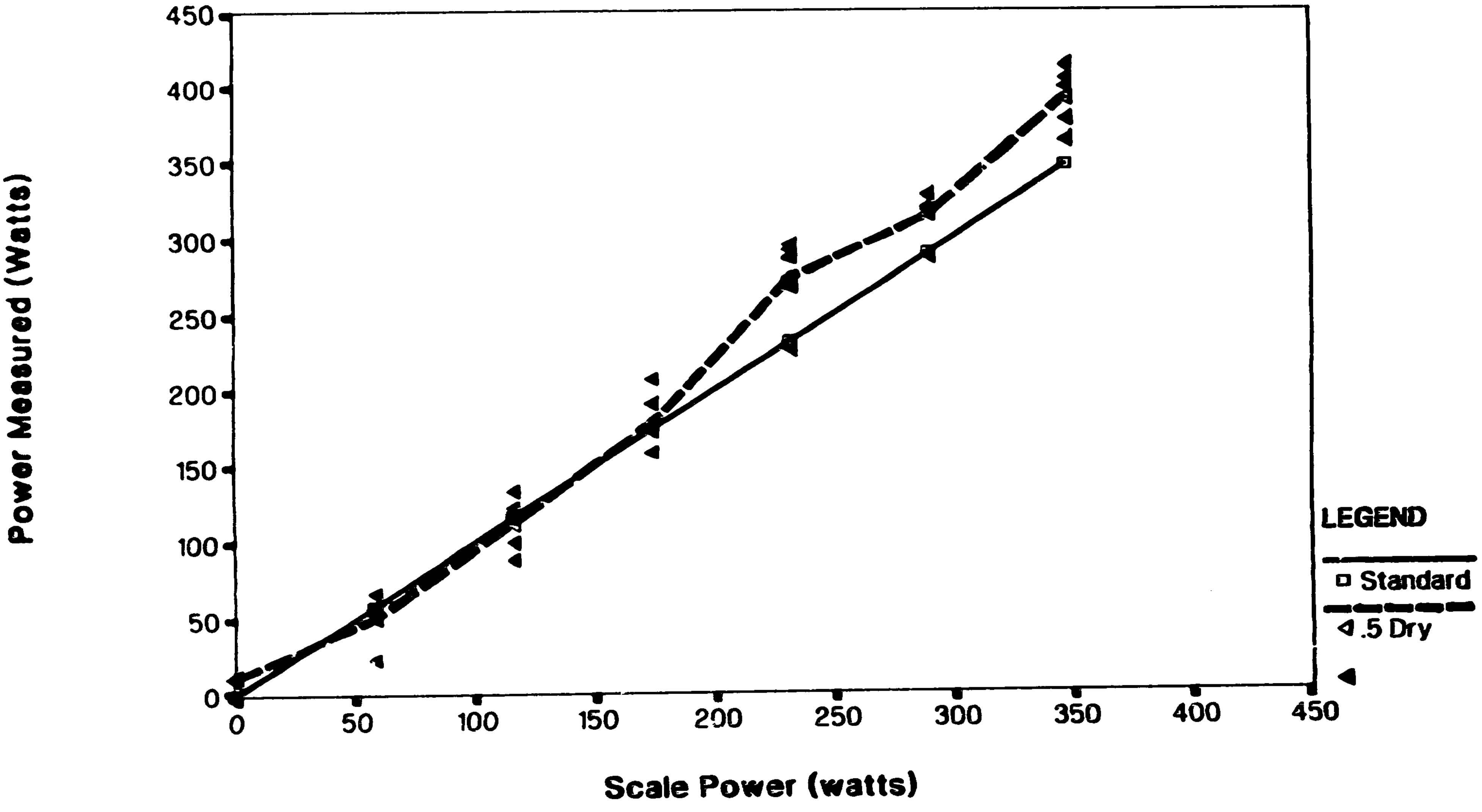


Figure II-3: Scale Power vs. Measured Power
(One-half inch tension - dry)

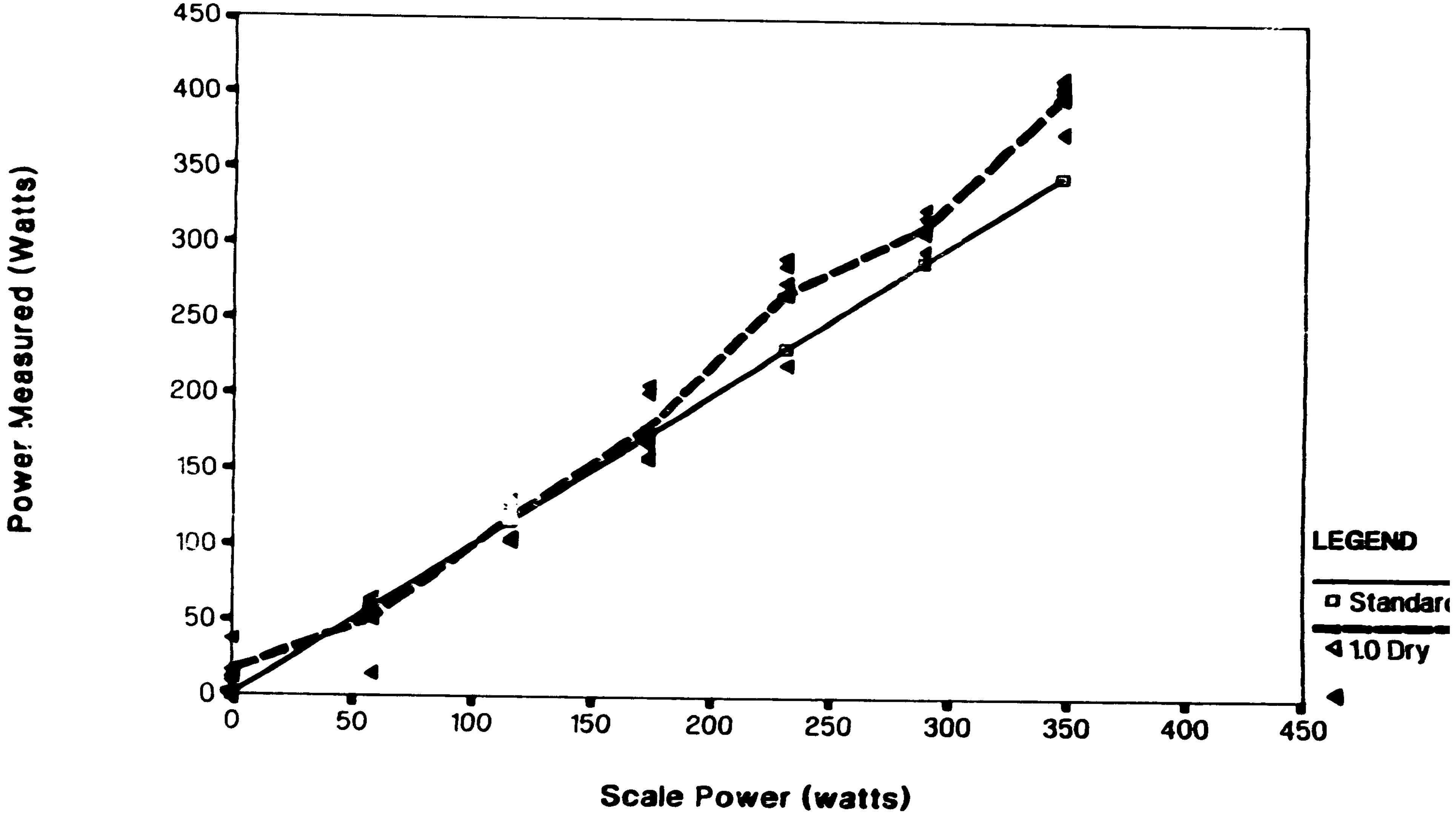


Figure II-4: Scale Power vs. Measured Power
(One inch tension - dry)

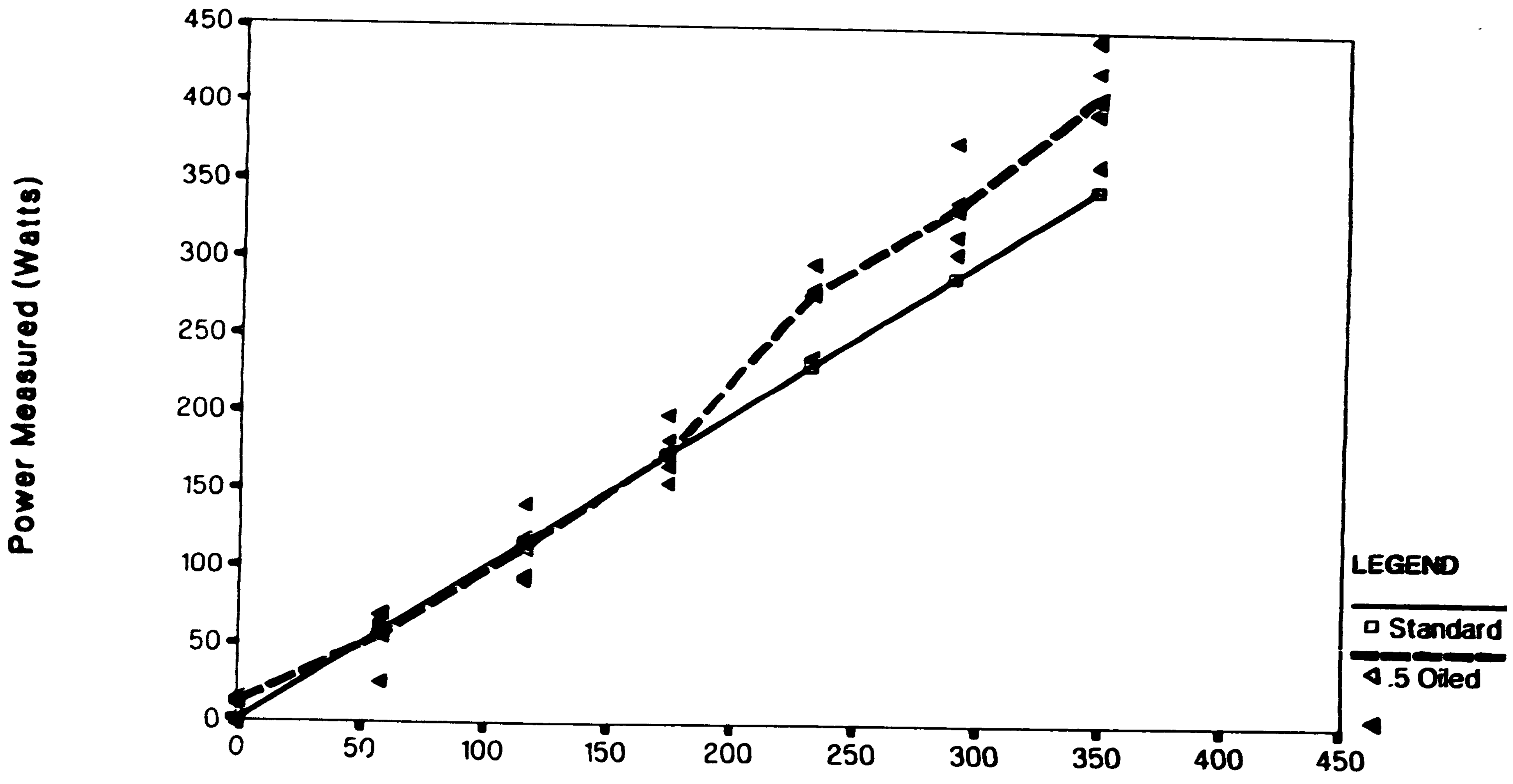


Figure II-5: Scale Power vs. Measured Power
(One-half inch tension - oiled)

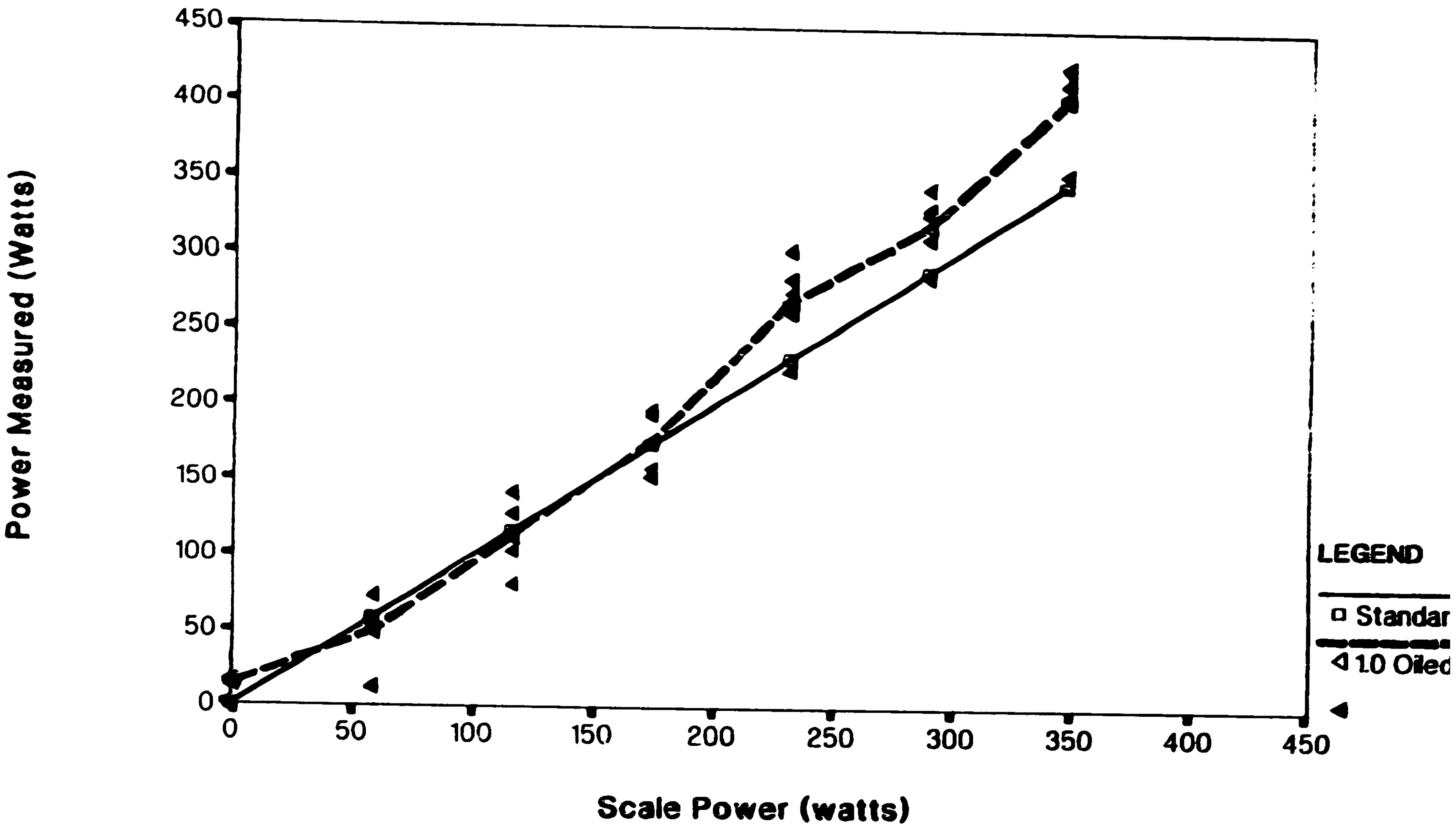


Figure II-6: Scale Power vs. Measured Power
(One inch tension - oiled)

between scale and measured resistance values reflect this divergence in that they also show an increase at 173.6 W. This trend may have resulted in significant differences had a larger sample of cycle ergometers been used. The use of alcohol as a solvent may have been a factor in the lack of significant results. This solvent is not as effective as some, and a small residue of oil may have been present in the bushings. This would have prevented a true "unoiled" condition from being measured. It should also be noted that most ergometers suffering from a lack of maintenance are not really "unoiled", since not only is the chain dry but an accumulation of dirt and grit is present. Had it been possible to measure cycle ergometers in this condition, a difference may have been uncovered.

A significant difference between the scale resistance value and the measured resistance value of 5.3 (SEM=1.7) per cent was revealed. Thus a significant difference was present between the scale and measured values when all of the testing conditions were considered. The analysis of variance with three factors on the repeated measures on the per cent difference in scale and measured values found no significant difference for any of the conditions studied. These findings suggest that while there is a significant difference in terms of per cent values between scale and measured values, this difference is not influenced by the changes in the condition of the chain studied herein or by the resistance level.

