EFFECT OF DROP-STYLE AND TRIATHLON HANDLEBAR
POSITIONING ON OXYGEN CONSUMPTION
DURING CONSTANT LOAD CYCLING

by

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ABSTRACT

Competitive cyclists have achieved marked performance improvements while using triathlon handlebar systems. The present experiment was conducted to evaluate cardiovascular behavior during cycling, while using both standard drop-style and triathlon style handlebars. The experiment involved 15 healthy male non-cyclists performing a series of four constant-load cycling trial sessions (five minutes each trial for three consecutive trials per session) in different position / workload configurations. The trial sessions were performed in both a low gear-ratio and high gear-ratio, each at a pedalling rate of 60, 75, and 90 rpm, and both in the drop-bar position and triathlon position. These trials were performed by each cyclist on a competitive racing bicycle which had been mounted to a wind trainer apparatus. The bicycle was modified to include the above mentioned handlebar configurations, racing saddle, and racing pedals / toe clips. The trial session work loads were randomly ordered and separated by at least a 24 hour rest period. Heart rate (HR) and oxygen consumption (VO_2) were monitored throughout each trial session. The data were analyzed using a 2 (Handlebar) x 5 (Workload) ANOVA for all 15 subjects (6 of which could not complete the high gear ratio, 90 rpm workload). An additional 2 (Handlebar) x 2 (Gear Ratio) x 3 (Pedalling Rate) ANOVA was performed for the nine subjects who were able to complete the final workload. A Newman Keuls Post-Hoc test was performed to locate any significant differences. All analyses were conducted with an alpha level of 0.05. No significance was found for handlebar format in either analysis. With the 2 x 5 ANOVA, significant differences were identified for workload in terms of all dependent measures. With the 2 x 2 x 3 ANOVA the high gear ratio produced

significantly greater HR and VO_2 values versus the low gear ratio. Additionally, HR and VO_2 values significantly increased with each increase in pedalling rate. The results indicate that the lack of significant differences between the two handlebar formats could be attributed to the relative equality between each format in terms of combined work demands (static & dynamic) on the cardiovascular system. This information will be potentially useful to both cyclists and non-cyclists for their understanding of riding position exercise efficiency.

CHAPTER I

INTRODUCTION AND JUSTIFICATION OF THE STUDY

Introduction

The world of competitive cycling has experienced the progressive development of bicycle technology and an exponential growth in the understanding of the scientific basis for conditioning and training. This growth originated in the enhanced understanding of unique structural and physiological characteristics associated with cycling performance, and has been accompanied by improvements in the overall performance of competitive cyclists.

Various physiological responses to cycling performance have been examined. For example, investigations have been aimed at determining the role that postional and performance characteristics might play in enhancing the cyclist's physiological function during training and competition (Beasley, Plowman, & Fernhall, 1989; Coast & Welch, 1985; Faria, Dix, & Frazier, 1978; Goodwin & Cornwall, 1989; Hagberg, Mullin, Giese, & Spitznagel, 1981; Nordeen-Snyder, 1977; Ryschon & Stray-Gunderson, 1991; and Walsh-Riddle & Blumenthal, 1989). Many different approaches to the testing of cycling performance have been developed.

Statement of the Problem

The purpose of this study is to determine if the triathlon-style handlebar system has any effect on the oxygen consumption behaviors of subjects while riding a bicycle in a constant load fashion. The independent variables are handlebar style and level of constant work load. The dependent variables are

heart rate (HR) and oxygen consumption (VO_2), both in terms of lean body mass (LBM VO_2) and total body mass (TBM VO_2). Gender is the categorical variable. The control variables are bicycle gear ratio (in meters), pedalling rate (in revolutions per minute; rpm) bicycle saddle height (in centimeters), testing procedure, and pre-test / post-test relaxation periods.

Extraneous variables are: (a) fitness level differences, due to different activity levels, (c) each subject's level of riding experience, (d) each subject's pretesting activity level and dietary intake.

Research Hypothesis

The oxygen consumption of a subject during constant load submaximal exercise on a bicycle/wind trainer system will be lower at various different workloads while properly positioned on triathlon-style handlebars versus conventional drop-style handlebars.

Operational Definitions

1. Bicycle gearing: A relative measure of gear ratio, expressed in terms of meters; used for comparison of gearing with changes in tooth-number of either the freewheel sprocket or chainring.
2. Cool-down period: A period of exercise time allowed at the conclusion of an exercise trial.
3. Drop-bar position: The position maintained by the cyclist, involving hand grasp to the drop-bar portion of the handlebars.
4. Exhaustion: The point in time during incremental exercise when the cyclist can no longer maintain the predetermined pedalling rate.
5. Heart Rate (HR): The rate of ventricular systolic beats per minute (bpm).

6. Lean body mass (LBM): The total body mass minus the calculated fat mass.
7. Modern racing bicycle: Consists of a lightweight bicycle intended for race competition. This bicycle must have drop-style handlebars and racing saddle. The pedal configurations could be one of two formats:
(a) racing pedals with toe clips and straps, or (b) clipless pedals. In addition, the bicycle must have a drive-train mechanism which will accommodate a rear wheel that is equipped with a Shimano 7-sprocket cluster freewheel.
8. Percent body fat: The amount of the total body mass that is fat tissue, expressed as a percentage of the total body mass.
9. Respiratory rate: rate of breathing; expressed in breaths per minute.
10. RER: The respiratory exchange ratio: The ratio of carbon dioxide produced to oxygen consumed; expressed in terms of VCO_2 / VO_2 (McCardle, Katch, & Katch, 1991).
11. Saddle height: the distance from the center of the crank bottom bracket spindle to the crest of the saddle; expressed in terms of % trochanteric height in centimeters (Nordeen-Snyder, 1977).
12. Triathlon bar position: The position maintained by the cyclist, involving elbows to the elbow pads and hand grasp to the distal portion of the handlebar apparatus.
13. Trochanteric height (TH): The distance from the floor to the femoral greater trochanter, while the subject is standing in an upright position. (Nordeen-Snyder, 1977).
14. U.S.C.F.: United States Cycling Federation.
15. VCO_2 : Carbon dioxide production, expressed in terms of ml / kg / min.

16. VE: Minute ventilation; the volume of air breathed each minute; expressed in terms of L / min (Simon et al, 1986).
17. VO₂: Oxygen consumption, expressed in terms of ml / kg / min.
18. VO₂ max: Maximum oxygen consumption, expressed in terms of ml / kg / min. This level of consumption is reached when the subject's VO₂ does not increase with increases in exercise intensity.
19. Warm-up period: A period of exercise time allowed at the beginning of a trial session, aimed at promoting subject familiarization and metabolic priming.

Basic Assumptions

Several basic assumptions exist in this study. First, it is assumed that all subjects are free from a physical limitation or medical problem (as per subject report) and are all capable of performing at similar levels of submaximal work. Secondly, it is assumed that subjects are relatively equivalent amongst themselves. Thirdly, it is assumed that the metabolic measurement instruments function at the proper levels of calibration (once the calibration measures are performed) and that they will remain calibrated throughout the trials. Fourthly, it is assumed that the cycle/wind trainer system is in proper working order, once a brief maintenance service is performed. Fifthly, it is assumed that the tension adjustments on the wind trainer mechanism remain constant during the trial sessions, once a preliminary adjustment has been made. Sixthly, it is assumed that the weighing scales (including the hydrostatic apparatus) are accurate. Finally, it is assumed that the methods of measurement and determination of derived values (such as VO₂ max) are accurate and reliable.

Limitations and Delimitations

Limitations

The limitations in this study include: (a) the possibility that the bicycle frame size is not perfectly proportioned to all of the riders' body dimensions, (b) the possibility that each rider may have different percent distributions of slow-twitch versus fast-twitch fiber types within the operant muscle groups, and (c) the possibility that riders could increase their efficiency of cycling due to a learning effect, or the riders improve due to learning more efficient ways to ride.

Delimitations

The delimitations in this study include: (a) all subjects must be of good health, with no recent history of (or not presently inflicted with) a musculoskeletal, neuromuscular, or general medical condition, and (b) all cyclists must wear appropriate shoes and clothing during the constant-load trial sessions.