Under zero load conditions a mean measured value of 13.4 W was required to maintain 59 revolutions per minute (rpm). This value is higher than the 9 W value cited by Russell and Dale (1986) to maintain the same rpm, using the same dynamic torquemeter. Russell and Dale used an Elema-Schonander electrically-braked cycle ergometer in their study; it is probable that the difference outlined is due to the difference in mechanical efficiency between the Elema-Schonander and the Monark cycle ergometers used in the present study.

In order to compare these results to those reported in the literature the most meaningful value would be the mean of the five cycle ergometers when the chain was oiled and the chain tension was .5 inches. This can be said to represent the "ideal" condition. Other researchers have not reported the conditions of the bicycles and cycle ergometers for which they discussed results, but it may be assumed from their descriptions that they were reporting upon ideal conditions. In this case, the mean % diff value for the five cycle ergometers under ideal conditions was 7.7 (SEM=3.3).

The % diff of 7.7 under ideal conditions is higher than the estimation of Kyle (1986) of losses due to gear train and bearings of three to five per cent, but slightly lower than Astrand's (undated) figure of nine per cent. The lower figure cited by Kyle (1986) may be due to the fact that he was considering the values for a racing bicycle, which is likely to incorporate a chain and flywheel designed to reduce friction.

The present value is close to that of nine per cent cited by Astrand (undated). It must be noted at this point that no value was given by Astrand for range or variation in his estimation of mechanical friction losses. The standard error of the mean for the ideal value found herein was 3.3, placing all values from the literature for losses due to gear train friction within the range of the present findings. This study appears to confirm the findings of Astrand, since the value that he cited in his undated manual is within the range of the present value.

This study has demonstrated that the dynamic torquemeter developed by Russell and Dale (1986) can be used to calibrate the flywheel-braked Monark cycle ergometer. Astrand's notion that friction in the drivetrain contributes to a discrepancy between scale and actual resistance values was confirmed, although a slightly lower figure was observed in this study. The increased tension measured due to friction does not seem to be affected by the condition of the chain with respect to lubrication and tension, although a trend was noted for increased friction at higher resistance values. Further research might reveal that bearing adjustment and maintenance has a greater effect on mechanical factors than does chain condition.

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Chapter III

A Modified Cycle Ergometer[1]

INTRODUCTION

Most exercise physiology laboratories have one or more bicycle ergometers to be used as testing or training devices. Typically, these cycle ergometers have "upright" or reversed "North Bend" handlebars and a wide, padded saddle. Some cycle ergometers have been modified for the use of cyclists through the substitution of a racing saddle and handlebars and the addition of toe clips and straps (LaVoie et al., 1978).

Even with these modifications, however, the cycle ergometer lacks several important features that are found on a conventional racing bicycle. As a result, competitive cyclists find that they cannot assume their accustomed riding position on the cycle ergometer and often complain of feeling "awkward" or "uncomfortable" during training or testing sessions.

Modifications intended to increase the resemblance of the cycle ergometer to each cyclist's own bicycle were formulated prior to undertaking a training study on competitive cyclists. A Monark Model 668 cycle ergometer was redesigned and rebuilt by framebuilder Brad Proctor of Proctor-Townsend Frames Limited.

The major difference between the cycle ergometer and a racing (or even recreational) bicycle is the difference in the angles and insertions of the frame's tubes. A road racing bicycle may have seat and head tube angles of 72 to 75 degrees. Racing bicycles tend to have steeper angles than do touring bicycles. Cycle ergometers do not have the same frame angles as road racing bicycles; the Monark Model 668 cycle

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[1] A version of this chapter has been published: Somerville, K.A. & Quinney, H.A. A modified cycle ergometer. <u>Can. J. Appl. Sport Sci.</u>, 12 (4), 1987, 225-228.

ergometer used in this study had a head tube angle of 85 degrees and a seat tube angle of 80 degrees.

Differences in frame angles among road bicycles lead to different handling characteristics as well as to the difference in each rider's position on his or her bicycle. Although handling characteristics are not important on an ergometer, the rider's position is critical to performance.

In addition to the different seat tube angle found on the Monark cycle ergometer, the seat tube is not joined directly to the bottom bracket as it is in a conventional bicycle. Instead, the seat tube is placed 10.15 cm behind the bottom bracket (see Figure III-1). This causes the cyclist to assume a position on the bicycle which is farther behind the bottom bracket than is usual. The usual rule for fore and aft position of the saddle is that when the forward crank is in the horizontal position a plumb line dropped through the centre of the cyclist's knee should fall through the centre of the pedal spindle (Kolin and de la Rosa, 1979). On the Monark ergometer, a line through the centre of the knee in this position usually falls behind the centre of the pedal spindle. As a result, the cyclist is unable to replicate her or his accustomed position on the bicycle.

METHODS

To alleviate this problem, a triangle was welded to the top of the seat post (Figures III-2 and III-3). The saddle was thus able to move fore and aft in a tongue-and-groove arrangement with a quick-release lever to secure the saddle position. In addition, the saddleclamp normally found on the Monark model was exchanged for an SR Laprade clamp with a multi-adjustable tilting capability. The saddle found on the Monark was substituted with a Sella Italia Mundialita model which more closely resembled that used by competitive cyclists. The cyclists' own saddle can easily be used for testing with a minimum of readjustment.

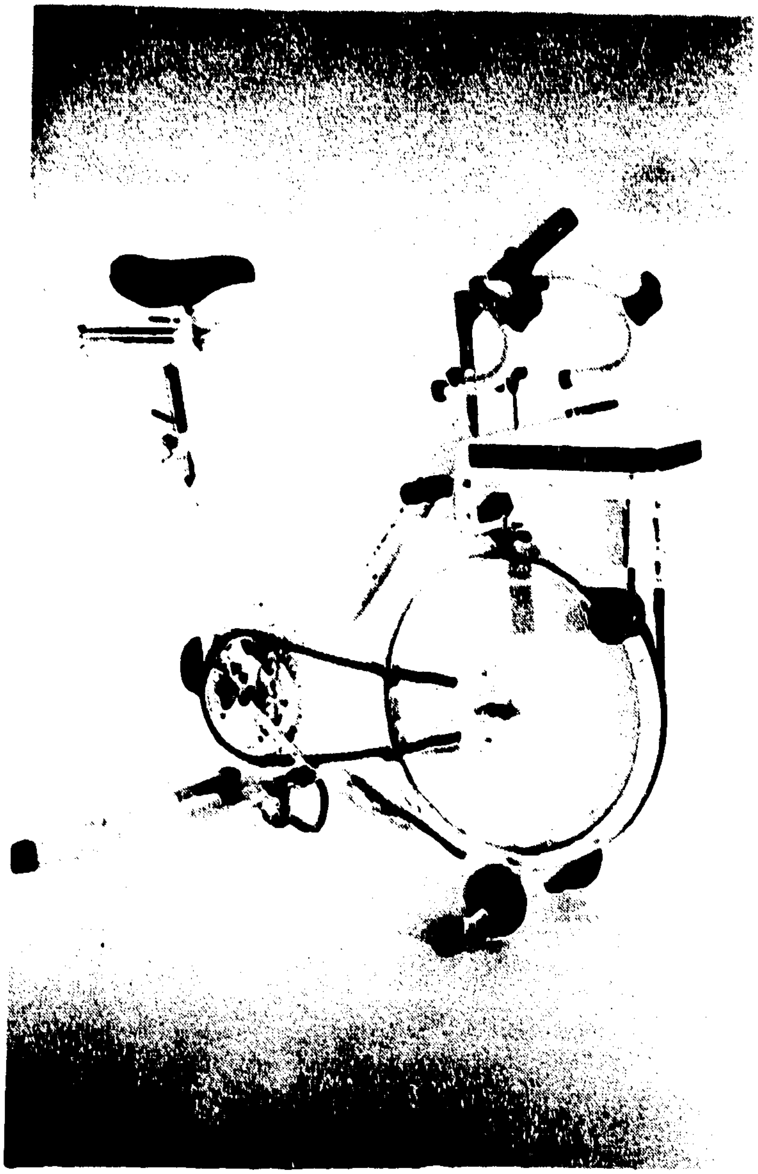

Figure III-1: The modified bicycle ergometer. Note that the seat tube is located 10.15 cm behind the bottom bracket.

Table III-1

Modified Cycle Ergometer Adjustment Ranges

Adjustment area	Minimum (cm)	Maximum (cm)
Saddle height	78.0	108
Handlebar reach	2.4	20
Handlebar height	17.7	30

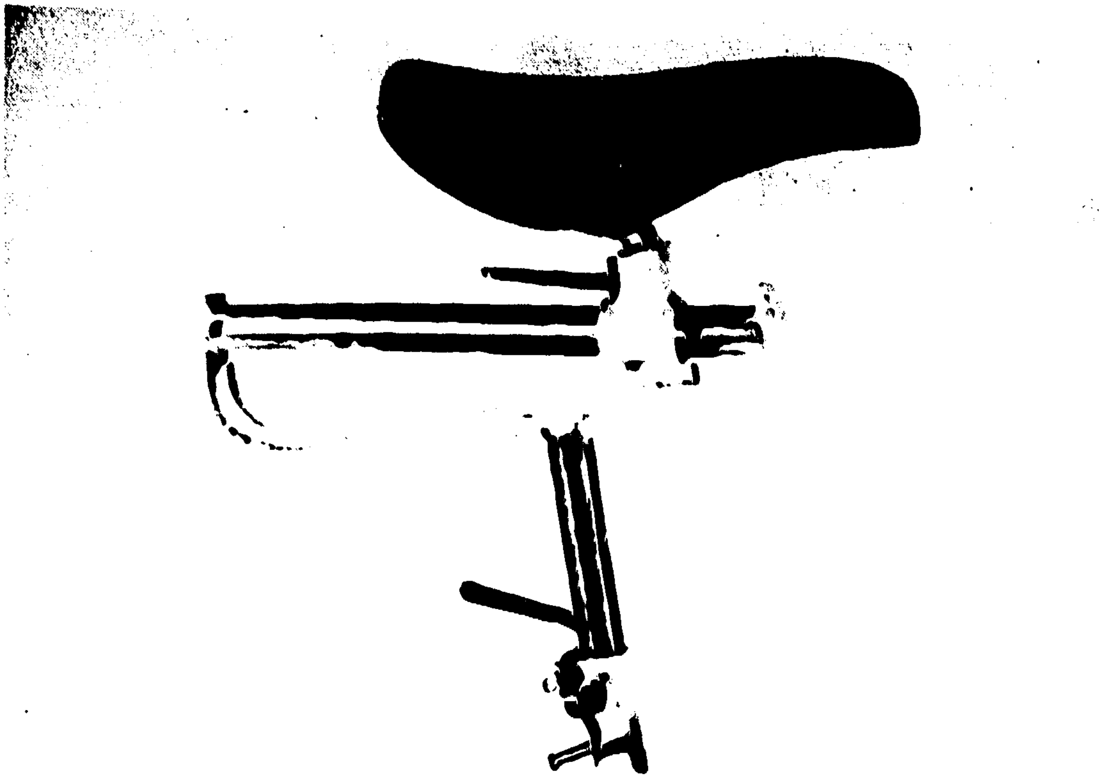

Figure III-2: The modified saddle/seatpost area, allowing fore and aft movement of the saddle.

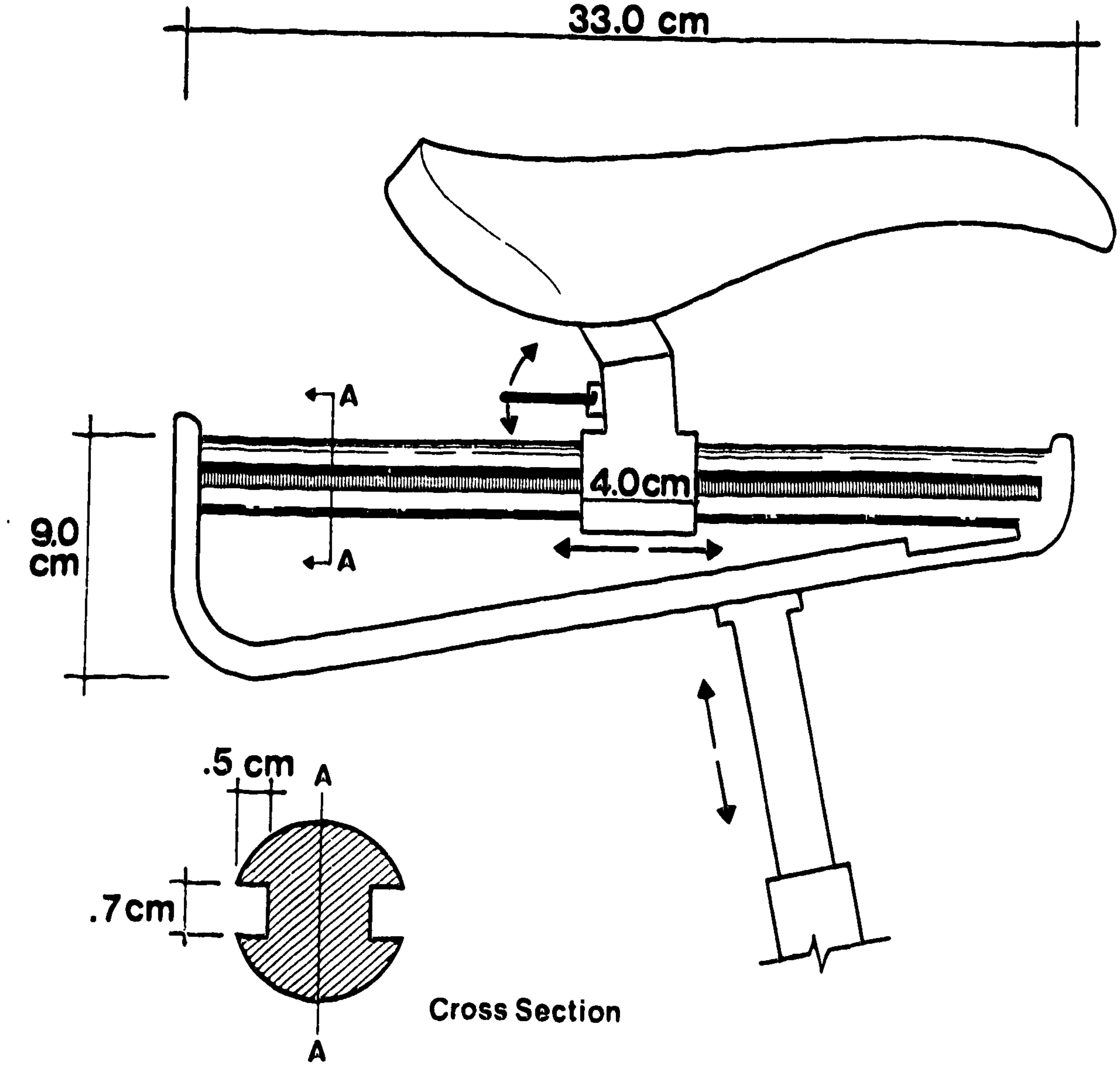

Figure III-3: Dimensions of the seat post triangle.

The seat post was reinforced with a metal cylinder to increase its strength, and a seat clamp secured with a quick-release lever was added to the top of the seat tube so that the seat post could be moved up or down in any increment desired. This allowed the replication of exact distance from the pedal spindle to the top of the saddle on the cyclist's own bicycle. Allowing for a seat tube insertion of 9 cm, the modification permits a minimum saddle height of 78 cm and a maximum of 108 cm, compared to the standard Monark 668 minimum and maximum heights of 74 and 104 cm respectively. The adjustment ranges for all modified areas of the cycle ergometer are included in Table III-1. The increase in minimum and maximum seat heights with modification can be attributed to the addition of the fore and aft triangle (see Figures III-2and III-3). The insertion of 9 cm on the modified Monark ergometer corresponds to an insertion of the seat post using the second-to-last insertion hole on the standard Monark seatpost. Use of the last hole on the standard Monark seat post as an insertion point is not recommended, owing to problems with inadequate strength and stability.

The one-piece crankset of the Monark cycle ergometer was removed, and a sleeve inserted into the bottom bracket to decrease the diameter to 3.4 cm. The crankset was then replaced with a Campagnolo Nuovo Record track crankset with quill pedals, toeclips and steel-reinforced toe straps with pull-tabs (Figure III-4). The steel reinforcements in the toe straps decrease the amount that the straps may stretch. The Campagnolo crankset is the same high-quality crankset that is used by many cyclists; it is strong, runs smoothly, and is easily serviceable. The chainring was drilled and tapped to accept three bolts. A microswitch adjacent to the bolts was thus triggered three times per revolution, giving increased accuracy in counting pedal revolutions during testing situations.

The length of the top tube and stem varies among bicycles and affects how far the cyclist has to reach for the handlebars. To duplicate the "reach" of each cyclist's bicycle, a square metal tube was welded at a 68 degree angle to the stem of the Monark. A square sleeve with a quick release was then slipped over this stem extension. A handlebar sleeve

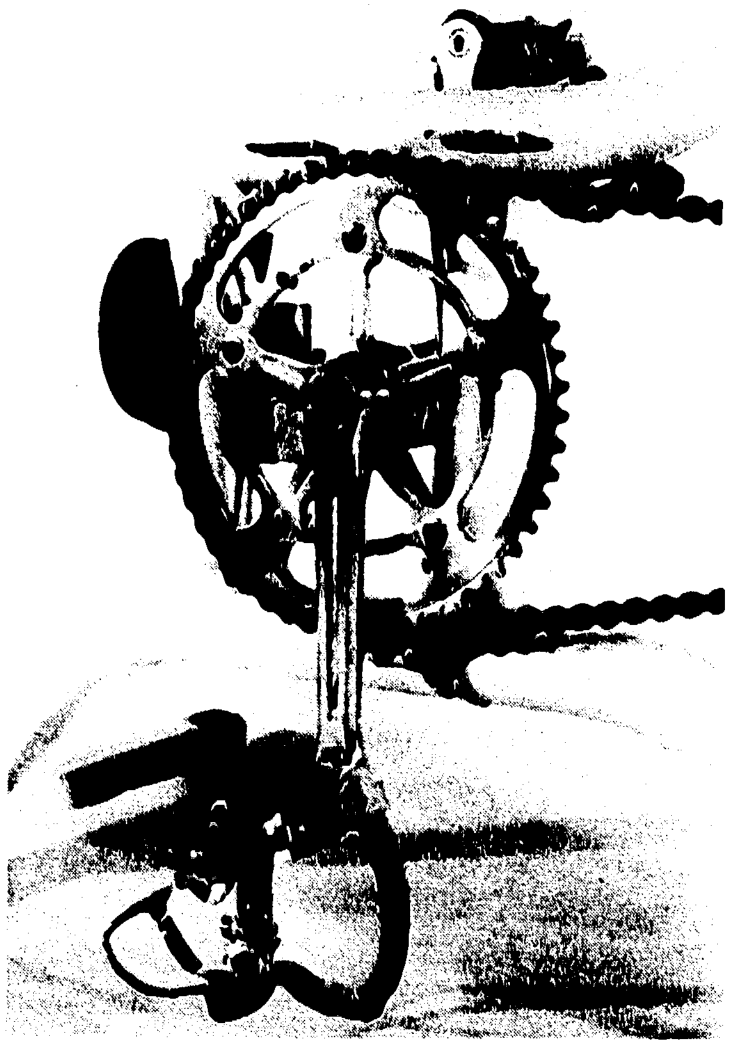

Figure III-4: The new crankset was drilled and tapped to accept three bolts that triggered a microswitch.

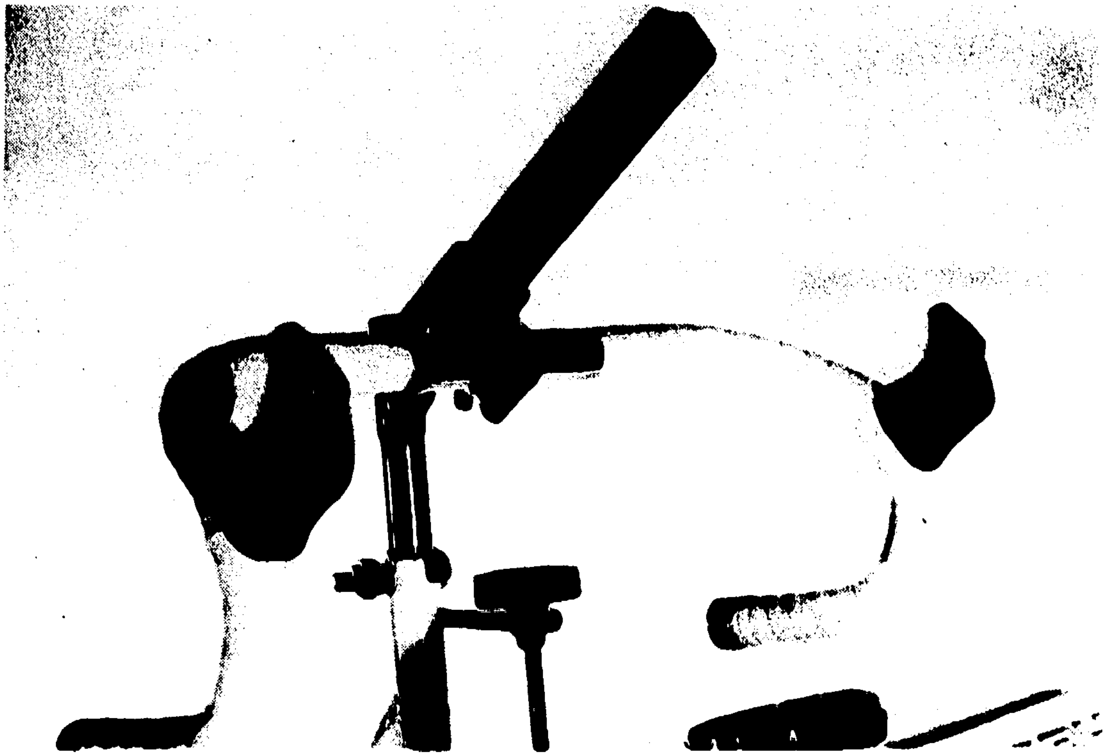

Figure III-5: The handlebars were inserted into a square sleeve which was held to a square bar by a quick release. Brake hoods were added to the handlebars.

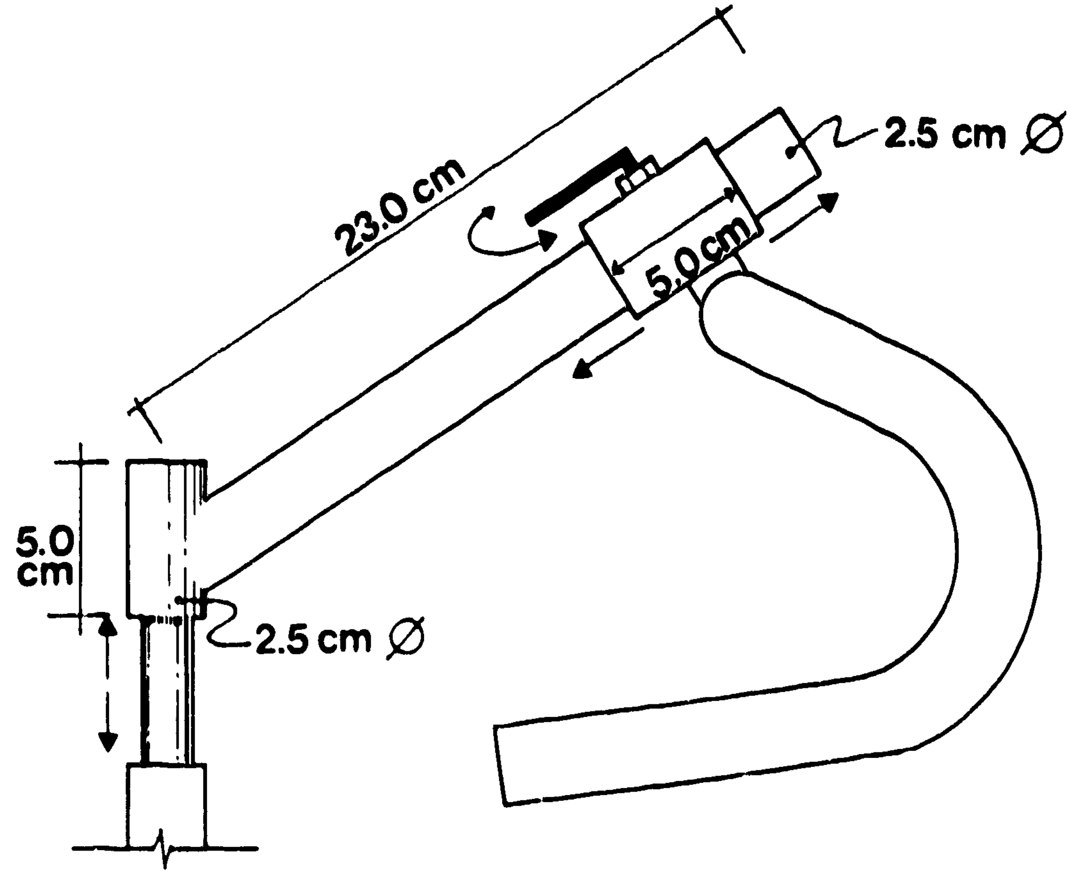

Figure III-6: Dimensions of the altered stem.

with an Allen key bolt was welded to the square sleeve (Figures III-5 and III-6). In this way, the handlebars could easily be moved back and forth depending on the length of the reach required. This modification resulted in an increase in handlebar reach from 2.4 cm to 20 cm (as measured from stem-bolt centre to handlebar centre). The angle of the stem extension allowed the handlebars to move up or down with the reach adjustment, since those subjects who required a longer reach were generally taller.

To adjust the height of the handlebars further, the metal reinforced neck around the upper part of the Monark stem was filed down to allow the stem to be inserted farther into the head tube, which lowered the minimum handlebar height from 25 to 17.7 cm. A quick-release lever was added to the head tube to facilitate rapid adjustment of handlebar height.

The handlebars supplied with the Monark cycle ergometer were replaced with Cinelli alloy Maes style handlebars. The handlebars have a reinforced sleeve in the stem area for additional strength. Problems had occurred in the past with steel Maes type handlebars when they collapsed at the stem during testing.

To give the cyclists a variety of hand positions, brake levers were modified by removing the levers. The brake housings were then clamped in the usual position on the handlebars, and rubber hoods added for comfort (Figure III-5).

To increase the stability of the cycle ergometer, the rear stabilizer bar was lengthened from 39 to 61 cm to provide a broader base.

RESULTS

With the modifications made to the cycle ergometer, it was possible to duplicate very closely the dimensions of the cyclist's own bicycle. Several measurements of the cyclist's own bicycle were made: the horizontal and vertical distances from the nose of the saddle to the centre of the upper portion of the handlebars, the vertical distance from the pedal spindle to the top of the saddle and the horizontal distance from the saddle nose to the centre of the bottom bracket spindle. The modified cycle ergometer was then adjusted to replicate these measurements. The distances of the adjusted saddle and handlebars from known landmarks on the modified ergometer were noted, so that subsequent use of the modified cycle ergometer was simplified.

The result of the modification was a cycle ergometer that could be made to resemble very closely the cyclist's own bicycle in approximately three minutes during testing sessions. The modified cycle ergometer was used by the cyclists in several testing sessions throughout the year. The cyclists found the modified device comfortable and very much like their own bicycles. Part of the acceptance of the new design by the cyclists may have originated from the framebuilder's decals displayed on the ergometer.

DISCUSSION

After employing this cycle ergometer over a period of two years, some minor modifications can be recommended. While the construction of the cycle ergometer is satisfactory for cyclists (who are able to apply maximum force to the pedals without moving their upper bodies significantly), some twisting of the seat post and handlebars has occurred with less-experienced cyclists. To avoid this problem, it is recommended that square tubes be substituted for the round tubes presently used for the seat post and stem.

A second problem arose from the use of steel in the tubing that was replaced. This steel quickly rusted upon use owing to the large amount of sweat with which it came into contact. This problem can easily be solved by having the steel chrome-plated.

Finally, the cycle ergometer's stability, while somewhat improved through the lengthening of the rear stabilizer bar, could be further improved by lengthening the front stabilizer bar as well. Some rocking of the cycle ergometer was noted during power tests with inexperienced cyclists.

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Chapter IV

The Effect of Cycle Ergometer Modifications upon VO_2 max and 30 Second Power Test Values in Male Competitive Cyclists

INTRODUCTION

While the modified cycle ergometer described in Somerville and Quinney (1987) was subjectively rated by cycling subjects as comfortable and similar to their own bicycles, the effect of the modifications upon test results is not known. This study will attempt to quantify the differences in the performance of an exercise test on a modified and a standard Monark 868 cycle ergometer.

There is now ample evidence in the literature suggesting that specificity in exercise testing is necessary in order to obtain the most valid test results possible. Originally, however, researchers felt that tests for maximum aerobic power (VO_2 max) were best carried out on the treadmill, as this testing device seemed to yield the highest VO_2 max values. When subjects were tested by producing the same amount of power on both the cycle ergometer and the treadmill, the values for VO_2 max on the treadmill were invariably higher. Miyamura et al., (1978) found that values for trained subjects were 8% higher and for untrained subjects 9.4% higher on the treadmill as compared to the cycle ergometer. McArdle and Magel (1970) found treadmill values to be 9.9% higher, McKay and Banister (1976) 10.5% higher, and McArdle et al. from 10.2 to 11.2% higher.

The significant similarity among these studies was that although in most cases trained subjects were used, very few of the subjects were trained cyclists. It was hypothesized by later researchers that since the subjects were not trained as cyclists, the relevant leg muscles were not well adapted and therefore fatigued before the central components of the cardiovascular system were maximally stressed (Stromme et al., 1977; Withers et al., 1981).

Roberts and Alspaugh (1972) found that when two untrained groups were trained for six weeks on either the treadmill or on the cycle ergometer (CE) that the treadmill (TM) group increased their VO_2 max values on both types of equipment, but that the VO_2 max of cyclists increased only on the cycle ergometer. Pannier et al. (1980) tested controls and runners and found that the controls showed no significant difference in VO_2 max between the CE and TM tests, but that runners had TM VO_2 max values 12.8% higher than for the CE. Withers, Sherman, Miller and Costill (1981) tested cyclists and runners and reported that runners had VO_2 max values which were 10.4% higher on the TM than the CE while cyclists had 4.5% higher values on the CE as compared to the TM (which was not statistically significant). The results of these studies indicate that testing is indeed activity pattern specific, and that cyclists should be tested on cycle ergometers in order to optimally stress the systems functionally required for cycling.

Having established that cyclists should be tested on cycle ergometers, the next logical step would be to make the ergometers resemble as closely as possible the cyclists' own bicycle, in order to stress the muscles for testing in precisely the same way that they are stressed during training and competition. The modified cycle ergometer described in Somerville and Quinney (1987) allowed the toe clips, crank length, saddle height, horizontal reach and vertical drop to the bars to be adjusted to replicate those dimensions found on the cyclists' own bicycle. Several studies have shown the value of some of these changes, while other changes remain untested.

LaVoie et al. (1978) reasoned that the use of toe clips might enable subjects to use a larger muscle mass in cycling tests and that VO_2 max values closer to those found in TM tests would therefore result. LaVoie et al. found that both competitive cyclists and recreational cyclists attained significantly higher VO_2 max values with the use of toe clips, and that VO_2 max values were significantly lower on the CE compared to the TM when toe clips were not used. The authors hypothesized that the higher values were due to the fact that toe clips enable the cyclist to push down with one leg while pulling up with the other, thus allowing the use of a larger muscle mass.

LaVoie et al. (1984) examined the use of toe clips in anaerobic power tests. These authors found a five to 12 % increase in values obtained on anaerobic power tests conducted on cycle ergometers equipped with toe clips versus without toe clips. Using exactly the same words, these authors concurred with the conclusion of the LaVoie et al. (1978) paper that the increased power output was due to the pulling action of the recovery leg, which allowed the use of a greater muscle mass.

Lafortune and Cavanagh (1983) studied the forces applied at the pedals by subjects with and without the use of toe clips and cleated shoes. These authors found a significant difference in the type of force applied to the pedal. In the non toe clip condition the peak normal force was greater, while the peak tangential force was greater when toe clips were used. The authors concluded that the greater tangential force was possible because the toe clips provided resistance to slip. Lafortune and Cavanagh also noted that even during the recovery phase the subject exerted force on the pedal, indicating that a portion of the propulsive impulse was used to lift the recovering leg. Lafortune et al. (1983) found that cyclists generated a negative torque which amounted to between 2.7 and 16.2% of the total propulsive impulse. These findings are in contrast with the hypotheses of LaVoie et al. (1978) and LaVoie et al. (1984), who theorized that cyclists used the toe clips to pull up during the recovery phase.