Significance of the Study

Individuals are experiencing competitive success while using the triathlon-style handlebar format. The exercise science community may question the same source of this success. The success could be a result of an enhancement of the rider-bicycle system's aerodynamics, and or due to the possible reduction in the cost of work afforded by the format. By eliminating any detriment invoked on test performance by wind, this investigation will help to establish the role which the handlebar format has in the physiological efficiency of competitive cycling. In addition, the investigation will give the scientific community an inference about the changes in aerodynamics that the rider may experience with subsequent triathlon handlebar use.

CHAPTER II

REVIEW OF LITERATURE

Introduction

Although many different investigations have been performed to study the effects of a wide variety of variables on cycling performance, the effect of using a triathlon-style handlebar format (commonly called "aerobar system") has not been thoroughly examined to date. The United States Cycling Federation (USCF) has recently approved this format for competitive purposes, and individuals are experiencing competitive success while using this format (Johnson & Shultz, 1990). The source of this competitive success is in question. The success has been attributed to an enhancement of the rider-bicycle system's aerodynamics, due to a reduction in the rider's frontal surface area and an increase in the streamlined airflow over the rider's head, as suggested by Kyle (1989), or due to the possible improvement in exercise efficiency afforded by the format. By eliminating any detriment invoked on test performance by wind, the investigation of triathlon-style handlebar use will help to establish the role that this handlebar format has in the physiological efficiency of competitive cycling. In addition, any investigation of triathlon handlebar use will give the scientific community an inference about the changes in aerodynamics which the rider may experience during competition.

Background

The measurement of aerobic capacity continues to be of great concern to the exercise and health science communities. The ability to measure maximum

aerobic capacity has developed into a precision science, and many different health-related fields both practice the measurement and or utilize the important information taken from test outcomes. Oxygen consumption, or VO_2 , is used as a measurement of aerobic function. Maximum oxygen consumption, or VO_2 max, can be used to represent maximum aerobic capacity (Powers & Howley, 1990). Furthermore, many approaches exist for measuring VO_2 , as do many effectors of the testing outcomes. Testing outcomes have a variety of uses and applications. This information can be useful for establishing the influence of various factors on aerobic performance, for observing the metabolic responses which are operant at different work loads, and for tracking the physiological changes that occur as result of training.

Measurement of VO_2 and the Determination of VO_2 max

Comparative Studies

Different exercise tools have been used to measure VO_2 and to determine VO_2 max, including bench step ergometry, upper extremity ergometry, bicycle ergometry, and treadmill ergometry. In addition, different approaches have been developed within each of these categories. Extensive research has been performed to evaluate the validity of these methods and the correlations that may exist between their outcomes (Faulkner, Roberts, Elk, and Conway, 1971; Hermansen, Ekblom, and Saltin, 1970; & McArdle, Katch, and Pechar, 1973). The variety of results from these studies reflects the difficulty which exists in determining which test is most reliable, valid, and representative of true VO_2 max.

McArdle et al. (1973) compared the VO_2 max test outcomes of seven different graduated exercise testing procedures. Fifteen healthy male subjects

performed six different graduated exercise tests, including a discontinuous cycle test (DC test), a continuous cycle test (CC test), a discontinuous treadmill test (DT test), a continuous treadmill test (CT test), a Mitchell-Sprout-Chapman treadmill test (MSC test), and the standard Balke treadmill test (BT test).

These investigators discovered that the VO_2 max outcomes for both cycling tests were from 10.2 to 11.2 % lower than any of the treadmill tests' outcomes. There was no difference between the VO_2 max values of the continuous and discontinuous cycle tests. In addition, no difference was found for the VO_2 max between any of the running tests. On the other hand, the VO_2 max values for the walking tests were significantly lower than the three running tests. Maximum heart rate values were significantly lower on the DC test, when compared to the CT test, and maximum minute ventilation (VE , max) was similar for all tests. From this data, the investigators recommended the use of the continuous treadmill test for the determination of reliable VO_2 max values in large numbers of healthy subjects.

Faulkner et al (1971) compared cardiovascular responses to submaximal and maximal efforts during both bicycle ergometry and treadmill testing. Cardiac output was determined and changes in heart rate, stroke volume, arterial-venous oxygen difference (a-v O_2 difference), and VO_2 were observed at various intervals throughout the testing. It was shown that heart rate and a-v O_2 difference increased significantly between five and 10 minutes of work, as well as during the transition from 90 to 100% maximum work capacity. Stroke volume and cardiac output decreased significantly during both cycling intervals. In addition, a significant difference in VO_2 did occur between cycle ergometry and treadmill during all equivalent stages. Furthermore, VO_2 max with cycle ergometry was 11% lower than with treadmill running. This difference was

believed to be due to a reduced stroke volume associated with cycling (in the presence of an equivalent heart rate and a-v O₂ difference between testing formats). This reduction in stroke volume at heart rates higher than 165 bpm was associated with diastolic intervals that were too rapid to allow for sufficient ventricular refilling time.

These findings are supported by a similar investigation that compared the VO₂ Max, cardiac output, arterial blood pressure (ABP), heart rate, blood lactate and hemoglobin concentrations, and oxygen partial pressure (pO₂) during maximum treadmill and bicycle ergometer tests (Hermansen et al., 1970). These investigators found that subjects produced significantly higher VO₂ Max values during treadmill tests than during bicycle ergometry tests. In addition, higher maximum heart rate values were produced with the treadmill tests versus the bicycle ergometer tests, but the differences were not significant. However, the heart rate values at a given VO₂ were significantly higher during the bicycle ergometry tests. Stroke volume values were significantly higher with the treadmill tests at both the maximal and submaximal levels. However, the cardiac output values during the bicycle ergometry tests were similar to those values during both running tests. It was suggested that these differences may be due to the differences in tensions developed during each exercise format, not differences in muscle mass.

VO₂ Max Measurement in the Semi-Standing Position

The previously mentioned tests produced values based on sitting positions maintained during the cycle testing trials. Kelly, Serfass, and Stull (1980) investigated the effect of performing a bicycle ergometer test in the semi-standing position. Twelve male subjects each performed two graduated

exercise tests to exhaustion on a bicycle ergometer in the seated position, on a bicycle ergometer in the standing position, and on a treadmill. Monitoring and determinations of heart rate, minute ventilation, VO_2 , and VCO_2 (a measurement of CO_2 production) were performed throughout the test.

From the testing outcomes, VO_2 max measurements showed standing cycle test and sitting cycle test values to be 96% and 92% of the treadmill values, respectively. Analysis yielded significant differences for minute ventilation, VO_2 max, and maximum heart rate. The highest value for VO_2 was associated with the treadmill test and the lowest value was associated with the sitting cycle test. In addition, maximum heart rate was significantly lower in both cycle tests compared to the treadmill test. A high reliability coefficient existed for both cycle tests. In addition, the correlation coefficients between treadmill testing and or sitting cycle test versus standing cycle test were high.

More recently, Tanaka, Nakadomo, and Moritani (1987) tested 28 subjects (six normals, 14 distance runners, and 8 rowers) in a comparative study observing the cardiovascular differences between standard treadmill running and bicycle ergometry performance in the semi-standing position. Each subject performed a graduated cycle ergometry test in the sitting position. The test was graduated until VO_2 max was reached. Once this point was reached, the subject then attained a semi-standing position (standing on the pedals with the hand grasp on the top portion of the handlebars) while maintaining the work rate associated with VO_2 max. In addition, each subject performed a graduated treadmill test with the monitoring of the same measures previously mentioned.

The results showed no significant differences for groups in terms of VO_2 max values. VO_2 max during semi-standing cycle ergometry was equivalent to

the values for the treadmill testing, and high correlation existed between the two exercise formats. It was suggested that the equivalency in outcomes was the result of recruitment of a greater muscle mass or increased vascular response during semi-standing cycling, when compared to seated cycle ergometry. This conclusion was supported by an appreciable increase in EMG activity when the subject changed from a seated to semi-standing position. Thus, the differences between cycle ergometry and treadmill testing must be rectified with the increases in aerobic performance with semi-standing positioning during cycling.

VO₂ Max Measurement with the Elite Athlete

In the case of testing elite athletes, the need to choose a VO₂ max testing format that closely resembles the athlete's event has become apparent.

Stromme, Ingjer, and Meen (1977) examined the maximum aerobic power of specifically trained athletes (runners, cyclists, rowers, and cross country skiers) during uphill treadmill running and during their specific sports activity. The aim of the study was to determine the most optimal format of testing for each athletic group. A total of 37 athletes were tested with incremental testing on a treadmill, and either (a) incremental testing on a bicycle (mounted on a treadmill), (b) uphill cross country skiing field test, or (c) a field rowing test. Intensity levels of all of the tests were adjusted to provide maximum work to exhaustion in approximately four minutes. Oxygen consumption was measured and VO₂ max was determined for each subject during each test.

A significantly higher VO₂ max was found with the skiing test versus the treadmill test when performed by the skiers. In addition, results showed higher VO₂ max produced by the rowers and a higher VO₂ max produced by the cyclists during each of their respective sport-specific tests versus during

treadmill uphill running. The investigators concluded that specifically trained muscle fibers associated with each sport governs the cardiovascular testing approach choice, and as result, the most preferable testing procedure should be the procedure which most resembles the athlete's sport.

Another important study which examined exercise testing format differences was performed by Hagberg, Giese, & Schneider (1978). Six competitive cyclists participated in a study aimed at examining the comparison of VO_2 max outcomes during bicycle versus treadmill graduated exercise testing. The subjects performed three progressive test protocols to establish their VO_2 max.

The tests included a progressive running treadmill test at 7, 8, or 9 mph to exhaustion; an incremental cycle ergometry test at 90 rpm; and finally, a progressive exercise test involving a riding session with the bicycle on a treadmill at 20 mph (the grade was increased 0.5 percent per minute until exhaustion). The data analysis revealed no significant differences with the VO_2 max values for the three protocols. These results reflected the competitive cyclist's ability to produce the same VO_2 max values on a cycle ergometer as on a treadmill, due to the adaptations induced by the advanced training level required for competition. In addition, the results reflected the ability of the competitive cyclist to produce VO_2 max values during a potentially hazardous condition which are similar to the values attained during a stable cycle ergometer test.

Effectors of Aerobic Capacity Testing

Many different factors can alter the metabolic pathways utilized, as well as the outcomes of VO₂ max testing. These factors include exercise duration, ventilatory muscle fatigue, skeletal muscle characteristics, and specific effectors associated with cycling. These factors must be taken into consideration when measuring aerobic capacity.

Exercise Intensity

Exercise intensity can alter the pathways utilized during exercise. Medbo and Tabata (1989) explored the importance of aerobic and anaerobic energy release during short duration intense exercise. Each of 17 healthy young males each performed a maximum cycle ergometry test at 1.5 Hz. Oxygen consumption was measured and O₂ demand was determined. Anaerobic energy release was quantified through analysis of the accumulated O₂ deficit.

The results of the study showed a significant linear increase in the work done and total energy release with exercise duration, as expressed by linear increases in accumulated O₂ uptake. The relative importance of aerobic processes rose 40% at the end of the 30 second exercise bout, 50% at the end the one minute bout, and 65% at the end the two minute exercise bout. The authors concluded that from 30 seconds to three minutes exercise duration, effort was significantly supported by both anaerobic and aerobic processes.

Ventilatory Muscle Fatigue

Ventilatory muscle fatigue can reduce exercise endurance by lowering VO₂ responses. Martin, Heintzelman, and Hsiun-ing (1982) performed an experiment aimed at determining the effect of hyperpnea (or previous

ventilatory work) on exercise endurance. Nine subjects performed both a controlled incremental treadmill run to exhaustion at a constant running speed, as well as an equivalent treadmill running test after previous ventilatory work was performed. This prior ventilatory work consisted of constant breathing at 66% of the 12-s MVV (maximum ventilatory volume) value for 15 minutes.

Results showed a reduction in short term maximal running performance during the trials involving prior ventilatory work. The HR and VE points at which exhaustive work was terminated were significantly lower during exercise with prior ventilatory work, when compared to controls. In addition, peak VO_2 was lower during the maximal running after ventilatory work. The investigators concluded that reducing ventilatory muscle endurance could significantly reduce maximum exercise endurance on a treadmill.

These findings were confirmed by Bye, Esau, Walley, Macklem, and Pardy (1984), who performed a study to determine whether normal ventilatory muscles experience fatigue during short term, high-intensity exercise. After performing an incremental exercise test on a cycle ergometer to determine maximum work capacity, seven normal subjects each performed exercise to exhaustion at a constant work load (80% maximum power output) while inspiring humidified 40% oxygen or humidified ambient air. Maximum transdiaphragmatic pressures (Pdi_{max}) and maximum expiratory pressure at the mouth (PE_{max}) were measured before and after activity. Pleural and gastric pressures (Ppl and Pga), as well as diaphragmatic EMG, were recorded. In addition, endurance time, VO_2 , VE, HR and end-tidal VCO_2 were all recorded.

Through *t*-test analysis, a significant decrease in Pdi_{max} was noted from the time interval between 0.5 and 2.0 minutes post-exercise during ambient air and 40% O_2 studies. During minutes 2.0 and 5.0 of the recovery period, partial

recovery of $P_{di_{max}}$ was noted with ambient air, and complete recovery was noted with 40% O_2 . During the post-exercise recovery period, a change was not noted with PE_{max} . These changes were accompanied by a reduction in VE and an increase in VCO_2 by the exercise completion. The investigators concluded that ventilatory muscles (particularly the diaphragm) do experience fatigue, as evidenced by the decrease in end-inspiratory P_{di} in two subjects by the conclusion of their exercise trials with ambient air. The prediction of fatigue through EMG changes in five subjects during exercise with ambient air, as well as the significant delays in those changes with the same subjects during trials using 40% O_2 supported the investigators' conclusions concerning the incidence of ventilatory muscle fatigue with progressive exercise.

The incidence of fatigue in ventilatory muscle was also seen in a competition-related experiment by Loke, Mahler, and Virgulto (1982) aimed at determining whether respiratory muscle would develop fatigue during endurance exercise activity. Forced vital capacity (FVC), One second forced expiratory volume (FEV_1), mid-max. expiratory flow rate (MMEFR), and respiratory muscle strength (PI_{max} and PE_{max} ; maximum inspiratory and expiratory pressures, respectively) were measured before and after a marathon race in four male runners.

Measurements after the race showed no significant changes in FVC, IC, or any flow rates. However, significant reductions were noted between pre- and post-race values for PI_{max} , and PE_{max} . From these outcomes, the investigators suggested that respiratory muscle fatigue does occur with long duration, high level aerobic activity.

Skeletal Muscle Characteristics

Apparently, an individual's skeletal muscle fiber composition can influence the performance outcomes in aerobic capacity testing. Burke, Cerny, Costell, and Fink (1977) proceeded to identify skeletal muscle characteristics that appear to be unique to the competitive cyclist. Twenty-nine competitive cyclists (19 untrained males, and 10 untrained females) were assigned to groups according to seasonal competitive success. A muscle biopsy was performed on each subject to determine relative activity of malate dehydrogenase and succinate dehydrogenase (MDH & SDH; enzymes of aerobic metabolism [Powers & Howley, 1990]) as well as phosphorylase and lactate dehydrogenase (LDH; enzymes of anaerobic metabolism [Powers et al, 1990]). Determination of percent slow twitch and fast twitch fiber areas was also performed. In addition, VO_2 max values were established through either cycle ergometer testing or testing using the subject's bicycle on a treadmill.

The outcomes of the experiment showed no significant difference between season's racing success and percent slow twitch and fast twitch fiber areas or mean activities of SDH or LDH. However, results did show that the trained group had significantly higher VO_2 max values and MDH / SDH activity levels. In addition, significant correlation did exist between VO_2 max and both SDH and MDH activity levels in all groups. In conclusion, the investigators determined that fiber compositions and enzyme activities are similar in male and female competitive cyclists, and that a particularly high concentration of ST or FT fibers is not a prerequisite to success in competitive cycling. In addition, it was suggested that VO_2 max values are better for predicting success than any histochemical or biochemical feature.

The Effect of Cycle Testing Format on VO₂ max

Extensive work has been performed by investigators to determine the effects of different factors on a subject's physical performance while exercising on a bicycle apparatus (Beasley et al., 1989; Coast & Welch, 1985; Faria et al., 1978; Goodwin & Cornwall, 1989; Hagberg et al., 1981; Nordeen-Snyder, 1977; Ryschon & Stray-Gunderson, 1991; and Walsh-Riddle & Blumenthal, 1989). These factors include body position, pedal shaft length, pedalling rate (or cadence), seat height, the use of toe stirrups and straps, and level of training. Manipulation of each of these factors has been found to have an influence on aerobic capacity testing outcomes.