Davis and Hull (1983) undertook a more detailed analysis of the forces involved in the use of non toe clip, toe clip and soft shoe and toe clip foot/pedal combinations. These authors found that during the first 25 degrees of arc in the foot cycle, the toe clips increased efficiency. Efficiency in this case referred to "the instantaneous percentage of the total load vector contributing to positive work" (p. 115). The increased efficiency during the first 25 degrees was due to increased dorsiflexion (which increased normal load utilization) as well as to increased positive shear

The use of cleated shoes, the authors found, further increased efficiency. An additional efficiency peak between 190 and 240 degrees was found and was attributed to a greater negative shear load during the backstroke with a pedal position that allowed effective use of the load. This, the authors concluded, permitted better control of plantar flexion and more work by the hamstrings. In addition to this, the authors found that maximum torque was lower with cleats and toe clips because the greater backstroke efficiency plus the negative shear load combined to create positive torque beyond 200 degrees of arc; with the cleated shoe, only 55 degrees of the arc was associated with negative torque. Thus the addition of toe clips and cleats increased efficiency early in the arc so that the extensor muscles were needed less to provide the major motive work, and the flexor muscles could increase their activity in the negative shearing in the backstroke. In contrast to early hypotheses, then, these authors found that most of the torque during the upstroke was created by inclining the pedal and pulling back, not by pulling up on the pedal; thus negative shear load was more important than positive normal load during this phase. In fact, the normal load almost invariably contributes negatively during the backstroke.

We can conclude from this that while toe clips provide greater dorsiflexion and shear loads during the early phase of the arc, cleats are necessary in order to allow an increase in flexor activity during the backstroke through increased negative shear. The modified cycle ergometer used in the present study employed toe clips and Campagnolo racing pedals to ensure that the cyclist maintained a good pedal/shoe interface. Recently a new type of pedal/cleat combination has been manufactured which employs a ski-boot style of binding. For the subjects in the sample of cyclists that used this type of pedal, the pedals were removed from their own bicycles and threaded into the cranks on the bicycle ergometer.

The adjustable dropped bars fitted on the modified cycle ergometer should also have an effect on the VO_2 max values elicited. Little research has been undertaken regarding the effect of hand position on the handlebars upon VO_2 max. In a 1967 paper Hamley and Thomas noted that at high work loads with the hands in a racing position on the drops lower heart rates and oxygen uptakes were observed, although significance, sample size and $V0\ 2$ values were not reported. Faria et al. (1978) found that cycling with the hands on the drops significantly increased maximum values for oxygen uptake, work output and pulmonary ventilation. Kolin and de la Rosa (1979) recommended that the angle of the cyclist's back be maintained at 45 degrees in order to involve the gluteal muscles in the pedalling effort; this requires that the hands be placed on the drops. It would seem advisable, therefore, to ensure that cyclists are tested with their hands on the drops of the bars in order to elicit maximal VO_2 max values. The cyclists used as subjects in pilot testing on the modified cycle ergometer invariably chose to place their hands on the drops during testing. In the present study all subjects were required to maintain a dropped hand position in order to standardize testing.

The length of the crank used for testing may also affect the performance values obtained. Conrad and Thomas (1983) found no differences in VO_2 max among seven crank lengths which ranged from 165 to 185 mm in 2.5 mm increments. Inbar et al. (1983) found that there was a small variation (1.24%) in peak anaerobic power when crank length ranged from 125 mm to 225 mm: the optimal crank length was found to be dependent on the subject's lower limb length. The authors concluded that the importance of crank length was only marginal, except when testing very short or tall adults.

The effect of crank length upon VO_2 max values does not seem to be a major consideration. The cranks on the modified cycle ergometer are 170 mm, which is the standard length used by cyclists. Whether or not VO_2 max is affected by crank length is probably less important than the fact that using the standard length will allow cyclists to use their accustomed cycling technique. By allowing the cyclists to use cranks which duplicate their own, maximum specifity of muscle groups may be attained.

Saddle height on the modified cycle ergometer is infinitely adjustable as compared to the standard Monark 868, which uses set increments of one inch. Various authors have reported that certain seat heights maximize VO_2 max values found in cycle ergometer tests. Hamley and Thomas (1967) found that the saddle height (SH) position which elicited greatest effectiveness in an aerobic power test was 109% of the distance from the symphysis pubis to the floor. Shennum and deVries (1976) recommended a saddle height of 103 to 104% of the inside leg measurement from the ischium to the floor to maximize power output. This corresponds to 105 to 108% of symphysis pubis height. Nordeen-Snyder (1977) found that a SH of 100% of trochanteric height (107.1% of symphysis pubis height) was the most efficient, while saddle heights above and below this value were less so.

Somerville et al. (1985) found that the mean SH used by a group of competitive cyclists ranged between 98.7 and 109.1% of trochanteric height, with a mean of 102.2%. While the average SH found is comparable to that found to be most efficient in earlier studies, the range of SH found is of importance. As Kroon (1983) has pointed out, the cyclist is sometimes not as concerned with maximal efficiency as he or she is with winning the race. If specifity of movement is to be considered, cyclists should be tested at the SH to which they are accustomed, whether or not it elicits maximal efficiency in a laboratory setting.

While some research has examined the effects of toe clips, shoe cleats, dropped bars, crank length and saddle height, no information is available concerning the effects of the rest of the cycle ergometer modifications. This study will attempt to determine whether the modifications made to the cycle ergometer will result in a more optimal test of the energy systems involved in cycling.

METHODS

Ten male competitive cyclists aged 27.0 ± 7.39 years and with 6.55 ± 3.52 years of competitive cycling experience completed an aerobic power test on a modified (Somerville & Quinney, 1987) and stock Monark 868 cycle ergometer which had been modified through the addition of quill-type pedals, toe clips, straps and a narrow saddle. The subjects wore their racing cleats in both tests and used the pedal type to which they were accustomed when using the modified ergometer. The cadence of 90 rpm was monitored on the modified ergometer with a Cateye cyclocomputer (model CC-2000) and with the cadence monitor supplied with the Monark cycle ergometer when the standard ergometer was used. All tests were preceded by a 5 minute cycling warm-up conducted at a resistance of 3 kiloponds (kp). The aerobic power test was a continuous progressive test in which the subject pedalled against a resistance of 1 kp for the first two minutes and 2 kp for the second two minutes. Thereafter the resistance was increased every minute by .5 kp until the subject could no longer continue the test. Cyclists were advised to maintain a seated position throughout the test. A Beckman Metabolic Measurement Cart was used to collect the expired gases and to analyze them every 30 seconds throughout the test. The Metabolic Measurement Cart was calibrated before and after each test according to the manufacturer's instructions (see Appendix B). VO_2 max was considered to have been reached at the point at which VO_2 reached a plateau or decreased with increasing resistance.

Eleven male competitive cyclists aged 27.7 ± 6.56 years and with 3.32 ± 2.61 years of competitive cycling experience completed a 30 second power test on a modified cycle ergometer and a standard Monark 868 cycle ergometer. The standard Monark cycle ergometer was modified somewhat through the use of quill-type pedals, toe clips, straps and a narrow saddle. Each cylist was tested at his optimal resistance, using a factor of either .085, .090 or .095 kp per kilogram of body weight. The optimal value was chosen through the use of pre-tests to determine the factor which produced the highest mean power output. The dynamic starting technique was used in all 30 second power tests. The power output was measured through the use of an electronic eye which registered fifths of a revolution.

A correlated t-test was used to determine if significant differences existed between the two types of ergometers in terms of aerobic and 30 second power output. Differences between ergometers for VO_2 values at the level of 70% of VO_2 max were examined using an analysis of variance.

RESULTS

The VO_2 max values for the 10 cyclists had a mean of 59.11 ± 2.81 ml/kg/min when tested on the standard Monark cycle ergometer and a mean of 61.19 ± 4.12 ml/kg/min on the modified cycle ergometer. A correlated t-test did not detect a significant difference between the mean of the two types of tests ($p=.310$). Intraclass reliability for the VO_2 max measures was established at .96 for a single measure.

Intraclass reliability was established for the 30 second power tests at .98 for a single measure. The results of the 30 second power tests were divided into peak and mean power outputs. On the standard Monark cycle ergometer the peak power output for the 11 cyclists was 12.68-1.20 W/kg. On the modified cycle ergometer the peak power output was 12.88-1.48 W/kg. A correlated t-test showed no significant difference between these two means ($p=.679$).

The mean power output on the standard Monark ergometer was 9.75-1.09 W/kg, while the mean power output on the modified cycle ergometer was 10.08-1.24 W/kg. A correlated t-test did not detect a significant difference between the mean power outputs for the two tests ($p=.272$). An analysis of variance revealed that no significant differences existed between VO_2 values at 70% of VO_2 max and at VO_2 max for either the standard or modified cycle ergometers ($p=.066$ and .104, respectively).

Subjectively, the cyclists unanimously preferred the modified cycle ergometer to the standard Monark cycle ergometer. All of the cyclists complained of discomfort and/or awkwardness when riding the unmodified cycle ergometer even though an attempt was made to adjust the ergometer to the cyclist.

DISCUSSION

The fact that no significant difference was found among tests conducted on the modified and standard cycle ergometers would seem to indicate that there are limitations to the extent to which specificity of exercise should be pursued. The lack of significant differences may indicate the following: either the changes made to the ergometer do not affect power output or the tests used are not sensitive enough to detect such differences.

Earlier researchers found that cyclists generated larger power outputs on a cycle ergometer rather than on a treadmill (Pannier et al., 1980; Roberts & Alspaugh, 1972), when toe clips were used (LaVoie et al., 1978, LaVoie et al. 1984; Davis & Hull, 1983) and when saddle height was optimal (Hamley & Thomas, 1967; Lawrence, Shennum & deVries, 1976). The modifications to the ergometer used in this study were not as extensive (in relative terms) as those described in the above studies. Earlier work entailed more drastic changes as the cycle ergometers were modified by adding toe clips and straps, cycling cleats, dropped handlebars, and through the employment of proper saddle height. In the present case one would expect to see only moderate alterations in the posture of the cyclist as compared to the modifications which occurred in the preceding research. There is no doubt, given the comments of the cyclists, that the present alterations were noticeable and welcomed. Smith et al. (1989) found that when cyclists were tested on both their own bicycle and a Monark ergometer no difference in VO_2 max was apparent, but ratings of perceived exertion were significantly lower when cyclists used their own bicycles. This agrees with the present finding that no significant difference in test values was found, but cyclists expressed satisfaction with the modified cycle ergometer.

It is possible that we have reached the point at which further postural changes will not be reflected in the outcome of tests. The exception to this would be pronounced changes in posture. Too (1989) concluded that an optimal body position does exist in order to maximize the results of a 30 second power test. This conclusion was reached after having the cyclists pedal in extreme postural conditions which created a range of hip angles from 25 to 100 degrees. The subject was strapped to a seat/backrest to maintain the extreme positions. Such large postural changes can affect 30 second power output values, but are unlikely to be practical for the competitive cyclist.

It should be noted that although no significant difference was found between the modified and standard cycle ergometers on the two tests, the values for the tests on the modified cycle ergometer were consistently slightly higher. It is possible that while a trend to higher results on the modified ergometer was present, it was not found to be significant because the testing equipment itself was not sensitive enough to detect such differences. This is especially true for the 30 second power tests, in which revolutions are recorded in fifths. If this value was measured on a continuous basis the test might be more sensitive to change. Further research might prove the value of this modification to the testing technique for the 30 second power test.

In conclusion, the use of a highly-modified cycle ergometer for VO_2 max and 30 second power tests did not lead to significantly higher test results, although the cyclists preferred the cycle ergometer. If such an ergometer is not available to the researcher, results should not be adversely affected. A cycle ergometer modified through the addition of toe clips, straps, racing handlebars and saddle seems to be sufficient to produce maximal results. The use of the modified cycle ergometer does seem to satisfy cyclists' physical need for comfort and perhaps a psychological need for familiarity in the testing instrument as well.

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Chapter V

Angular Velocity of the Knee in Cycling[1]

INTRODUCTION

The value of velocity-specific testing and training has been the topic of several papers (Sale & Norman, 1982; Moffroid & Whipple, 1970). When conducting performance tests on elite athletes, the test results must reflect as closely as possible the abilities of the subjects. To this end, the angular velocity at which the tests take place should be identical to that of the actual sport performance of the subjects (Sale & Norman, 1982). Unfortunately, little information exists concerning the angular velocity of the knee in competitive cycling.

Desipres (1974) studied the knee angular displacements of three experienced competitive male cyclists at a cadence of 90 revolutions per minute (rpm) with a saddle height of 95% and 105% of symphysium height. The average amplitude of the angular displacement at 95% symphysium height was 70 degrees and at 105% symphysium height was 75 degrees. Nordeen-Snyder (1977) analyzed the knee angular displacement of 10 female non-cyclists at a cadence of 60 rpm at saddle heights of 95, 100, and 105% trochanteric length. Angular displacements were 72.2, 73.2 and 80.7 degrees respectively, and angular velocities were 139.7, 144.4 and 157.5 degrees per second respectively (read from graphs).

Two problems arise in the use of these studies for information on angular velocity of the knee in cycling. The first is that the saddle height used by competitive cyclists may or may not be identical to the values used in the studies.

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[1] A version of this chapter has been published: Somerville, K.A., Gervais, P. & Quinney, H.A. Angular velocity of the knee in cycling. Can. J. Appl. Sports Sci., 10 (4), 1985, 31P.

The use of a saddle height calculated as a percent of an anthropometric measurement originated with the work of Hamley and Thomas (1967) in which an optimal saddle height for performance on a bicycle ergometer test was determined. Other researchers have attempted to determine the optimal saddle height for oxygen efficiency (Nordeen-Snyder, 1977; Shennum and deVries, 1976).

Recently it has been stated that formulae which provide an optimal position for testing are not necessarily the best formulae for actual riding conditions (McCullagh, 1984). Kroon (1983) has pointed out that a competitive cyclist in a race is not as concerned with high efficiency as he or she is with winning the race. It is therefore perhaps more desirable to use the cyclists' own saddle height rather than an optimal height when testing. Because this study involved the measurement of the angular velocity of the knee during cycling, an attempt was made to replicate the actual conditions of competition. To this end, saddle height was not manipulated.

The second problem in previous research has been the lack of a standardized cadence that matches that of the cyclist during competition. By examining angular velocities of the knee at 75, 90, 110 and 150 rpm a range of possible values was obtained in the present study.

This study, therefore, undertook to find values for knee angular velocity in competitive cyclists at four cadences with the saddle height adjusted to that normally used by the subjects. Electrogoniometry was chosen as the method of determining angular velocity as it is an efficient, quick and inexpensive method of recording joint motion.

METHODS

Nine male cyclists from local cycling clubs volunteered for the study. All were Senior A competitive cyclists aged 25.0 ± 3.67 years with competitive cycling experience of 3.89 ± 2.89 years.

Measurements were made of the dimensions of the cyclists' racing bicycles. Saddle height was measured parallel to the seat tube from the top of the saddle to the pedal spindle with the crank parallel to the seat tube. The distance from the nose of the saddle to the centre of the bottom bracket spindle was measured using a plumb line. The distance from the saddle nose to the centre of the handlebars and the drop between the top of the saddle and the tops of the handlebars was also measured. A specially-modified Monark cycle ergometer was then adjusted to replicate exactly each of these measurements (Somerville & Quinney, 1987).

The trochanteric height of each cyclist was measured with the cyclist standing next to a wall in bare feet. The centre of the greater trochanter of the femur was palpated and a mark made on a measuring chart opposite the landmark using a Broca plane.

The electrogoniometers (elgons) were identical to the modified hinged elgons described in the work of Gollnick and Karpovich (1964). The elgons were placed on the cyclists according to the techniques of Karpovich et al. (1960).

The cyclists pedalled the bicycle ergometer at cadences of 75, 90, 110 and 150 rpm at a resistance of two kiloponds. A Cateye Solar Cyclocomputer (Model CC-2000) was used to monitor cadence (± 1 rpm). The data were normalized in terms of cadence allowing data to be reported for the exact cadences being examined. The amplitude of the cyclists' knee displacement was recorded using a Sanborn 964 digital recorder with a chart speed of 25 millimetres per second.

Each subject pedalled at the required cadence for a period of two to three minutes before a recording was made, with the result that all peaks in each measurement were identical. The average angular velocity over a one second time period was obtained from the chart readings for each cadence by calculating the degrees of movement per second. The actual cadence of the cyclists was also recorded from the charts. The data obtained were expressed as means. An analysis of variance with repeated measures was used to detect significant differences among amplitudes at each cadence.