Body Position

Many studies have been performed to assess the effect of body position on cycling performance (Beasley et al., 1989; Faria et al., 1978; Kelly et al., 1980; Ryschon & Stray-Gunderson, 1991; and Walsh-Riddle & Blumenthal, 1989). These studies have been aimed at both examining the body position in terms of the position of the trunk, as well as examining the effect of the handlebar grip position on performance (the hand position maintained on the handlebars during cycling directly influences body position; thus, hand position can be considered a body position variable).

Walsh-Riddle and Blumenthal (1989) performed a study comparing of cardiovascular responses in upright (UR) and semirecumbent (SR) cycle ergometry testing. It was found that peak HR values were significantly higher in the upright position, as were the peak VO₂ values. In addition, the HR and minute ventilation values were lower in the SR condition at the same absolute

and relative work loads. From these results, an obvious difference was appreciated between the two formats.

Faria et al. (1978) evaluated the effect of body position on cycling performance and changes in cardiovascular responses. Eight healthy subjects with a competitive cycling history each performed two continuous multi-stage VO_2 max tests on a modified fixed-gear bicycle ergometer. The subjects performed the randomly assigned tests in both the top-bar position (hands on the top portion of the handlebars with the knuckles facing upward and the elbows straight) and the drop-bar position (hand grasp to the downward turned position of the handlebars with the knuckles up and the elbows slightly flexed). VO_2 and VCO_2 analysis were performed, and maximum values for minute ventilation and tidal volume were determined from ventilatory measurement outcomes.

The test results showed a significant difference between positions in terms of VO_2 max and maximum aerobic power. The top-bar position produced a VO_2 max equal to 93% of the drop-bar position. The drop-bar position produced a maximum aerobic power that was 1.26 ml/kg/minute greater than the top-bar position. It was suggested that these differences were due to a greater muscle mass being recruited during the drop-bar position, resulting in reduced peripheral resistance and greater cardiac output. The drop-bar position produced significantly greater values for work output, work output / kg body mass, maximum minute ventilation, and maximum tidal volume. These increases were attributed to a reduction in ventilatory cost of work. It was suggested that this increase in ventilatory efficiency would contribute to enhanced cellular oxygen consumption.

As mentioned previously, maintaining a semi-standing position during cycling can enhance VO_2 max. outcomes (Kelly et al., 1980). In addition, hand position on the handlebars may influence cycling efficiency outcomes. Ryschon and Stray-Gunderson (1991) studied the influence of body position on the energy cost of steady-state cycling. Four different body position /pedalling rate configurations were compared during constant load exercise: (a) seated, with hands to brake hoods and a pedalling rate 80 rpm, (b) seated, with hands to drop bars and a pedalling rate of 80 rpm, (c) semi-standing, with hands to brake hoods and a pedalling rate of 60 rpm, and (d) seated, with hands to brake hoods and a pedalling rate of 60 rpm. Heart rate was continuously measured throughout each trial.

Test results showed no significant differences were found for VO_2 between seated / hoods configuration and seated / drops configuration, each at 80 rpm. The standing / hoods configuration at 60 rpm had a significantly higher VO_2 compared to the seated / hoods configuration at 60 rpm. Heart rate followed the same pattern of results as the VO_2 pattern. VO_2 was significantly higher during the seated / hoods configuration at 60 rpm, when compared to the same configuration at 80 rpm. From these findings, it was concluded that cycling in the seated position was more efficient than cycling in the semi-standing position.

Bicycle Saddle Height

Bicycle saddle height can influence the outcomes of aerobic capacity testing on a cycle ergometer. Nordeen-Snyder (1977) investigated the effects of bicycle seat height variation on oxygen consumption in 10 healthy women cyclists. Each subject performed three submaximal cycling tests on their own

bicycle (which was mounted on a tension-resisted roller system). Each subject performed a 10-12 minute trial at each of three saddle heights (either 95, 100, or 105% of their own trochanteric height; measured from the floor to the center of the femoral greater trochanter in standing with the knee fully extended). Results showed significant differences between groups. Oxygen consumption was lowest with the 100% trochanteric height. The authors concluded that saddle height has a direct influence on the cardiovascular performance associated with bicycle riding.

Pedal Crank-Arm Length

Pedal crank arm length has also been studied for its effect on cycling performance. Goodwin and Cornwall (1989) observed range of motion and phasic muscle activity changes in the knee system during cycling with two different pedal crank arm conditions. The first condition involved an ergometer with a crank arm shaft length of 17.8 cm and the second condition involved a crank arm shaft length of 8.9 cm. Measurements of maximal knee flexion, as well as electromyographic phasic activity of the rectus femoris and gastrocnemius, were performed. A significant reduction in maximal knee flexion was observed during the shortened pedal shaft condition. No significant differences were found between the different conditions in terms of muscle recruitment during the appropriate corresponding phases of the pedalling sequence.

Pedalling Rate

Though no oxygen consumption effect was observed by Goodwin and Cornwall (1989) with changes in crank arm length, another dimension involving

the pedal crank system may have significant impact on performance: pedalling rate, or cadence. Hagberg et al. (1981) conducted study of competitive cyclists concerning the effect of pedalling rate on submaximal exercise responses. They discovered that during the constant-load cycling equal to 80% VO_2 max, the most economical rate was 91 rpm. This rate was also the average of the most desirable rate by the cyclists.

In a more recent study, the concept of standard optimum rate was questioned. Coast & Welch (1985) investigated the linear increase in optimal pedal rate with increased power output in cycle ergometry. Five trained competitive cyclists each performed five progressive maximal cycle ergometry tests at one of five different pedalling rates (40, 60, 80, 100, and 120 rpm). Oxygen consumption and heart rate were continuously monitored and throughout the trials. Determinations of fractional expired O_2 and CO_2 , as well as minute ventilation, were performed during the third minute of each power output.

The VO_2 values and heart rate cost of cycling values were determined at power outputs of 100, 150, 200, 250, and 300 watts. Oxygen cost of cycling and heart rate lines were constructed from these values. Cost of riding values for different pedalling rates were compared at equal power outputs. The optimum pedalling rate was determined through the averaging of values from all subjects. A curve of best fit was developed for heart rate or VO_2 versus pedalling rate at every power output. The optimal pedalling rate was represented by the point on the curve which had a corresponding slope of zero.

The results of the study by Coast and Welch (1985) displayed a linear increase in heart rate and VO_2 with increase in power output. Results also showed that the values for both heart rate and VO_2 were significantly different

during different pedalling rates at equal power outputs. A positive linear relationship existed between power outputs and optimal pedalling rate. Correlation between the curves of both heart rate versus pedalling rate and VO_2 versus pedalling rate ranged from 0.86 and 0.99. Furthermore, VO_2 max and maximum power output were both significantly different at different pedalling rates, with the greatest values for each occurring at 80 rpm. The investigators concluded that (a) optimal pedalling rates do exist, (b) those rates vary according to the power output at which the cyclist is performing, (c) the optimum pedalling rate increases as the cyclist's skill level improves, and (d) the testing format utilized should be custom-tailored to the subject in terms of pedalling rate, instead of using a standardized format.

Toe Clips and Straps

The third dimension of influence involving the pedal-crank system deals with the pedal-toe stirrup configuration. Nakadomo, Tanaka, Watanabe, and Fukuda (1986) explored the effect of toe stirrup use with cycle ergometry on VO_2 max outcomes. They discovered that no significant difference existed between subjects who used toe stirrups and those who did not during cycle ergometry in the seated position. However, a 17.8 % higher VO_2 max was appreciated with standing cycle ergometry with toe stirrups when compared to sitting with toe stirrups. So, in the case of toe stirrups, the effect was influenced by the position of the body.

Multifactorial Effects

The effects of bicycle factor combinations (pedaling frequency, use of toe clips, and body posture) were investigated by Beasley et al (1989). Treadmill

testing performance was compared with performances during standard cycle ergometer testing (ie., having no modifications to the ergometer and a pedaling frequency of 50 RPM) and optimized cycle ergometer testing (ie., using an ergometer with toe clips, racing seat, and drop-style handlebars at a pedaling frequency of 90 RPM). Ten male competitive cyclists and 10 male competitive runners were grouped according to sport. Each subject performed the three maximal continuous graded exercise tests to exhaustion.

Resulting values for absolute VO_2 max, submaximal VO_2 , maximum heart rate, ventilation rate, respiratory exchange ratio, and workload were analyzed. Results demonstrated a higher VO_2 max for runners during treadmill testing compared to the cycle tests. In addition, runners exercised longer than the cyclists during treadmill testing (displaying specificity of training). There were no differences between runners and cyclists in terms of achieved maximal workloads. However, when comparing workload to submaximal VO_2 , the optimized cycle test was significantly more economical than the standard test for both groups. No group or test differences for absolute VO_2 max were observed for the two cycle tests.

Although each of the ergometry modifications included in the optimized test may have singularly increased VO_2 max in former investigations, they apparently were not additive in this study (contrary to the examiners' expectations). The increase in workload by both groups during the optimized test with no concurrent increases in VO_2 max suggested that the data was valid maximal data. Conclusively, differences were not found between the optimized and standard tests in terms of VO_2 max, but were found between groups in terms of greater exercise economy (at a given % VO_2 max).

Steady Rate Measurement During Constant-Load Cycling

Once VO_2 max has been determined, the value can be used for determination of oxygen consumption efficiency. At any given work rate, the operant VO_2 can be expressed in terms of $\% \text{VO}_2$ max. The greater the value that is found for $\% \text{VO}_2$ max, the lower the operation efficiency becomes. This information can be useful for establishing the influence of various factors on aerobic performance, for observing the metabolic responses operant at different work loads, and for tracking the physiological changes occurring as result of training.

As mentioned before, constant load exercise was used to investigate the effects of body position on aerobic capacity (Ryschon & Stray-Gunderson, 1991). During this study, the authors described the following criteria for identifying steady state VO_2 : (a) Display of a consistent plateau for VO_2 during on-line analysis, (b) VO_2 must not vary more than .2 L / min above and below the steady state value, once the value has been established, and (c) HR must not vary more than four bpm at the plateau level VO_2 . However, constant load, steady state exercise does not insure that VO_2 will not change.

Intensity of Constant-Load Exercise and VO_2

Intensity of exercise can have an impact on exercise efficiency. Whipp and Wasserman (1972) performed a study aimed at investigating the effects of exercise intensity on VO_2 during constant load exercise. Six healthy subjects performed six exercise tests on different days. Each trial consisted of 10 minutes of rest, followed by performing a minimum of six minutes of exercise on a bicycle ergometer at approximately 60 rpm, followed by a rest-recovery period of time sufficient to allow VO_2 to return to a resting level. Each subject

performed each trial at 50, 75, 100, 125, 150, and 175 watts (trials were randomly ordered.). Oxygen consumption, minute ventilation, lactate levels, and pyruvate levels were all determined and analyzed for each trial.

The experimental results showed that: (a) Steady state was reached within three minutes at low work rates, and (b) time to steady state was increased during higher work rates, in that no steady-state was reached within the six minutes of exercise at 125, 150, or 175 watts. Rapid O₂ deficit and debt were exhibited at low work rates. Delayed O₂ deficit and debt were observed with higher work rates. In addition, a similarity was observed between magnitudes of O₂ deficit and debt (when the traces were measurable). Furthermore, the time required for the change in VO₂ (during the three to six minute interval of exercise) was directly proportional to increases in the work rate. Arterial lactate increased exponentially with increases in work rate and was generally higher in poorly trained individuals. Finally, it was established that the pattern of VO₂ during steady and non-steady rate exercise was dependent on the work rate exhibited, as well as physical fitness level of the subjects.

Cycle Testing Formats and Methods

Many different approaches have been utilized for aerobic capacity testing with a bicycle. These methods have encompassed both laboratory and field conditions, and have used both modifications of a true racing bicycle and a standard cycle ergometer. The measurement of work, power, and fatigue have relied on several different combinations of motion resistance and recording apparatus. Each format has provided both advantages and disadvantages to the rider and investigator.

The first format that has been widely used is the standard cycle ergometer. This device, with a standard bicycle saddle and upright-style handlebars, has been extensively utilized by numerous investigators for aerobic capacity determination, especially for preliminary determination of VO_2 max (Beasley et al., 1989; Coast & Welch, 1985; Faulkner et al., 1971; Hagberg et al., 1978; Tanaka et al., 1987; and Whipp et al., 1972). This format provides an easily reproducible approach with readily measurable performance outcomes, such as work and power.

Though this format is widely used, it presents several drawbacks:

(a) the equipment on the bicycle, including the saddle, pedals, and handlebars, does not resemble the equipment on a true competition racing bicycle; (b) the body position maintained during the use of this format does not resemble the position used during racing bicycle use; (c) the rider is expected to accommodate the dimensions of the ergometer, even in the presence of limited available adjustments; and (d) the total body movements used with a racing bicycle are not duplicated on this format, including body sway and those associated with coordination demands. Therefore, the performance outcomes produced while using this format may not represent the performances on a true bicycle during competition, and these performance differences may be reflected in different aerobic capacity outcomes.

Attempts have been made to modify the standard ergometer (with racing style handlebars, racing saddle, and racing toe clips with straps). These changes were aimed at overcoming some of the previously mentioned limitations (Beasley et al., 1989; and Faria et al., 1978). Though the the ergometer's equipment resembled that of a true racing bicycle, the other

limitations to using cycle ergometry as a valid aerobic capacity measurement tool remained unchanged.

A third approach involves placing the rider's bicycle onto a roller apparatus. The device does not, however, provide measured resistance to the riding, thus making measurement of work difficult. Nordeen-Snyder (1977) overcame this obstacle during her investigation of the influence of seat height on aerobic capacity. Each subject performed three submaximal cycling tests on their own bicycle (which was mounted on a roller system). The tension was produced by wrapping a tension belt from a conventional ergometer system around the rear roller drum. This system provided the measurements of work necessary for calculations. In addition, this approach allowed cyclists to ride on a bicycle which could be totally adjusted to each of their own body dimensions. Furthermore, the natural total body movements were allowed. However, this arrangement may have produced error in two ways. First, the belt system relied on the accuracy of the ergometer through a configuration not originally intended for this device. secondly, friction loss between the cycle tires and the well-machined metal roller drum may have allowed slippage. Both of these elements may produce error in VO_2 measurement.

A fourth approach to measurement of VO_2 through cycle testing involves field testing. The measurements of aerobic and ventilatory performance have been performed on riders using their bicycles in the "real-world" (McCole, Claney, Conte, Anderson, and Hagberg, 1990). Measurements of this type are potentially valuable in terms of preserving external validity, but possibly not valuable for preserving internal validity. In other words, if the effect on physiological measures is being measured with testing, then this format may

provide variables that tamper with the physiological responses to the independent variables.

Another approach involves placing the rider's bicycle on a treadmill and operating the treadmill at a steady-state fashion (Burke et al., 1977; Hagberg et al., 1978; Hagberg et al., 1981). Ryschon and Stray-Gundersen (1991) used this method to investigate the aerobic response at constant load exercise in different body positions. Several factors were identified as reasons for choosing a bicycle-on-treadmill design, in favor of the standard ergometer or bicycle field test.

The first factor involves air resistance. It was suggested that air resistance, owing to either forward movement or opposing airflow during conventional field VO_2 testing, is eliminated by this format. Secondly, the air resistance encountered by the spokes is made constant. Thirdly, a standardization of pedalling rate and a constant mechanical power recruitment is produced. In addition, the cyclist's individualized bicycle dimensions are allowed, thus increasing the efficiency of operation. It was also suggested that functional rocking in the collateral directions is allowed with this design. The rocking is increased by semi-standing and decreased by sitting, and functions as an aid to the increasing of efficiency with pedalling. With the standard cycle ergometer, the rocking will be eliminated and the testing will not be representative of true cycle performance. (The authors noted that VO_2 max values attained with this format were identical to values attained on a modified ergometer format, but that this format presented significant risk to the rider and examiner during testing. Therefore, the modified ergometer format was recommended for VO_2 max testing).