RESULTS

The saddle heights of the cyclists ranged from 98.7 to 109.10% trochanteric height, with a mean of 102.22% (± 3.68%). The values for the angular velocity of the knee at each cadence are displayed in Table V-1. Table V-2 contains the values for the angular displacement or amplitude of the knee at each of the four cadences. Figures V-1 and V-2 provide a visual representation of the trends in amplitude and angular velocity at each cadence.

An analysis of variance with repeated measures revealed a significant difference among the mean amplitudes at each cadence ($p=.029$). A Scheffe post-hoc analysis found that the value for amplitude at a cadence of 150 rpm was significantly higher than the other amplitude values.

DISCUSSION

The value obtained in this study for the mean saddle height expressed as a percentage of trochanteric height (102.22 ± 3.68%) is close to the values identified in previous research. It is important to realize that a difference of 1 or 2% in saddle height is a large one in terms of the cyclists' comfort and familiarity with the position. Therefore the relatively large range of saddle heights used by the cyclists in this study reinforces the notion that the saddle height used for testing purposes should be that which is chosen by the cyclist.

Hamley and Thomas (1967) found that a saddle height adjustment of 109% symphysis pubis height elicited the best results on a test of power output (time to complete a given amount of work). Nordeen-Snyder (1977) reported an optimal saddle height setting of 100 % trochanteric height (107.1% symphysis pubis height) for greatest oxygen efficiency at 60 rpm and with a resistance of 799 kilopond-metres per minute. Shennum and deVries (1976) proposed a saddle height of 103 to 104% of the distance from the ischium to the floor (108 to 109% symphysis pubis height) for the "best oxygen

Table V-1: Angular Velocity (degrees per second)

RPM	Mean ± s.d.
75	176.7 ± 30.1
90	227.0 ± 31.5
110	260.9 ± 21.4
150	396.0 ± 66.7

Table V-2: Amplitude (degrees)

RPM	Mean ± s.d.
75	74.7 ± 10.2
90	74.9 ± 10.1
110	73.2 ± 7.8
150	79.7 ± 12.8

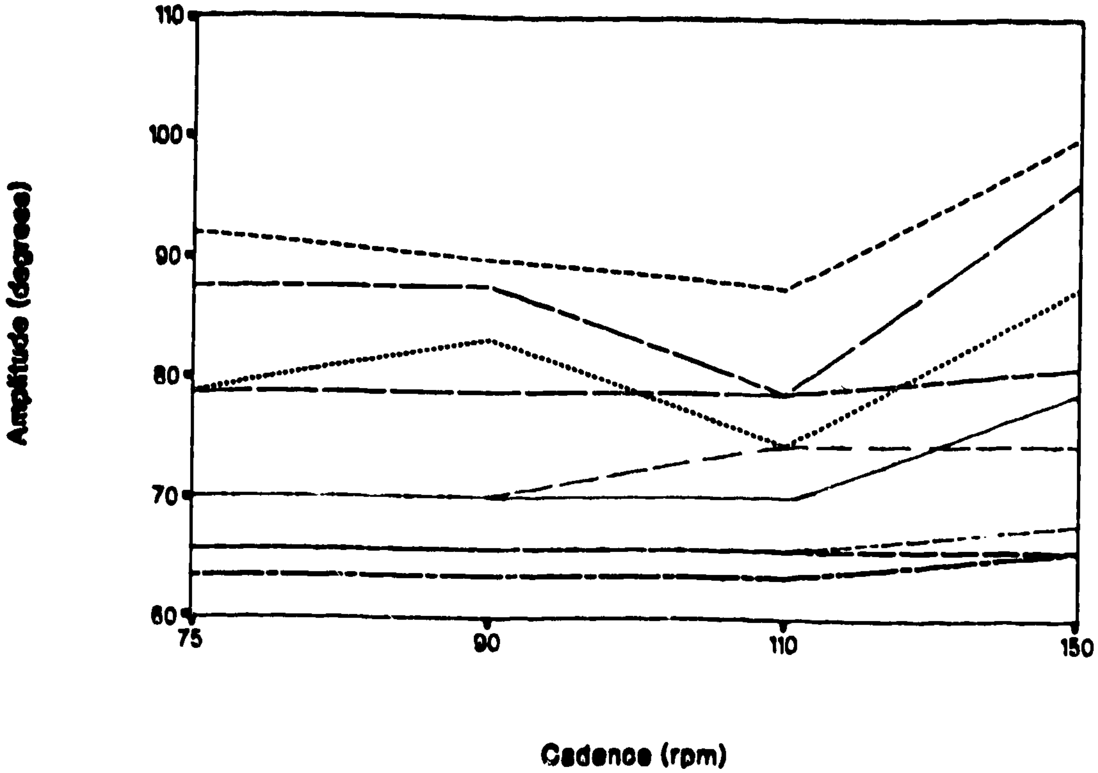

Figure V-1: Amplitude at Each Cadence

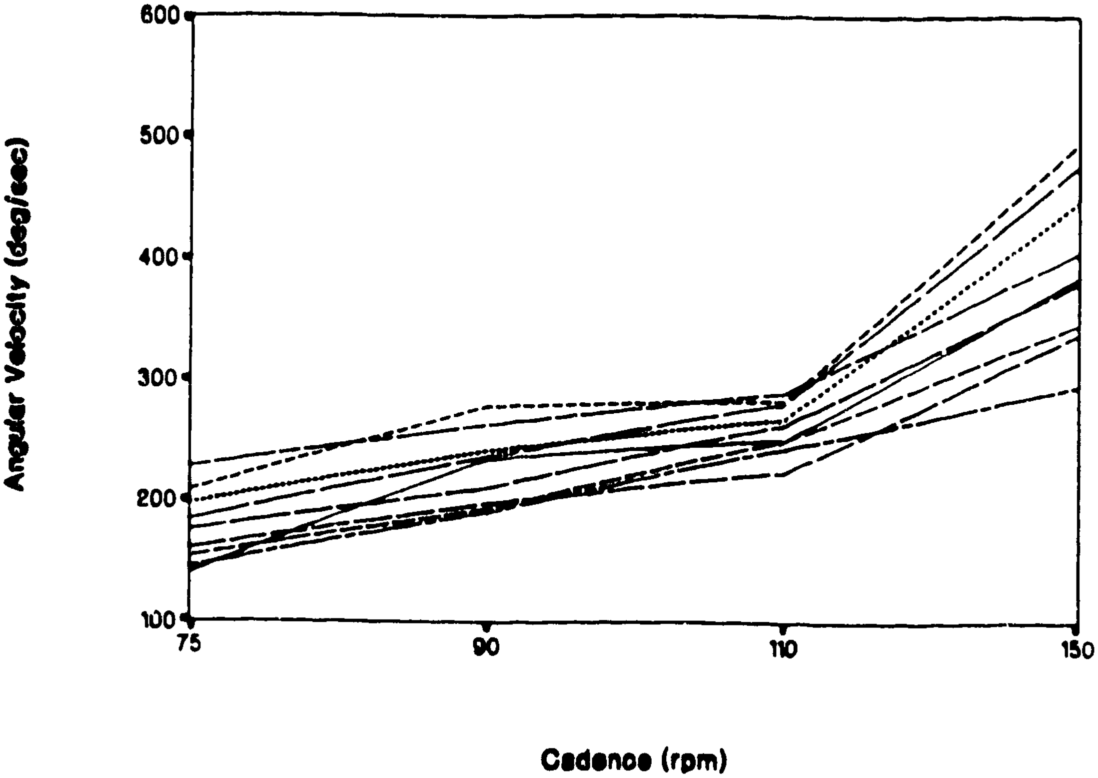

Figure V-2: Angular Velocity at Each Cadence economy". The cadence used in their tests was 60 rpm, and the resistance increased in 25 watt increments from 50 to 200 watts.

An attempt to convert percent trochanteric heights to percent symphysis pubis heights was not made in the present study. Measurement of per cent trochanteric height was felt to be the least intrusive measurement while providing a suitable anthropometric proportion for the expression of saddle height. The researchers therefore propose that future measurements follow this trend. It must also be noted at this point that while this measurement may standardize the height of the saddle, it does not standardize the actual movement of the cyclist while pedalling. If the cyclist shifts her or himself forward on the saddle while pedalling (which often happens during intense effort) the saddle height may be effectively reduced by approximately one centimetre. The actual distance from saddle to pedal is also affected by the length of the cyclists' feet; this factor is not accounted for in the measurement techniques described above.

The angular displacement of the knee in this study ranged from 73.2 ± 7.8 degrees to 79.7 ± 12.8 degrees with a mean saddle height of 102.2% trochanteric height. This finding is in agreement with the findings of previous researchers. Desipres (1974) found values of 70 degrees and 75 degrees at 95 and 105% symphysium height respectively. Nordeen-Snyder (1977) reported values of 72.2, 73.2 and 80.7 degrees at saddle heights of 95, 100 and 105% trochanteric height. Rosler et al. (1986) reported a value of 74 degrees for angular displacement of the knee during cycling, but did not report saddle height.

A significant difference was found between the amplitudes at each cadence (p=.029). In this case the displacement of the knee increased when cadence was increased to 150 rpm; this is illustrated graphically in Figures V-1 and V-2. The fact that angular displacement of the knee increased at the increased velocity suggests that at this velocity cyclists changed their pedalling pattern. It must be remembered that the cyclists were being asked to increase their cadence to 150 rpm while pedalling against the same resistance. What probably occurred in this case was that the cyclist was generating a cadence and therefore power output greater than that which was necessary to overcome the resistance. This would lead to a situation in which the cyclist was spinning too quickly, a condition which usually results in a relative loss of control over the movement pattern. A similar effect might be realized if one was asked to pedal continuously down a steep hill in a fixed gear; eventually the speed of the bicycle is such that pedalling is no longer effective, and the legs are no longer applying force in their accustomed pattern.

Various researchers have confirmed that cyclists normally favour cadences between 80 and 110 rpm, with preference being given to the high end of the range by more experienced cyclists (Kroon, 1983; Whitt & Wilson, 1974; Pugh, 1974). Cyclists therefore tend to choose a gear ratio which allows them to pedal at these speeds. It would seem that in order to maintain an increased cadence against a necessarily lower force, cyclists must change their movement pattern, which may result in an increased angular displacement about the knee. This implies that the pattern of force application is less efficient, even though greater overall forces are probably being developed. This is consistent with the findings of Hagberg et al. (1981) that it is not recommended that road cyclists use a cadence over 110 rpm, while track cyclists may use a cadence as high as 160 rpm for short sprints. When sprinting for short durations, high power output is the desired outcome, and some efficiency must be sacrificed in order to attain this.

The values for angular velocity of the knee at a mean saddle height of 102.2% trochanteric height were comparable to those found by Nordeen-Snyder (1977). She reported an angular velocity of 144.4 degrees per second and 157.5 degrees per second at 100 and 105 percent trochanteric height respectively, with a cadence of 60 rpm. An angular velocity of 176.7 ± 30.1 degrees at 75 rpm was found in the present study. When Nordeen-Snyder's results are recalculated for a cadence of 75 rpm (assuming amplitude does not change) the resultant angular velocity is 180.5 degrees per second. Therefore the difference between the present findings and those of Nordeen-Snyder is probably a result of the differences in cadence. Rosler et al. (1986) found a knee angular velocity of 200 degrees per second at 80 rpm, which falls between the values found for 75 and 90 rpm in the present study.

The results of this study confirm the findings of previous researchers with regard to angular velocity of the knee during cycling. Previous research was expanded upon by examining a wider selection of cadences and by using the saddle height chosen by the cyclist. The values contained herein should assist in the development of specific testing and training protocols for competitive cyclists. While this and other studies provide mean values for angular velocities at specific cadences, given the wide range of values found here it may be desirable to test athletes individually at their own preferred cadences to obtain angular velocities specific to the athlete.

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Chapter VI

The Effect of Starting Technique upon Peak and Mean Power Output Values in a 30 Second Power Test

INTRODUCTION

Many studies have been undertaken which employ a protocol designed to measure 30 second power output. Within this large body of literature, the techniques used to apply the resistance as the test begins are seldom mentioned, and the reasons for their use even more infrequently explained.

Some researchers (Katch and Weltman, 1979) employed the technique in which the subject begins to pedal as fast as possible as the clock is started, with the resistance then applied as quickly as possible. Other researchers (Simoneau et al. 1983 and Bar-Or, 1987) had the subject reach a predetermined pedalling speed, set the resistance, and then began timing the test. For the purpose of this paper, the first technique will be referred to as a "static" start, and the second as a "dynamic" start.

It should be noted that there is a significant range of times among studies within which the correct resistance has reportedly been reached. Katch and Weltman (1979) claimed that they were able to set and stabilize the resistance within an average of one second, with a maximum lapse of one and a half seconds. Simoneau et al. (1983) reported that in their studies, resistance adjustment took two to three seconds. Bouchard et al. (1982) stated that a period of two to three seconds is required to obtain the correct resistance setting. The difference in reported times may be due to several factors: inaccurate estimations of time elapsed by observers, skill levels of testing technicians, or method of tension application. While the tension of the braking belt has traditionally been increased by turning a knob which is attached to a threaded bolt, new methods have been devised in the last few years. Some laboratories use a set of weights which can quickly be added to hangers and others have welded a bar to the tension roller in order to use simple leverage to set the tension.

The time period required to set the resistance does vary, and can be considered to be of significance, especially when the test itself may only be 30 seconds in length. Whether this time lapse occurs before or after the timing of the test begins may have an effect on the results of the test.

In the case of the clock being started as the "go" command is given with the subsequent setting of resistance, the inclusion of the inertia of the flywheel in the test results may decrease the subject's recorded peak power output. As Lakomy (1986) noted, it is generally assumed that the flywheel revolves at a constant angular velocity, with the result that the inertia of the flywheel is ignored. When Lakomy corrected test results to account for flywheel acceleration, he found that the highest power output value over a five second period (maximal anaerobic power) was underestimated by 29.4%. Lakomy also found that one second averaged peak power values were 32% higher when corrected, and that they occurred an average of 2.1 seconds earlier than uncorrected values. It is evident that the effects of flywheel inertia upon the development of peak power are significant; not only are corrected values higher, but Lakomy also showed that peak power output actually occurs earlier than expected. This is not measureable, however, because of the effects of inertia.

Kyle and Caiozzo (1986) showed in their studies that peak power output occurred at 0.1 seconds, rather than during the usual peak power output period of three to seven seconds (Katch & Weltman, 1979; DiPrampero & Mognoni, 1981; Boobis et al. 1982; McCartney et al., 1983). Lakomy (1986) suggested that this phenomenon explains the observation of Katch and Weltman (1979) that power outputs achieved on friction-loaded cycle ergometers are lower than those obtained using other devices, such as isokinetic cycles.

While the effect of inertia may lower recorded peak power values, the effect of the time lapse in the setting of the resistance may mitigate or eliminate the inertial effects. As noted before, it may take as long as three seconds for the full resistance value to be applied. Peak power has been known to occur at the three second point, as discussed earlier. This peak power value is obtained through the measurement of the revolutions per minute (rpm) of the pedals. If the resistance is not set quickly, falsely high rpm's may be recorded, since the subject is not pedalling against full resistance. Thus while the inertia of the flywheel may lower recorded peak power values, an overestimation of resistance applied may falsely increase peak power values.

If the 30 second power test protocol is such that measurement begins before the initial inertia is overcome, peak power output values may be underestimated if a friction-loaded cycle ergometer is employed. It is not known if this effect is mitigated or even eliminated by the delayed attainment of the final resistance. As was previously mentioned, the other alternative is to have the subject begin pedalling before the clock is started. There are several factors in this approach which differentiate it from the approach discussed above, and which may create a difference in the results obtained through the two methods.

If the subject begins pedalling before the clock is started, the effects of the pre-test pedalling may constitute a type of warm-up period. The warm-up may actually serve to increase measured peak power outputs.

Wootton and Williams (1983) found that in a series of six second cycling bouts, the second set of bouts had the highest results, suggesting that the first six second bout may have acted as a beneficial warm-up for the second bout. Dolan and Sargeant (1983) found that a warm-up conducted at less than 60% VO_2 max resulted in an increase of eight to 15% in peak power output. McKenna et al. (1987) found that peak power increased with a moderate warm-up (150 W for a period of 0.50, 2 or 5 minutes). The warm-up significantly increased the test results of both a 10 second and a 60 second maximal cycle ergometer test. Each of these studies demonstrated that a pre-test warm-up may have a beneficial effect on test results. Only the study of McKenna et al. (1987) came close to duplicating the conditions of the 30 second power test protocol in question, since they used a warm-up of 30 s at 150 W. It therefore cannot be positively concluded from the results of previous research that the cycling period prior to the starting of the clock constitutes a warm-up and that this warm-up will increase test results. It seems unlikely, however, that this is the case since the warm-up in this protocol consisted only of a five second period. Because a warm-up occured before the actual test, it doesn't seem likely that an additional five seconds would make a difference. The "warm-up" factor would only have a possibility of being significant if the test was conducted without a warm-up. Even then, it is unlikely that a warm-up of five seconds or less would contribute to a higher test result.