Considerations Related to the Problem

To establish the role that the triathlon-style handlebar format has in cycling performance, one must consider the anatomical and physiological differences that may exist between the two formats. Understanding these differences may lead to greater insight into the physiological contribution the triathlon format gives to cycling performance.

Anatomical Features of Triathlon Positioning

A cyclist who is correctly using the conventional drop-style handlebar format will incorporate muscles of the shoulder, elbow, forearm, wrist, and hand for both upper body stabilization and bicycle navigation during fitness training and competitive riding. This cyclist is required to grip the handlebars to a certain degree, while maintaining a continuous contraction of the triceps brachii and shoulder musculature. This static activity is required throughout the complete duration of the exercise experience.

A cyclist, who is correctly using the triathlon handlebar format, is allowed to rest the elbows on the elbow pads and maintain a very loose hand grasp of the distal apparatus. Much of the resting force between the upper body and handlebars appears to be non-contractile and static in nature. In addition, the static loading force appears to be transmitted longitudinally through the long shaft of the humerus. The shoulder muscles are apparently contracting as before, but possibly to a lesser extent, due to the shorter lever arm of the upper extremity resting on the handlebar bar pad at the elbow. This construct would allow an investigator to suggest that with a reduction of muscle involvement in the upper extremity during use of triathlon handlebars might come a reduction of overall metabolic cost of work to the system, which would lead to a greater

efficiency of operation and reduced fatigue at a given work load. The following investigations appear to support this idea.

Forearm Vascular Changes with Gripping Activity

Humphreys and Lind (1963) investigated the vascular responses within sustained muscle contractions of various levels of percent maximum muscle contraction tensions. Their aim was to: (a) determine the critical pressure at which intramuscular pressure overcomes the perfusion pressure of the blood within the contracting muscle, (b) determine the vascular response occurring within muscle at different contractile tension levels, and (c) assess the functional significance of vascular responses within contracting muscle.

Four subjects of high motivation performed contractions on a simple hand-grip strain gauge dynamometer. A preliminary value for maximum voluntary contraction (MVC) was established. Subsequently, each subject performed sustained hand-grip contractions at 30, 40, 50, 60, or 70% maximum contraction level after submerging the forearm for 30 minutes in water of a 18, 26, 34, or 42 degree Celsius temperature. Forearm blood flows were measured before, during and after each contractile event in three of the subjects. All measures were repeated (one set accompanied by blood flow measurement and one set without this measurement), and EMG was used to confirm activity of the muscle groups expected to operate during the trial.

From the results, the investigators found that blood flow was sustained throughout the contractile activity during tensions up to 60% MVC. At lower tension levels, the blood flow's rate of rise increased progressively, until fatigue occurred. However, at higher tensions (up to 60%) the rise of blood flow was linear. Increases in pre-exercise water temperature caused progressive

increases in the total amount of blood which flowed through the muscle during the trial duration. In addition, the systemic blood pressure increased throughout the duration of the contractile trial. This attenuated the final blood flow value, in that the blood pressure increase counteracted the increased blood flow during the end of the event. Thus, at tension values above 70% MVC, it was presumed that blood flow would be relatively occluded.

EMG assessment identified the extensor carpi radialis, flexor digitorum superficialis, and flexor digitorum profundus as the three primary muscles of activity during the trials. These muscles were considered the primary focus for the incidence of occlusion to local vasculature. In addition, consistent increases in core temperature of active muscles were seen during tensions up to 50% MVC. These increases were consistent with the increases in vascular flow to the same activated muscles. The investigators concluded that vascular flow increased within muscles during sustained contractile activity of up to 70% MVC, and that the increases in flow were confined to the active muscle only.

Bystrom and Kilbom (1990) performed a study investigating the development of fatigue during isometric handgrip exercise. Six healthy subjects each participated in a total of 15 experimental trials involving four combinations of contraction-relaxation periods of right-handed dynamometer activity (time, in seconds, for contraction & relaxation; 10 seconds + 10 seconds, 10 seconds + 5 seconds, 10 seconds + 2 seconds, and continuous) with three different contraction intensities (10, 25, and 40% of predetermined maximum voluntary contractions, MVC). Local blood flow was measured before, during, and after exercise in the distal portion of the upper extremity. EMG analysis of the upper extremity and pain perception analysis were performed as well.

Results indicated no differences emerged between pre- and post-exercise resting blood flow measures and MVC's. Blood flow significantly decreased and reached a steady state during the 10% MVC activity, then rapidly returned to resting state post-exercise. Blood flow during intermittent contractions was greater than during constant load activity. This difference was attributed to the relative increase in blood flow during the relaxation cycles of intermittent exercise.

Perceptions of pain and effort were less during intermittent exercise than with the constant load activity. With constant load activity, the EMG changes during the contractions were significantly greater during the contraction phase versus the relaxation phase of exercise. This was not the case during intermittent exercise. Additionally, it was observed that blood flow enhancement during the relaxation phase was significantly greater with the 25% MVC trial versus the 10% MVC trial. There was no difference found between the 25% MVC versus 40% MVC trials for the same variable measurement.

The investigators suggested that these differences were a reflection of the operational influence of the autonomic nervous system during different patterns of exercise. The investigators concluded that fatigue is directly related to the reduction of blood flow and that a means of handgrip activity that would avoid fatigue involves intermittent activity at either 10% MVC (10 seconds + 5 seconds) or 25% MVC (10 seconds + 10 seconds).

From both of these investigations, it can be seen that alterations in the vascular response in the forearms can occur as result of forearm muscle activity associated with gripping. This activity can lead to both fatigue and metabolic

changes. These changes could contribute to overall performance during concomitant activity.

Cardiovascular Responses to Combined work

Lind and McNicol (1967) performed an experiment involving four healthy male subjects aimed at observing the circulatory responses to sustained handgrip contractions during additional aerobic exercise. The subjects performed multiple sustained contraction trials. Each subject performed multiple contractions in three different fashions. First, they performed contractions in the forearm muscle groups (associated with hand grip) and the knee extensor groups (separately and then together at 20, 30, and 50% MVC). Secondly, they performed multiple sustained contraction simultaneously in the muscle groups of two or more extremities, with tensions at different levels of % MVC (at 10% MVC in one extremity and 30% MVC in another extremity). Finally, one extremity was contracted at 30% MVC while another was contracted at 70% MVC. Heart rate and blood pressure were monitored throughout the trials. These trials were aimed at determining the functional benefit acquired by the extremity contracting at a lower % MVC.

From these trials, it was found that heart rate and blood pressure increments were equal for simultaneous or separate contractile activity in two different extremities (if performed with the same % MVC tension). Additionally, the results showed equal heart rate and blood pressure values associated with both equal and unequal contractile activity in two different extremities. Finally, the blood flow to a muscle engaged in sustained contractions was increased to that muscle group when an additional muscle group was involved in exercise at a higher work level.

Sanchez, Monod, and Chabaud (1979) performed an investigation aimed at observing the cardiovascular changes associated with dynamic, static, and combined work. Three male subjects performed work in a dynamic, static, and combined fashion. The dynamic work consisted of walking on a horizontal treadmill at four velocities (0.56, 0.83, 1.11, and 1.39 meters / second). The static work consisted of three forms of activity, all with elbows flexed to 90 degrees: (a) pushing a load forward, (b) moving a load horizontally, or (c) supporting a load vertically. The combined work sessions consisted of combining one of the static tasks described above while walking at one of the described treadmill velocities. Thirty four of the 60 combination possibilities were performed by each subject. Heart rate and VO_2 were measured continuously during the different activities.

Cardiac cost and oxygen cost (difference between the mean heart rate or VO_2 for the final two minutes of work and the resting values of heart rate or VO_2 observed during the time prior to work) were measured. An extra-cost for combined work was determined by calculating the difference between the cost of combined work and the sum of the costs of each component.

The results showed that during the static trials, the costs of work linearly increased with increases in load. Both cardiac and oxygen costs of work increased linearly during the dynamic trials with increases in velocity of walking. The costs of work also increased linearly with the increases in load during the combined sessions. Velocity had no effect on the physiological costs during pulling activities. Furthermore, pushing while walking had a significantly higher cost than pulling or holding while walking at the same velocity with the same load.

Determination of extra-costs were always positive during pushing, and increased with increases in the load at the same velocity, or increases in the velocity at the same load. A high positive correlation existed between load value and extra oxygen cost during activities which involved pulling. Extra oxygen and cardiac costs were negative during the pulling of low loads, but became positive during higher loads. Extra costs during holding and walking were slight and always negative. The investigators concluded that physiological responses to combined work vary in values, and depend on the type of work load being combined.

Harper and Byrd (1987) compared the heart rate, systolic blood pressure, and diastolic blood pressure of 18 young health males during dynamic and combined work loads. Each subject was selected on the basis of aerobic capacity and pretested with a maximum handgrip test plus a submaximal graduated treadmill test to 85% MHR for the purpose of VO_2 max extrapolation. Next, each subject was randomly assigned to one of three groups: group 1 (static exercise group) performed a five minute standing test while gripping a briefcase containing sufficient weight to elicit a grip value equal to 20% of the maximum grip value; group 2 (dynamic exercise group) performed a five minute treadmill exercise at a constant-load of 30% VO_2 max; group 3 (combined exercise group) performed a five minute treadmill exercise at 30% VO_2 max while gripping a briefcase containing weight of equal value to the static group.

Analysis of pretest group differences indicated no significant differences. Further analysis showed significance for groups in terms of heart rate and diastolic blood pressure. Static exercise heart rate was significantly greater than dynamic exercise heart rate, which was significantly greater than

combined exercise heart rate. These differences were attributed to the increased O₂ demand of each appreciably higher heart rate. Static exercise diastolic blood pressure was significantly higher than combined exercise diastolic blood pressure, which was significantly higher than dynamic exercise diastolic blood pressure. These differences were attributed to the relatively higher level of peripheral resistance associated with each exercise format producing a higher diastolic blood pressure. There was no difference between groups in reference to systolic blood pressure, when comparing static versus dynamic exercise. However, combined exercise systolic blood pressure was significantly higher than the other two formats. This increase was attributed to an increase in rate-pressure-product (product of heart rate x systolic blood pressure divided by 100; Powers & Howley, 1990) associated with the combined exercise format.

These studies reflect the added stress that is imposed on the cardiovascular system by combined work. The increased stress can translate into an increased oxygen consumption, thus lowering exercise efficiency. The combined work models from these studies potentially represent the model of additional physiological work during use of the drop-style handlebar format.

Applied Investigations

Dlin, Hanne-Paparo, and Tenenbaum (1990) performed a study investigating the influence of static handlebar gripping on blood pressure responses to cycle ergometry. Thirty nine active healthy males were evaluated with a pre-exercise resting electrocardiogram and blood pressure measurement. After the evaluation, each subject performed a continuous graded exercise protocol consisting of a 3-min. bout at 100 watts (W) power,

followed by a 6-min. bout at 150 W. The subjects had been randomly divided into two groups prior to exercise. Group I gripped the handlebars during the first 3-min. bout of exercise and pedalled without gripping during the second 3-min. bout. Group II performed the same test but with opposite sequence.

Heart rate was recorded during the final 30 sec. of each power load. Blood pressure was recorded with an arm-cuff mercury sphygmomanometer. Analysis of data indicated no significant difference for group or sequence at a work rate of 150 W in terms of heart rate, heart rate change, systolic blood pressure, systolic blood pressure change, or systolic blood pressure / heart rate. A significant group effect was seen for diastolic blood pressure and diastolic blood pressure change, but the group was not identified. No significant effects for sequence were seen with the same variables. From these results the investigators suggested that the influence of normal static handgrip on the handlebars (at < 20% of maximum voluntary contraction) does not significantly effect systolic blood pressure, diastolic blood pressure, or heart rate response to dynamic exercise at the intermediate power load.

Though a significant difference did not occur for contractions less than 20% MVC, the ability for a cyclist to maintain this reduced level may be compromised, especially during the competitive condition. The amount of cognitive involvement that would be required to keep the grip output low could also potentially create a distraction to the rider. Fatigue must now also be considered in this applied work scenario.

Petrofsky and Lind (1978) investigated the effect of lifting on the fatigue of forearm musculature. Three trained individuals performed training regimens of lifting, bicycling, hand-grip isometrics, and back muscle isometrics for 12 weeks. Each subject was subsequently tested for heart rate, VO_2 , and

electromyography outputs (lumbar paraspinals and forearm musculature) in each of the formats (cycle ergometry, lifting tasks, and extended lifting). The investigators found that VO_2 max was always lower during lifting tasks versus ergometry. Additionally, extended lifting tasks of one to four hours elicited a work load that equalled 50% of the VO_2 max during cycle ergometry.

Furthermore, a lifting work load equalling 25% of the cycle ergometry VO_2 max was the upper work limit available to the subjects without incurring fatigue. Isometric endurance levels and electromyographic readings confirmed the existence of significant fatigue in the forearm musculature during the lifting activities.

Though this experiment involved lifting tasks and not supportive tasks, the principle of peripheral upper extremity work could be applied to the triathlon handlebar scenario. Furthermore, cycling with the drop-style handlebars can involve the wrist and finger flexors, which are a portion of the agonists in the previously mentioned lifting task. From all of the previously mentioned studies, one can deduce that the cost of work during cycling may be reduced if the work of the upper extremities is reduced. However, another component may interplay into this reduced cost of work model: the ventilatory cost of work.

Body Position and the Ventilatory Cost of Work

Another element which must be considered when comparing the drop-style handlebars and the triathlon handlebars involves the change in the position of the torso and the impact that this can have on the ventilatory cost of work. The proper use of the triathlon handlebar system can lead to the lowering and anterior displacement of the shoulder complex and upper torso. This is

afforded by the positioning of the elbows on the elbow pads. This repositioning may have several consequences.

Early investigations were aimed at the examination of the ventilatory cost of work. Craig (1960) reported that the expiratory reserve volume (ERV) reflects the resting position of the lungs and thorax, and is the most variable subdivision of the lungs' total capacity. The experiment involved the measurement of the ERV on the subjects (N not available) in various different positions (including supine, sitting, sitting with the elbows on the armrests of the chair, sitting with the elbows on the armrests of the chair and the trunk inclined forward, and positioned on hands and knees).

Values for expiratory reserve volume in straight sitting were used as the standard values for comparison. Increases in ERV represented the desirable condition. Results showed a significant decrease in ERV in supine positioning. ERV increased 3.1% when sitting with the elbows on the armrests of the chair, and a 7.1% increase when sitting with the elbows on the armrests of the chair and the trunk inclined forward. ERV values were 10.3% increased when positioned on hands and knees. Craig postulated that positions which support the upper extremities (which removed the shoulder girdle weight from the total thoracic cage weight) reduce the weight against which the muscles of respiration perform work, thus lowering the ventilatory cost of work.

As mentioned before, Walsh-Riddle and Blumenthal (1989) performed a comparative study of cardiovascular responses in upright (UR) and semirecumbent (SR) cycle ergometry testing. Ten male and 10 female subjects between the ages of 34 and 52 years of age with documented histories of mild hypertension (systolic BP $\geq$ 140 mmHg; Diastolic BP $\geq$ 90 mmHg) performed maximal exercise testing on both an upright and semirecumbent cycle

ergometer. The tests were performed at 50 rpm to VO_2 max levels on each device. Oxygen Consumption, minute ventilation, rate-pressure-product, and HR values were all determined at absolute and relative loads, as well as at rest and peak performance levels.

Several differences emerged from test outcomes. First, the rate-pressure-product values were lower in the SR condition at rest, as well as work levels equalling 75% and 90% VO_2 max. Males had a significantly lower heart rate during both submaximal and maximal conditions when compared to females. In addition, the heart rate and minute ventilation values were lower in the SR condition at the same absolute and relative work loads. Peak heart rate values were significantly higher in the upright position, as was the peak VO_2 value. From these outcomes, the investigators suggested that upright cycling was preferred for producing maximum exercise performance outcomes among patients with mild hypertension.

These studies support the notion that decreasing the functional weight of the shoulder girdle and torso during cycling will reduce the ventilatory cost of work. They also harmonize with the other investigations (Bye et al., 1984; Loke, Mahler, & Virgulto, 1982; Martin et al., 1982), which suggested that ventilatory muscles experience fatigue during exercise. Thus, any measure which will reduce ventilatory work will reduce the cost of work and the time that is necessary to arrive at steady state during constant load activity. This concept was supported by Wasserman, Whipp, Koyal, and Beaver (1973), who investigated the alterations in gas exchange during incremental cycle ergometry exercise. They concluded that increases in work load requires increased time for the subject to reach a steady state of oxygen consumption.