In contrast to the possible beneficial effects of the "warm-up" prior to starting the clock, the subject may actually become exhausted prior to starting the test and peak power values may decrease. Dolan and Sargeant (1983) found that while a warm-up of less than 60% VO $_2$ max increased test results, higher intensity warm-ups led to a 20 to 40% loss in measured peak power. As McKenna et al. (1987) noted, a warm-up should serve to optimize muscle temperature without depleting stores of creatine phosphate and increasing lactate levels. It appears that the warm-up must be of sufficient intensity to elicit a positive response; if the intensity is too great a negative effect will result.

The two test conditions discussed above seem to contain contrasting implications with regard to their effect on 30 second power test results. If the clock is started as the command to pedal is given, flywheel inertia may decrease measured peak power output values, while the lapse in time before the correct resistance is reached may falsely increase calculated peak power output. If the subject begins pedalling before the clock is started, the initial pedalling period may serve as a beneficial warm-up or as a detrimental period of energy store depletion. The present study was designed to determine which of the two 30 second power test protocols elicited a greater measured peak power value.

METHODS

Twelve male competitive cyclists aged 26.5 ± 7.17 years and with 3.21 ± 2.23 years of competitive cycling experience were recruited on a volunteer basis from local cycling clubs. Each cyclist underwent both of the 30 second power tests in a randomized order following a five minute warm-up at 3 kiloponds. The two tests were conducted at least 24 hours apart.

In one 30 second power test the cyclist was instructed to begin pedalling as the clock was started, and the resistance was then set as quickly as possible. In the other test, the cyclist pedalled for approximately three to five seconds against an increasing resistance before the test began. At the end of the acceleration period the cyclist had reached a maximal rpm just as the resistance was optimal; the clock was then started.

The cycle ergometer used was modified to incorporate a lever arm into the pendulum mechanism. Rather than using the threaded rod to set resistance, the lever was depressed. This technique bypassed the threaded rod and set the resistance immediately upon depression of the lever. This modification was especially important for the setting of resistance in the static tests, which took approximately one to three seconds.

Reliability was not calculated for the static start, but was found in another series of tests on the same cyclists to be .94 for peak and .98 for mean power output with a dynamic start. In both tests measurements of power output were calculated every five seconds over the entire 30 seconds of the test. Peak power output and mean power output were calculated. A correlated t-test was used to determine whether a significant difference existed between the two tests, in terms of either peak or mean power output.

A two-way analysis of variance with repeated measures was performed on the data to determine whether significant interactions occurred with regard to starting technique and time period.

RESULTS

The peak power output for the static start was 12.24 ± 1.09 Watts per kilogram of body mass (W/kg). The peak power output for the dynamic start was 13.03 ± 1.37 W/kg. A correlated t-test revealed that the peak power output in the dynamic start was significantly greater than that of the static start (p =.01).

The mean power output for the static start was 9.94 ± .679 W/kg, while the mean power output for the dynamic start was 9.92 ± .721 W/kg. Although the mean power output for the static start was higher than that of the dynamic start, no significant difference was found using a correlated t-test.

The time frame at which peak power output occurred was delayed in the test which employed a static start. In every subject tested, peak power output was observed during the second five second period of the test, between six and 10 seconds. In the dynamic start power tests peak power was recorded only during the first five second time period. Figure VI-1 graphically illustrates the difference in power output patterns.

A two-way analysis of variance with repeated measures produced a significant interaction effect of starting technique and time (p=.001). A Bonferoni analysis revealed that the difference occurred in the first five second time period, as can be inferred from Figure VI-1.

DISCUSSION

The fact that peak power output was significantly greater when the dynamic start was employed indicates that a false peak does not occur with a static start, as was

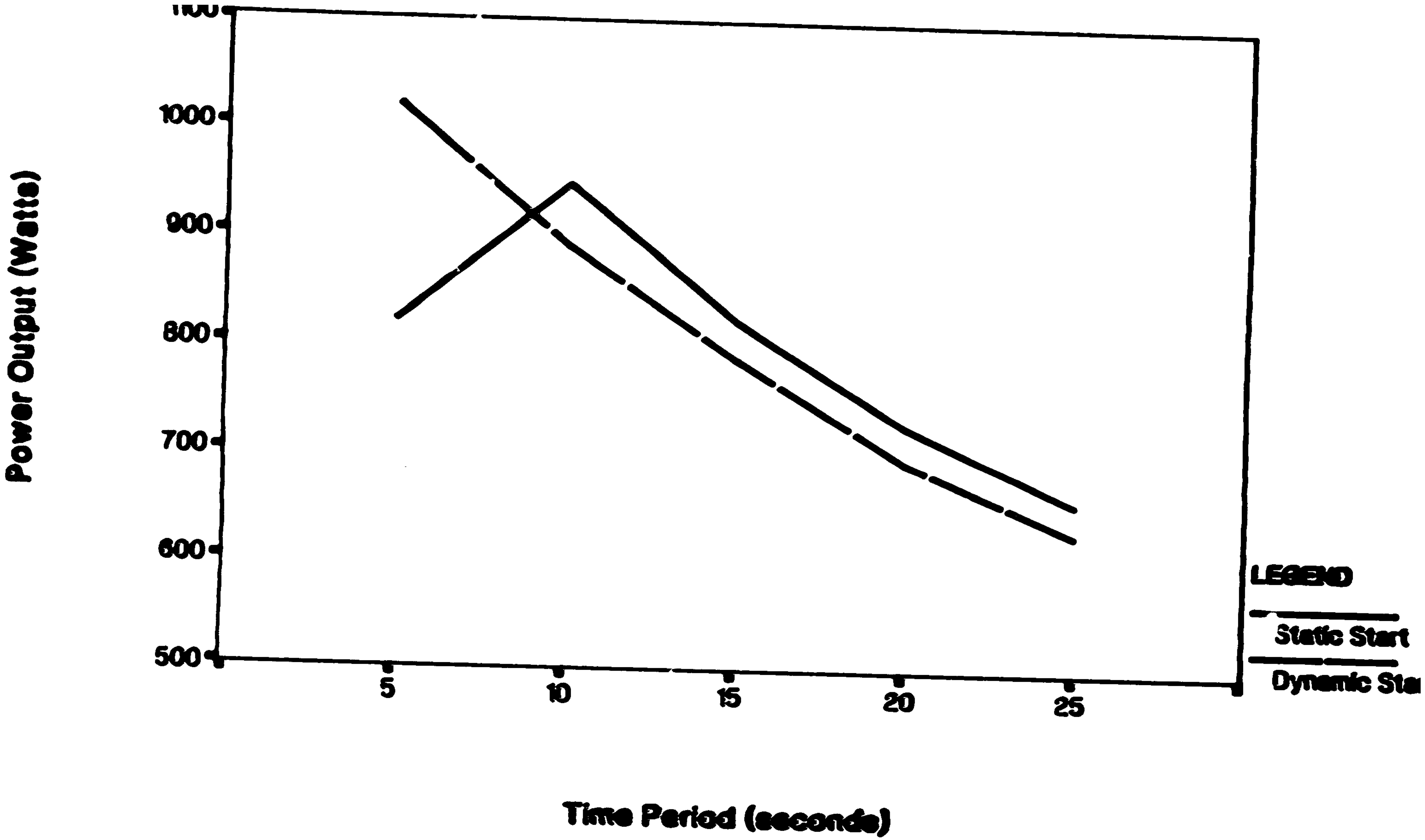

Figure VI-1: Power Output Patterns for Static and Dynamic Starts hypothesized earlier. The setting of resistance has been reported to take between one and three seconds (Katch and Weltman, 1979; Simoneau et al., 1983; Bouchard et al., 1982); in this study a time lapse of one to three seconds was also estimated to occur. During this time resistance is gradually applied while the cyclist accelerates; this may create a falsely high peak power output due to an increase in revolutions per minute. The results of this study demonstrate that this was not the case. This may have been because the lever employed allowed the resistance to be set almost instantly. Thus in the static start the cyclist had to overcome not only the inertia of the flywheel but also the added resistance which was quickly created by the lever, which would prevent a false peak in revolutions per minute. This is evidenced by the fact that peak power output was not attained in any of the static tests until the second five second period. This agrees with the work of Lakomy (1986) in which he found that peak power output corrected for flywheel inertia occurred 2.1 seconds earlier than the uncorrected values reported.

Of further interest is the fact that higher peak power outputs were obtained using the dynamic starting technique. This difference may be accounted for in light of the lower estinate of reliability for peak vs. mean power output. The higher peak value may be due to the lower reliability of this starting technique. Other explanations can be offered, however: it appears that when the cyclist has to overcome flywheel inertia during the testing period a lower peak power output is observed. This is most likely due to the fact that the cyclist is using some of his or her potential power output just to move the flywheel, an effort which cannot be measured in the present test. Lakomy's work (1986) once again agrees with the present findings. He found that peak power outputs over a five second period were underestimated by 29.4% when flywheel inertia was not taken into consideration. Bassett (1988) recommended that the flywheel power output be subtracted from the uncorrected power output in order to eliminate the effects of the kinetic energy related to the rotation of the flywheel. It seems, therefore, that not only does flywheel inertia increase the time to peak power output, it also decreases the peak power output.

The finding that peak power output was significantly greater in the dynamic test and that mean power outputs did not differ significantly is an indication that the brief period of acceleration not included in the measured time of the dynamic test does not exhaust the energy supplies of the subject, as considered earlier. Had the acceleration period been of an exhaustive nature it is likely that peak or mean power outputs of the dynamic tests would have been decreased; this did not occur.

It is interesting that while peak power outputs were significantly greater in the dynamic start tests, mean power outputs did not differ significantly. One might expect that if peak power output is increased that a higher mean power output would also result. Instead, it seems that when peak power output was increased a subsequent decrease in power output occurred which offset the initial increase. This trend is similar to one observed by Wilberg and Pratt (1988) in a study of elite pursuit and kilo track cyclists. These researchers noticed in their examination of short-duration high-intensity events that subjects who accelerated quickly at the start experienced the greatest subsequent decline in power output and in fact lost races to individuals who maintained a more even pace. The authors hypothesized that a greater initial acceleration and more uneven pace caused a loss of time later in the race. Wilberg and Pratt assumed that the resulting poor performance was caused by a "failure to expend their available energy resources efficiently over the total race" (p. 213).

This hypothesis seems reasonable in the case of a 30 second power test, in which creatine phosphate (CP) is the primary source of energy. Researchers have cited a loss in muscular stores of adenosine triphosphate (ATP) and CP as an important factor in muscular fatigue in short-duration high-intensity exercise (Wenger and Reed, 1976). Anaerobic glycolysis also contributes significantly to the energy supply used in a 30s power test. Serresse et al. (1988) estimated that 49% of the energy supplied during a 30s power test derived from the glycolytic pathway. Boobis, Williams and Wootton (1983) found that during the first six seconds of supramaximal ergometer exercise 50% of ATP resynthesis was accounted for by lactate accumulation. At this point there was a decrease in power output even though CP was not depleted. In contrast, McCartney et al. (1983) found that induced acidosis in six subjects led to a slight but not statistically significant decrease in peak and mean power on a 30s power test. The small sample size used in this study may have led to the lack of statistically significant findings. The role of proton accumulation is not clear in very short term exercise, but it seems likely that it can be considered to be a factor.

In the present study it is possible that muscle stores of CP were exhausted more rapidly in the dynamic start and that this created a situation in which anaerobic glycolysis began earlier than in the static start. The early exhaustion of the muscle phosphagens and the subsequent use of the anaerobic glycolysis system may have caused a more rapid decline in power than in the static test. This may explain why peak power was greater in the dynamic start while the mean power output did not increase. From the above findings it can be inferred that if peak power output is the prime focus of research that a dynamic start should be used in a 30 second power test. If mean power output is the factor being examined, however, either a static or dynamic start may be employed. One related observation from the present study is that most of the cyclists preferred the dynamic start. The amount of resistance applied during the tests created a large amount of inertia which had to be overcome in order to begin the tests. Most cyclists complained that this task was difficult. Since resistance is calculated using body mass, one can imagine how difficult a static start would be for a large individual unaccustomed to cycling. This factor should be taken into consideration when choosing a starting technique. The present study seems to promote the dynamic start as the technique of choice.

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Chapter VII

Discrimination Between Novice and Competitive Male Cyclists with a 30 Second Power Test and an Aerobic Power Test

INTRODUCTION

The previous studies in this series have provided information regarding techniques and protocols for the 30 second power test and the aerobic power test. The final study as outlined below attempted to incorporate the information garnered and to create a 30 second power test and an aerobic power test which discriminated between cyclists with regard to their physiological profiles.

The thirty second power test for the cycle ergometer has become a popular means of measuring short-term peak and mean power output. The peak power output is the highest power output observed during the test, and usually is recorded within the first three to eight seconds. The mean power output represents the average power output over the duration of the entire 30 second test. Some researchers have associated the first 10 seconds of the test (and therefore usually the peak power output) with the alactic energy system, and the remainder of the test with the lactacid energy system (Crielaard & Pirnay, 1981; Bouchard et al., 1982; Simoneau et al., 1983). Recent research has revealed, however, that even in exercise lasting less than 10 seconds the glycolytic energy system is activated. It seems that the alactic and lactacid energy systems probably act together shortly after exercise begins (Vandewalle et al., 1987). The results of the 30 second power test used in the present study will not be separated into maximal alactic capacity and lactacid components.

Several other points must be considered when peak power values are obtained from a 30 second cycle ergometer test. All peak power measurements in such a test are not true maximal power values, since the measurement is never instantaneous. One might expect that when the measurement sample period is five seconds, (as it will be in the present study) instantaneous power is not being measured. Thus, even "peak" power outputs are actually mean power outputs, although they may represent the highest power output sampled during the course of the 30 second test. Sargeant et al., (1981) and Sargeant et al. (1984) compared power outputs using a friction-loaded ergometer and an isokinetic cycle ergometer and found that the mean power output measured during one revolution on the former was 50 to 60% of the peak power as measured on the latter. These findings are similar to those of Hoes et al. (1968), in which the pedal load during one downstroke was found to be approximately twice the load-setting indicated on the ergometer. Kyle and Caiozzo (1986) found that maximal power output occurs before it is even measured. These authors found that peak power output occurred at 0.1s, as opposed to the usual observation of peak power between three and eight seconds.

True peak power actually occurs at a specific point in the pedal revolution, but this could not be measured using the equipment available for this research. Therefore the peak power that was measured in this study was actually averaged over a five second period. It is important that the actual meaning of "peak" power output is acknowledged in the discussion of 30 second power tests.

It is also critical that the actual testing protocol to be used be discussed; the absence of consideration of protocol is a source of confusion in the literature.

The cyclists in this study employed the modified cycle ergometer as described in Somerville and Quinney (1987). The results of earlier studies in this series indicated that the use of the modified ergometer did not lead to significant performance differences. The modified ergometer was felt to be more comfortable by the cyclists in both pilot work and the studies of this series, however, and may prevent injuries, especially with regard to cleat placement on the pedals. The work of Smith et al. (1989) supports the use of the modified ergometer; when tested on their own bicycle and on a Monark cycle ergometer cyclists exhibited no difference in VO_2 max but ratings of perceived exertion were significantly lower on the former.

The starting technique used for the 30 second power test was the dynamic start, shown earlier in this series of papers to elicit higher peak power values. Subjects were required to remain seated during the test. While some studies have been undertaken in which the cyclist was permitted to pedal in a standing position (McKenna et al., 1987), the cyclist usually remains seated (Crielaard & Piernay, 1981; LaVoie et al., 1984). It has been demonstrated that standing cycling protocols elicit both an increased maximal aerobic and 30 second power output (Vandewalle et al., 1987; Tanaka et al., 1987). It was therefore desirable to require all cyclists to maintain a seated position throughout the entire test in order to ensure that no cyclist gained an advantage by standing for some portion of the test.

Cyclists were also required to maintain a position in which the hands were on the drops of the handlebars throughout the test. Katch et al., (1979) stated that they required their subjects to bend forward during testing in order to prevent the subject from straightening up and gaining a mechanical advantage. It seems likely, however, that the opposite is true: the cyclist will gain a mechanical advantage by bending forward, especially with the hands on the drops. Kolin (1984) noted that while this position is uncomfortable for prolonged riding, it is an "optimum position for maximizing power to the pedals" (p. 17). Kolin and de la Rosa (1979) stated that the lower cycling position allows the cyclist to use the arm, back and shoulder muscles, and that the gluteus maximus comes into greater use when the back is bent below 45 degrees. In pilot testing, cyclists invariably chose the dropped hand position in order to attain maximum power output on a 30 second power test: this would seem to support Kolin's (1984) and Kolin and de la Rosa's (1979) assertions. In order to ensure that testing conditions were as consistent as possible within the subjects, all subjects maintained a dropped hand position.

The amount of resistance required to elicit maximal power outputs has been the subject of much debate in the literature. Originally, the Wingate group suggested a resistance of 0.075 kiloponds per kilogram of body weight (kp/kg) (Bar-Or, 1987). Since that time, other groups have recommended other resistances which elicited mean maximal 30 second power outputs in their specific test populations. Evans and Quinney (1981) recommended the use of 0.098 kp/kg, Bar-Or (1987) a value of 0.100 kp/kg, Dotan and Bar-Or (1983) used 0.087 kp/kg, and Patton et al., (1989) found that 0.094 kp/kg elicited the highest mean power values. The latter two groups also noted that different resistances were required in order to obtain maximal peak 30 second power and maximal mean 30 second power values: higher resistances were needed to elicit maximal peak power. Smith and Stokes (1985) noted that optimal resistance for peak (but not mean) power output varied among athletes of different sports and states of training, and recommended that second and third tests of 0.005 kp/kg above and below the original resistance be undertaken in order to achieve load optimization. Dotan and Bar-Or (1983) found that using a force 0.5 Joules per revolution per kilogram of body weight (0.009 kp/kg) higher or lower than the actual optimum value resulted in an underestimation of mean power output of less than 1.4%. Vandewalle et al. (1987) noted that a 10% difference in braking force (0.09 kp/kg) around the optimal resistance had only a "slight" effect on peak power. A factor to be considered is that while cyclists may show a trend as a group for optimal resistance, all cyclists have individual optimal values. It therefore seems important to treat each case individually in order to achieve each subject's maximum potential.

Both force and velocity must be optimal in order to attain maximal power values. Simoneau et al. (1983) utilized a resistance of 0.090 kp/kg in their tests while adjusting the resistance throughout the test to maintain a speed of 10 to 16 metres/second (100 to 160 rpm). Vandewalle et al. (1987) recommended an optimal pedalling rate of 125 rpm for male power athletes; Davies et al., (1984) found an optimal rate of 120 rpm and

McCartney et al., (1983) and McCartney et al., (1985) found the optimal velocity to be between 120 and 160 rpm, the precise value of which changed with each cyclist. McCartney et al. (1983) hypothesized that one cyclist may have had an optimal value as high as 170 rpm, although this was not confirmed through testing.

The higher values found in the McCartney et al. (1983) study seem most reasonable for several methodological reasons. Davies et al. (1984) used a device in which the pedal rate was created by a motor, and the force supplied by the subject. They found that peak power occurred at 120 rpm, and that maximum velocity was 240 rpm as estimated by linear regression. It should be noted that the highest actual unloaded velocity attained in their study was approximately 185 rpm. McCartney et al. (1983) and McCartney et al. (1985) used a device in which the subject drove the cranks and the motor was used only to prevent the surpassment of a pre-determined velocity; these authors argue that their device may have elicited a more truly voluntary effort. In the latter study (1985) the authors uncoupled the drivetrain of the cycle ergometer to simulate an unloaded condition and found a maximum velocity in one subject of 212 rpm, with the rest of the subjects attaining velocities in the range of 181 to 192 rpm.

In pilot testing on a group of competitive cyclists, the maximal velocity of one cyclist was measured using a Monark cycle ergometer without resistance and the drivetrain intact: he reached a maximum velocity of 340 rpm. This finding does not seem unreasonable when compared to the above studies, which employed untrained male and female students. Therefore the recommendation made by McCartney et al. (1985) to test for maximal external power in the range of 120 to 160 rpm was followed in the present work, with emphasis placed on the higher end of the range.

One final factor was considered concerning the administration of multiple 30 second power tests. In a study such as this one, in which a number of 30 second power tests must be completed by the subjects, the question arises as to how much time must elapse between two tests. A recovery period of thirty minutes between tests was selected for evaluation; it was hypothesized that in 30 minutes recovery would be complete and thus test results would not be affected by the close time proximity of the tests.

The primary sources of energy during a 30 second power test are the muscle stores of phosphocreatine (PC), adenosine triphosphate (ATP), and glycogen, with some contribution from the the oxidative energy system. Possible limiting factors in the performance of two exercise bouts would therefore be depletion of PC stores, depletion of glycogen stores and lactate accumulation. Essen and Kaijser (1978) found that 80% of PC stores can be replenished within 15 seconds of cessation of a period of 15 seconds of heavy cycling, while Fox (1973) reported that these stores are completely replenished within two minutes. Replenishment of PC does not seem to pose a problem in terms of the performance of two consecutive tests separated by 30 minutes.

Muscle glycogen stores within the muscle are sufficient for approximately 80 seconds of intense exercise (Lamb, 1984). It seems likely that muscle glycogen stores are sufficient to supply energy for both work bouts. Serresse, et al. (1988) estimated that the relative contributions of the energy systems during a 30 second power test were: 23% phosphagens, 49% anaerobic glycolysis, and 28% oxidative pathways. These authors found that the glycolytic energy system contributed maximally between the 16th and 30th seconds of a 30 second power test. This indicates that a limiting amount of muscle glycogen is not used during a 30 second power test. The 30 minute rest period between tests would also enable muscle glycogen stores to be replenished via blood glucose from the liver. Muscle glycogen stores would therefore not represent a limitation in two maximal exercise bouts separated by 30 minutes.

Because anaerobic glycolysis contributes to the energy supply during a 30 second effort, some accumulation of lactate can be anticipated. When exercise is undertaken with high levels of muscle and blood lactate performance has been shown to decrease (Klausen et al., 1972 & Karlsson et al., 1975). Belcastro and Bonen (1975) noted that moderate exercise is a very effective means of muscle lactate removal, since little lactate is produced but the enhanced skeletal muscle blood flow increases transportation of lactate from the muscle. These authors found that when subjects performed exercise at a self-selected intensity during a 30 minute recovery period an effective rate of lactate removal resulted.

To determine the effect of recovery time on 30 second power test results the cyclists completed a set of four tests; two were conducted one day apart, and two were conducted 30 minutes apart. During the 30 minute recovery interval the subjects were asked to pedal a cycle ergometer at a comfortable intensity.

The second part of the final test battery consisted of an aerobic power test. The test employed the modified cycle ergometer described earlier in this series of studies. During the test, therefore, each cyclist used his own pedals and cleats on a cycle ergometer which replicated the frame geometry of his own bicycle. In several instances the cyclists favoured a snap-in type of binding and compatible shoes that have recently been developed. To keep the test as specific as possible these cyclist provided the researcher with their own pedals, which were then threaded into the modified cycle ergometer. In this way, every cyclist completed the tests using the pedals to which he was most accustomed. Not only did this increase the specificity of the test, but it avoided possible injuries related to cycling at a high speed and resistance with improper cleat placement.

Studies by Vandewalle et al. (1987) and Tanaka et al. (1987) demonstrated that a higher VO_2 max was attainable when subjects were permitted to stand while pedalling during the test. Tanaka et al. (1987) asserted that subjects who otherwise would have dropped out of an aerobic power test could actually endure the test a few minutes longer when permitted to stand. In this study the subjects were required to maintain a seated position, due to the range of experience of the cyclists. It was felt that the cyclists with more experience would have an unfair advantage, since they would presumably be more aware of the fact that they could use this technique to extend their testing time and perhaps increase their results.

Subjects were also advised that they must keep their hands on the drops of the handlebars. During pilot testing cyclists tended to change hand positions throughout the test, using the dropped position almost exclusively as they became more fatigued. This observation agrees with that of Kolin (1984), who stated that while the dropped position is uncomfortable for prolonged use, it is a position which the cyclist uses when she or he wishes to maximize power output. For the purpose of standardization (given the range of experience of the subjects) a dropped hand position was maintained throughout the tests.

The cadence at which an aerobic power test should be carried out has been the subject of some debate, but it is generally agreed that VO_2 max increases with an increased pedalling rate. Gueli and Shepard (1976), Faria et al. (1982) and Croisant and Boileau (1984) all noted that VO_2 max values were higher at increased pedal rates. McKay and Banister (1976) found that a cadence of 80 rpm elicited a significantly higher VO_2 max than did 60 or 120 rpm. Coast and Welch (1985) found that the more highly trained the cyclist, the higher the pedalling rate required to elicit the highest VO_2 max; these authors found that 80 rpm elicited the highest VO_2 max values. Jordan and Merrill (1979) found a 10% increase in VO_2 max values as the pedalling rate increased from 60 to 135 rpm. Most studies carried out on competitive cyclists utilize a pedalling rate of 80 rpm (Withers et al., 1981) or 90 rpm (Hagberg et al., 1978; Burke et al., 1981). Thoden et al., (1982) recommended that cyclists be tested at 90 rpm. Cyclists in the present study were required to maintain a cadence of 90 rpm.

METHODS

30 Second Power Test

The methodology of the 30 second power test employed in this study exhibited consideration for both the velocity and the resistance at which the test took place. All tests in this study were preceded by a warm-up of five minutes of cycling at three kiloponds. The starting technique chosen for all of the 30 second power tests was the dynamic start.

The pedal revolutions per minute were measured using a digital counter which registered each fifth of a revolution.

Twenty seven cyclists aged 26.8 ± 7.5 years and with 4.85 ± 3.76 years of experience underwent an initial test at a resistance setting of 0.090 kp/kg. The subjects then completed a second test after a 24 hour rest period. The resistance setting for this test was determined by the velocity attained by the cyclist on the first test. If the subject was unable to approach 160 rpm as a maximal velocity, the second test employed a resistance of 0.085 kp/kg. If the subject was close to 160 rpm in the first test, the subsequent test took place with a resistance of 0.095 kp/kg. A value of 140 rpm was used as the cut-off point for determination of subsequent resistance. The optimal resistance for both peak and mean 30 second power was noted, and correlated t-tests were used to detect significant differences. Twenty four of the above cyclists aged 25.9 ± 7.2 years completed three more tests after the optimal resistance had been established through the first two tests. Twenty four hours following the second tests, the cyclists completed another 30 second power test at the previously derived optimal resistance. After a 30 minute rest period during which the subject pedalled a cycle ergometer at a self-selected intensity the cyclist then repeated the test using the same resistance. The reliability of both sets of data was calculated, and an analysis of variance with repeated measures on two factors was used to determine if a significant difference existed due to the timing of the tests.

Fifteen male competitive cyclists aged 28.5 ± 7.8 years and with racing experience of 5.8 ± 5.76 years and 15 novice competitive cyclists aged 23.5 ± 6.2 years and with 1.03 ± .13 years of cycling experience underwent a 30 second power test at an optimal resistance. A one-way analysis of variance did not find a significant difference between the ages of the two groups (p=.077). The subjects employed their own shoes and pedals on the modified cycle ergometer described in Somerville and Quinney (1987). A discriminant function analysis was used to determine whether group membership (novice or experienced) could be predicted with the results of this test combined with the results of the aerobic power test.

Aerobic Power Test

Fifteen experienced male competitive cyclists aged 28.5 ± 7.8 years with racing experience of 5.8 ± 5.7 years and 15 male novice competitive cyclists aged 23.5 ± 6.2 years and with 1.03 ± .13 years of cycling experience participated in an aerobic power test. The subjects employed their own shoes and pedals on the modified cycle ergometer described in Somerville and Quinney (1987). Cadence was 90 rpm and was monitored by a Cateye cyclocomputer model CC-2000. The aerobic power test was a continuous, progressive test in which the cyclist pedalled against a resistance of one kilopond for the first two minutes and two kiloponds for the second two minutes. Thereafter the resistance was increased every minute by .5 kiloponds until the subject could no longer continue the test.

A Beckman Metabolic Measurement Cart was used to collect the expired gases and to analyze them every 30 seconds throughout the test. VO_2 max was considered to have been reached at the point at which VO_2 reached a plateau or decreased with increasing resistance. The ability of the aerobic and 30 second power tests to discriminate between the two experience levels of cyclists was determined through the use of a discriminant function analysis.

RESULTS

Twenty seven road event cyclists aged 26.8 ± 7.5 years and with 4.[illegible] 5 years of cycling experience underwent an initial 30 second power test at a load of .090 kp/kg, and a second test at either .085 kp/kg or .080 kp/kg, depending upon the velocity achieved in the first test. A correlated t-test on the peak power outputs did not reveal a significant difference (p=.300); a correlated t-test on the mean power outputs for the two tests also showed no significant difference existed (p=.267). In all but four subjects, peak and mean power output were elicited at the same resistance. For those four subjects, peak power output was realized at a higher resistance.

Intraclass reliability was established for both peak and mean power outputs for all sets of tests at the optimal resistance: those separated by a day or by 30 minutes. Intraclass correlations for the tests separated by one day were .94 and .98 (for a single measure) for the peak and mean power outputs, respectively. For the tests conducted 30 minutes apart, intraclass correlations were .86 for peak power output and .80 for mean power output, both for a single measure.

To determine whether both peak and mean power output results would be affected when two 30 second power tests were performed just 30 minutes apart, 24 of the cyclists completed four 30 second power tests. Two tests were conducted one day apart and two tests were conducted 30 minutes apart. Mean power outputs for the four tests appear in Table VII-1. An analysis of variance with two factors on the repeated measures did not reveal a significant difference in either peak or mean power outputs between the pair of tests performed one day apart versus the pair of tests performed 30 minutes apart (p=.328 and .207, respectively). A significant difference (p=.002) was found for the interaction effect for mean power outputs. A Scheffe post-hoc analysis determined that a significant difference existed between the two values collected 30 minutes apart.

The differences between the four pairs of means (peak day 1 vs. peak day 2, mean day 1 vs. mean day 2, peak 0 hours vs. peak .5 hours and mean 0 hours vs. mean .5 hours) demonstrated that the only significant difference occurred between the mean values for 0 and .5 hours (p=.004). Intraclass reliability for the VO_2 max tests was established at .97 for a single measure.

A one way analysis of variance did not detect a significant difference between the novice and experienced groups with regard to 30 second power test results (p=.513). A one way analysis of variance did uncover a significant difference between groups in terms

Table VII-1

Mean and peak power outputs for 30 second power tests conducted one day or 30 minutes apart

Power Output (W/kg)	Time of Test			
	Day 1	Day 2	0 Hours	.5 Hours
Mean	10.27 ± 1.05	10.18 ± 1.01	9.87 ± 0.74	10.22 ± 0.94
Peak	13.06 ± 1.30	13.03 ± 1.22	12.91 ± 1.32	12.88 ± 1.21

of VO_2 max (p=.044). No difference between VO_2 values at the submaximal level of 70% was discerned when a one way analysis of variance was performed (p=.110). A multiple regression was performed to obtain the regression coefficient necessary for a two-group discriminant function analysis (Huck, Cormier & Bounds, 1974). The 30 second power test was deleted as a predictor variable in the stepwise multiple regression. The beta weight for the 30 second power test results was .067; the beta weight for the aerobic power test results was .379. Based upon the aerobic power test results as the predictor variable, the multiple r was .379, the coefficient of determination was .144 and the standard error was .479. An analysis of variance revealed that the multiple r of .379 was significant (p=.039) with aerobic power test scores as the predictor variable. The values obtained from the multiple regression were employed in a discriminant function analysis in order to predict group membership. Group membership was predicted successfully 76.7% of the time, which compares well with the chance prediction success rate of 50%.

DISCUSSION

In contrast to the findings of Dotan and Bar-Or (1983), Patton et al. (1985) and Smith and Stokes (1985), the optimal resistance for peak and mean power output did not differ; in 23 of the 27 subjects maximal values were obtained at the same resistance. In the other four subjects, the higher resistance setting resulted in an increased peak power output.

The results of the present study do agree with the work by Dotan and Bar-Or (1983) and Vandewalle et al. (1987) in that a difference of .05 kp/kg in the resistance setting did not create a significant difference in either peak or mean power outputs. This seems to indicate that the values used for resistance in this study were close to optimal, so that small differences did not affect maximal power output.

All pedalling velocities fell between 122.4 and 168 rpm during the initial testing. As discussed previously, cyclists with rpm values closer to 120 rpm were tested again at a lower resistance setting, while those with rpm values closer to 160 rpm were re-tested at higher resistance settings. This procedure did not result in a significant difference in power outputs. McCartney et al. (1985) found the optimal pedalling velocity to be between 120 and 160 rpm; the present findings appear to confirm this. Based on the notion that maximal velocities for trained cyclists are probably higher than those reported by McCartney et al. (1985) it was hypothesized that the pedal velocity should be maintained in the upper end of the 120 to 160 rpm range to obtain maximal power outputs. However, the present data show that for 11 of the 27 cyclists (40.7%) the highest values obtained were at the lower rpm values, although all values were within the 122.4 to 168 rpm range. This finding suggests that maintaining a velocity in the 120 to 160 rpm range is sufficient to maximize results.

In spite of the fact that no significant difference was found between the two resistance formulae, it was observed that the resistance which elicited a maximal power output differed for each cyclist. Thus the recommendation by Smith and Stokes (1985) to optimize resistance for each athlete by testing the subject at more than one resistance seems to be warranted.

Twenty four subjects completed four 30 second power tests in order to determine whether recovery time affected peak or mean maximal power outputs. An analysis of variance with two factors on the repeated measure did not detect a significant difference between the mean power outputs for the two tests conducted one day apart and the two tests conducted 30 minutes apart or between the two tests conducted one day apart. A significant interaction effect was indicated (p=.001). The Scheffe post-hoc analysis revealed a significant difference between the two tests separated by 30 minutes. No significant differences were found among any of the values for the peak power outputs. The means for all of the tests appear in Table VII-1.

It is interesting to note that while there was a significant difference between the two tests conducted 30 minutes apart, the values increased from the first test (9.87 ± .74) to the second test (10.22 ± .94). It was postulated that if the recovery time of 30 minutes was insufficient, the values for power output would decrease due to a combination of phosphagen and glycogen depletion and lactate accumulation. In this case, however, values increased slightly.

One possible explanation for this is that the first test and the recovery exercise served as a warm-up for the second test. It is possible that this period of approximately 30 minutes of cycling was more effective than the 5 minute pre-test warm-up, and allowed cyclists to perform better in the second test. Another likely explanation is that when the two tests were performed within such a short period a motivational factor was present. Each cyclist demonstrated a strong desire to do his best on each test. It is possible that having completed the first test, the cyclist wanted to better himself on the second. Because the cyclists being tested could communicate with each other between tests, it is also possible that external motivation was present. Thus goal-setting may have occurred independently or through interaction with other cyclists. This explanation seems plausible, given the competitive nature of the subjects. Motivation should not play a part in test results, however, and the present finding should serve as a warning that motivation should be maximized for every test.

A further interesting point is that no difference existed between the two tests for peak power output, while mean power output increased slightly. It may be that completing the second test right after the first allowed the cyclist to pace himself better in the second test, thus increasing the mean power output. Since the cyclists had completed quite a few 30 second power tests prior to this portion of the testing, however, it is likely that any learning effect had been minimized.

When the data for the four sets of tests is viewed in its entirety, very little difference exists among the values for any of the tests, indicating that similar results will be obtained if tests are separated by at least 30 minutes. The small difference noted between the values obtained on one day indicates that care must be taken to ensure that each subject performs maximally on all tests.

The results of the 30 second power tests were not significantly different between the novice (1.03 ± .13 years of cycling experience) and experienced (5.8 ± 5.7 years of cycling experience) groups of cyclists ($p=.613$). A significant difference was found between the two groups when VO_2 max was measured ($p=.044$). The discriminant function analysis demonstrated that the best predictor of group membership (either novice or experienced) was VO_2 max, although the strength of this variable as a predictor was not high since the multiple r was .379 and the coefficient of determination was .144. Only 14% of the variance in group membership was predictable on the basis of VO_2 max, and vice-versa.

The finding that VO_2 max was the best predictor of cycling experience in this group of cyclists is not surprising in light of the fact that all of the subjects were road, rather than track cyclists. Very little anaerobic training was undertaken by the subjects; most of their training involved distance riding. The time at which testing took place (February) may have contributed to the lack of significance of the 30 second power test results. In a study of track cyclists, White et al. (1982) found that increases in short term power output sufficient to differentiate between select and non-select cyclists did not appear until late in the competitive season. During the winter months the competitive cyclists presently studied performed virtually no sprints; all training was of the endurance type. Perhaps tests later in the season would have revealed differences in the 30 second power test results, although it must be kept in mind that the work of White et al. (1982) was with track cyclists; it is possible that a difference would not be evident in road cyclists.

It is also not surprising that VO_2 max was the best predictor of cycling experience, since VO_2 max can be improved with training (Burke, 1986). Burke (1980) reported a significant difference in VO_2 max between men's senior and junior teams which he concluded was most likely due to differences in amount of training and level of competition. Krebs et al. (1983) related VO_2 max to experience, since as training continues VO_2 max approaches one's physiological potential. Sjogaard (1984) found lower VO_2 max values for competitive cyclists compared to elite cyclists, and hypothesized that this was due to much lower training and competition intensity levels in the competitive group. In the present study it is very likely that in addition to the lower amount of cumulative training done by the novices the training and competitions in which they were involved were not as intense, leading to lower VO_2 max values. Barlow et al. (1985) found that VO_2 max was significantly higher in competitive cyclists compared to non-cyclists, and noted that research has shown that VO_2 max is higher in endurance athletes. Within a homogeneous group of trained endurance athletes, however, VO_2 max values play a smaller role in differentiation. Barlow et al. (1985) concluded, as did Burke (1986) that VO_2 max can be useful in making gross separations among athletes. The findings of the present study agree with the above conclusions, since VO_2 max was found to predict novice and experienced group membership; this can be considered to be a relatively large differentiation.

The present findings indicate that during the off-season VO_2 max is the better of the two predictors studied in terms of cycling experience, which can be explained by the relationship between VO_2 max values and the amount and intensity of training and competition. The relatively low coefficient of determination (.144) and multiple r (.379) should induce caution. It is evident that other factors must also be related to years of cycling experience and presumably would be co-predictors with VO_2 max.

Many studies have attempted to predict cycling performance (but not experience) using various physiological factors. The overwhelming conclusion to be drawn from these studies is that while factors such as lactate threshold (Barlow et al., 1985; Coyle et al., 1988) and muscle enzyme activities (Sjogaard, 1984) have been linked to performance levels in competitive cyclists, experience is one of the most important factors in the prediction of performance (Burke, 1986; Krebs et al., 1983, Wilberg & Pratt, 1988). While these findings cannot be applied to the present attempt to predict group membership as defined by years of cycling experience, they do imply that other factors aside from VO_2 max could be used in this prediction.

This study was an attempt to determine whether 30 second power and aerobic power test protocols designed for competitive cyclists could discriminate between novice and experienced groups of cyclists. Some adaptations to existing protocols were made on the basis of the findings of this series of studies; a modified ergometer was used, cyclists were tested at individualized optimal resistances and a dynamic starting technique was used.

Using the adapted protocols, significant differences were found between VO_2 max values for the two groups, but not for the 30 second power test values. A discriminant function analysis had a 76.7% success rate in predicting group membership on the basis of VO_2 max; 30 second power test values were not a valuable predictor. It appears that while group membership for road cyclists can be partially predicted by VO_2 max values, other factors would also contribute to a more successfull prediction of group membership. This finding also confirms the notion that tests must not only be sport-specific (cycling), but also event-specific (road vs. tr [illegible] rther testing of these protocols employing track cyclists might reveal the predictive value of 30 second power test results.

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Chapter VIII

GENERAL DISCUSSION

This series of six papers represented an attempt to evaluate the many procedures and techniques involved in 30 second and aerobic power tests for cyclists and to develop protocols suitable for the physiological testing of competitive cyclists. The need for standardized testing protocols has been called for by coaches in the cycling community (Burke, 1982) and is evidenced by the wide variation in reported protocols.

A summary can be formed for both the 30 second and aerobic power tests from the results presented and literature examined in the previous papers.

30 Second Power Test

This test should be preceded by a warm-up, which in this case consisted of five minutes of cycling at a resistance of three kiloponds. A warm-up has been found to be beneficial to performance providing that it consists of moderate exercise that will not deplete energy stores or cause lactate accumulation (McKenna et al., 1987).

Several researchers have demonstrated the value of modifying the standard cycle ergometer in order to perform tests on cyclists. Cycle ergometers should incorporate toe clips and straps as well as cleated shoes (LaVoie et al., 1984; Davis & Hull, 1983). Maximal power output may also be increased through the use of dropped handlebars, since cycling with the hands on the drops allows the cyclist to transmit more power to the pedals (Kolin & de la Rosa, 1979). Further modifications to the cycle ergometer (Somerville & Quinney, 1987) did not produce a significant difference in either peak or mean 30 second power output values, although cyclists felt that the modified ergometer was more comfortable.

The optimal resistance used for 30 second power tests was found to differ for each cyclist, but the results of tests conducted at two resistance values within the probable optimal range were not significantly different. As discussed by Smith and Stokes (1985) resistance should be optimized for each athlete. When the resistances used are in the optimal range, however, it seems that small adjustments in resistance will not greatly affect test results (Dotan & Bar-Or, 1983; Vandewalle et al., 1987).

Increases in 30 second power output have been effected by allowing the subject to stand for portions of the test (Tanaka et al., 1987). In the present studies standardization was sought, however, so all subjects were required to remain seated.

Both dynamic and static starting techniques have been employed (Simoneau et al., 1983; Katch & Weltman, 1979) in the 30 second power test. The dynamic starting technique was found in the present work to produce a significantly higher peak power output. Cyclists subjectively preferred the dynamic start; it appears that this technique is preferable to the static start.

The 30 second power test should therefore be preceded by a warm-up, be conducted on either a partially or fully modified ergometer, employ a resistance optimized for the individual athlete, and begin with the dynamic starting technique.

Aerobic Power Tests

The aerobic power test, like the 30 second power test should be preceded by a warm-up for possible maximization of performance (McKenna et al., 1987). A five minute warm-up consisting of cycling at three kiloponds was required before the aerobic power tests.

A modified cycle ergometer was also used in the aerobic power tests, although no significant difference was found when the results of VO_2 max tests were compared for a standard and modified cycle ergometer. It became clear in the present study that while some modifications do affect aerobic power output (LaVoie et al., 1978; Davis & Hull, 1983), there is a limit to the extent of increases in performance with modifications to the cycle ergometer. The fully modified cycle ergometer was preferred by the cyclists. The work of Smith et al. (1989) demonstrated that the use of the cyclists' own bicycle did not increase VO_2 max, but the rating of perceived exertion was significantly lower. Thus the use of a fully-modified cycle ergometer is recommended, but will likely not increase VO_2 max values.

The cadence used for VO_2 max tests for competitive cyclists has been the subject of many studies. A review of the findings suggests that while untrained subjects and non-cyclists are usually tested at 60 rpm (Astrand, 1977), competitive cyclists tend to perform at cadences between 80 and 110 rpm (Hagberg et al., 1981; Whitt & Wilson, 1974) and so should be tested at higher cadences. Thoden et al. (1982) recommended a cadence of 90 rpm; this cadence has been chosen in many studies (Hagberg et al., 1978; Burke et al., 1982). In the present study a cadence of 90 rpm was employed.

While it has been found that VO_2 max can be increased if the cyclist is permitted to stand while pedalling (Vandewalle et al., 1987; Tanaka et al., 1987) this study required subjects to remain seated. If standardization of testing is not a requirement, cyclists may increase values by standing, but if tests must be standardized cyclists should remain seated.

As in the 30 second power tests, it has been recommended that cyclists use the dropped hand position to maximize power output (Kolin & de la Rosa, 1979). For reasons of standardization, all cyclists in this study were required to maintain the dropped position.

When conducting aerobic power tests on competitive cyclists, it is desirable to include a warm-up, use a partially or fully modified cycle ergometer, employ a cadence between 80 and 110 rpm, have the subject stand for maximized (but not standardized) results, and use the dropped hand position for maximal power.

When all of the preceding information was combined into two testing protocols, an attempt was made to distinguish between novice and competitive cyclists on the basis of the results. Only the results of the VO_2 max test assisted in the prediction, which probably reflects the fact that the subjects were road cyclists and that other factors might also be used for prediction. Thus, it is evident that testing must be sport-specific, and within each sport must be event-specific; this level of specificity is sometimes overlooked. Future research might follow up on these results by testing cyclists during the competitive season to determine whether 30 second power test results might be a predictor or by using the same test protocols to determine group membership with track cyclists as the subjects.

In addition to the information generated regarding testing protocols for aerobic and 30 second power tests, other issues examined were calibration of the cycle ergometer and the angular velocity of the knee in cycling at different cadences.

In the past, calibration of cycle ergometers has been of a static nature, utilizing weights hung from the tension strap of the ergometer (Astrand, undated). Problems with inaccurate static calibration due to interference by the flywheel were eliminated by developing a split weight-hanger which did not allow the weights to touch the flywheel. Accurate calibration is especially important for tests designed to measure power outputs, such as the 30 second power test. A dynamic torquemeter (Russell & Dale, 1986) was employed to determine whether chain condition or resistance level had any effect on friction in the gear train. No significant differences were detected under any of the conditions. The use of the dynamic torquemeter also confirmed Astrand's (undated) estimation of nine per cent for drive train friction. This finding emphasizes the importance of incorporating this value into calculations of power output.

The angular velocity of the knee during cycling at four cadences was examined. It has been proposed that performance testing should take place at the same velocity found in the sport performance (Sale & Norman, 1982). The values obtained demonstrate that when sport-specific velocity testing is conducted, the cadence used by the cyclist during the performance must be considered in order to determine the correct angular velocity. Additionally, cyclists exhibited variations in angular velocities at each cadence, indicating that the angular velocity for testing should be optimized for each individual.

The basic premise of this series of papers was that protocols for testing competitive cyclists should be carefully developed in order to maximize testing specificity. In some areas modifications to the existing protocols resulted in higher values, while in other areas no effect was observed. It is quite possible that given the testing instruments currently available, maximum sport-specificity potential in some facets of testing has been reached. There is no doubt, however, that future research will bring about more effective modifications.

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APPENDIX A

Dynamic Torquemeter Calibration

The dynamic torquemeter was calibrated by hanging known weights from a lever attached to the spring and measuring the resistance which developed. A multiple regression was performed to create a prediction equation from which test values could then be obtained.

Regression Output:

constant = 1.028920

x coefficient = 44.46936

Conversion Factor:

revolutions per minute = 59

1 rpm = .10472 rad/s

59 X .10472 = 6.17848

Formula:

Watts = 44.46936 X R + 1.028920 X 6.17848

APPENDIX B

Beckman Metabolic Measurement Cart Calibration

CO_2 and O_2 pumps turned on 45 minutes before testing

- operating buttons depressed
- cart set on "Average" mode
- mode knob on "Manual/Load"
- peak detector knobs of pumps on "Off Cal"

Dry Rite replaced if necessary

Valves put into hose, 4 - 5 breaths to prime CO_2 analyzer

- mode knob set to "Manual/Load"
- display knob on C0 2
- digital display to read greater than 2.00%

Volume Calibration:

- display knob on "Volume"
- mode knob on ' Manual/Load"
- "Data Reset" pressed
- "Start" pressed
- zeroed with "Zero SCHF Air" knob by switching back and forth with "Data Reset" and "Start"
- digital display read + .03% in 30 seconds
- time knob set at 30 seconds
- if out by more than + .03%, following procedure performed
- calibration pump connected to valve

- display knob on "Volume"
- mode knob on "Manual/Load"
- "Data Reset" pressed
- "Start" pressed
- calibrabration pump pushed 10 times in 30 seconds
- digital display read 11.00 (range 10.90 - 11.10)
- if not calibrated, digital gain adjusted

Gas Calibration:

CO_2 with N_2:

- 1000 cc/min of N_2 fed into calibration nozzle.
- mode knob on "Manual/Load"
- display knob set to CO_2
- "Calibration/Sample" switch pressed to calibrate
- digital display to read 0
- zero knob of CO_2 analyzer adjusted to get zero, keeping toggle depressed to calibrate

O_2 and CO_2 with Calibration Gas:

CO_2:

- display knob set to CO_2
- mode knob set to "Manual/Load"
- calibration toggle switch depressed

- digital display read same as percentage of CO_2 in calibration tank
- if not, gain knob of CO_2 analyzer adjusted

O_2:

- display knob set to O_2
- mode knob set to "Manual/Load"
- calibration toggle switch depressed
- digital display read same as percentage of O_2
- if not, gain knob of O_2 analyzer adjusted.