Comprehensive Investigations

As previously mentioned, few studies have been performed to evaluate the physiological effects of triathlon handlebar use. Johnson and Shultz (1990) recently investigated the physiological effects of triathlon-style handlebars during submaximal effort. These investigators performed this study to test the change in gross efficiency of exercise and ventilatory function during the triathlon handlebar use. The investigators asked elite cyclists to perform on a modified cycle ergometer for 10 minutes with both standard drop-style handlebars and triathlon handlebars with a 90 rpm pedalling rate, at a workload equalling 80% of their individual pre-determined VO_2 max value.

Johnson and Shultz (1990) discovered no significant differences between the two different formats in terms of VO_2 , gross efficiency, minute ventilation, tidal volume, heart rate, or respiratory rate. From these results the investigators suggested that: (1) the triathlon handlebar use was at least as efficient as the standard handlebar use; (2) Triathlon handlebar use did not compromise ventilatory function, as evidenced by significant similarities between formats; and (3) any physiological benefits attained with triathlon handlebar use would only enhance the already established aerodynamic benefits.

CHAPTER III

METHODOLOGY

This chapter will present an explanation of the experimental methods that will be used to collect data pertinent to the study. The subjects, test apparatus, measurement instruments, methodology, and data analysis techniques will be discussed.

Subjects

Fifteen male non-cyclists volunteered for this study. All subjects were healthy with no recent history of (or not presently afflicted with) a musculoskeletal, neuromuscular, or general medical condition, as determined through self-report on an intake questionnaire provided by the investigator. Each subject was given written informed consent in accordance with the Human Subjects Committee of Texas Tech University, and in accordance with the Institutional Review Board of Texas Tech University Health Science Center. Additionally, each subject was instructed to adhere to the following guidelines (McArdle et al., 1991): (1) avoid food intake any sooner than three hours pre-test (so to allow sufficient ingestion); (2) practice adequate hydration; (3) avoid strenuous activity during the testing period, so to reduce carbohydrate depletion (which could lead to premature fatigue); and (4) avoid caffeine intake during the test period.

All subjects were weighed on a Detecto balance beam scale. Percent body fat was calculated for each subject using a underwater weighing technique described by Powers and Howley (1990, pp. 385--386), where % body fat is defined by equation 3.1, i.e.,

$$\% \text{ body fat} = (495 / \text{Density}) - 450 \quad (3.1).$$

Body density is described by equation 3.2, i.e.,

$$D = \frac{M}{V} = \frac{(M_A)}{\frac{(M_A) - (M_w)}{(D_w)} - [(V_R) + (V_{GI})]} \quad (3.2).$$

M_A = weight measured in air

M_w = weight measured under water

D_w = density of water

V_R = residual volume

V_{GI} = volume of gas in GI tract.

Lean Body Mass (LBM) was calculated by equations 3.3 and 3.4, i.e.,

$$(\% \text{ body fat})(\text{total body mass}) = \text{Fat Mass} \quad (3.3).$$

$$\text{Total Body Mass (TBM)} - \text{Fat Mass} = \text{Lean Body Mass} \quad (3.4).$$

Lean body mass values were used for the calculations of values of VO_2 per kg of body weight (relative oxygen consumption). Additionally, a target submaximal HR (THR) was established for each subject using the equation 3.5, i.e.,

$$\text{Target HR} = (220 - \text{Age} - \text{RHR}) .85 + \text{RHR} \quad (3.5).$$

Where:

HR = Heart Rate

RHR = Resting Heart Rate

.85 = percentile of maximum.

The THR percentage value (.85 x age-adjusted max HR) was selected in accordance with Powers and Howley (1990), who suggested that a submaximal incremental exercise test is performed until 70-85% of the individual's age-adjusted max HR is reached. Furthermore, these authors provided a relationship as a guide to estimating an individual's submaximal oxygen consumption from heart rate values (see Table 3.1 below). The .85 value provided a limit below which each subject would be operating at, or slightly above, his onset point of blood lactate accumulation (OBLA). Thus, each subject's trials would be primarily aerobic in nature (Powers & Howley, 1990).

Table 3.1: Relationship of Percent of HR max and % VO₂ max

<u>% VO₂ max</u>	<u>% HR Max</u>
50	65
55	68
60	72
70	79
75	83
80	87
85	91
90	94

Apparatus

This experiment incorporated a racing bicycle equipped with racing saddle, drop-style handlebars, a Profile Aero-II triathlon handlebar extension apparatus, and racing pedals with toe clips. Riders of a height under 72 inches rode a Schwinn Tempo racing bicycle with a Shimano 105 component group and a 700c x 20c rear wheel (equipped with IRC clincher tires). Subjects with a height over 72 inches rode a Centurion Ironman Expert bicycle with identical components. Both bicycles were equipped with 42 and 52 tooth chainrings and the following freewheel: 13, 14, 15, 17, 19, 21, & 23 teeth.

Either bicycle was mounted atop a Slocum wind trainer. The height of the variable support post was adjusted to provide standardized level of friction (15#) between the rear tire and the turbine, while maintaining a level bicycle top-tube. The friction between the rear tire and the turbine was determined by applying a strain gauge to the spoke nearest to the tire's contact point with the turbine, manually stabilizing the turbine, and pulling on the strain gauge until the tire exceeded frictional resistance. The strain gauge was pulled in a direction that was tangential to the circumference of the tire, as illustrated in figure 3.1 below:

Figure 3.1: Strain gauge application for measurement of tire friction against the wind turbine.

Rear tire air pressure was maintained at 100 pounds per square inch, as measured with a Zefal floor pump.

Instrumentation

Expired air was measured and analyzed continuously by an open circuit, on-line spirometer system (Beckman MMC Horizon System with Beckman O₂ and CO₂ analyzers; from Sensormedic, Anheim, CA). The gas analyzers were calibrated to room temperature and known gas prior to each trial session. Additionally, volume and barometric pressure calibrations were performed prior to each trial session. Heart rate was monitored with a Polar Pacer heart rate monitor, whose electrodes were fastened to each subject along the bilateral inferior borders of the pectoralis major muscles. The receiver unit was donned by the subject on his right wrist. Pedalling rate was cued with both audible and visual stimuli from a Seiko DM-40 digital metronome positioned in front of the subject at approximately 5 centimeters below eye level.

Procedures

Each bicycle's saddle height was adjusted to 100% of the subject's trochanteric height, as described by Nordeen-Snyder (1977). The triathlon bar position was adjusted in the following fashion: (1) the length of the bars was adjusted to allow the subject to rest his hands comfortably on the ends and his elbows on the pads, while maintaining his wrists in a neutral position; and (2) the angle of inclination was selected with the subject's hands on the bars and the bars positioned to allow the hands to be approximately 5.0 cm below a horizontal line that coursed level with the subject's eyes (while the subject's head was positioned in a fashion to allow him to view straight ahead).

Each subject performed four incremental test procedures (two in the drop-bar position, and two in the triathlon bar position). Each format's two trial sessions were performed at either a low gear ratio or a high gear ratio (5.27 and 6.53 gear-meters, respectively; the order was randomly assigned), on four separate days, with at least 24 hours interposed between the trial sessions. Gear ratios were determined in accordance with Konopka (1982), as described in equation 3.6, i.e.,

$$\text{Gear (in meters)} = \frac{z_1 \times u}{z_2} \quad (3.6)$$

where:

z_1 = number of teeth on the chainring
 z_2 = number of teeth on the rear sprocket
 u = circumference of the rear wheel

After a five minute rest period each cyclist performed a warm-up session of five minutes with the hands positioned in the position of testing for that trial session; either on the drop portion of the handlebar (the drop-bar position), or with the elbows positioned on the triathlon pads (the triathlon bar position). Prior to testing, each subject was given verbal instructions as to the proper riding technique. The warm-up session was performed at 60 rpm with the bicycle drive train adjusted to a gear ratio of 4.27 gear-meters, allowing each individual to become acclimatized to the trial session.

After the familiarization period, each subject performed a session of three consecutive trials of five minutes duration each in either the drop-style or triathlon handlebar position at progressively increasing pedalling rates of 60, 75, and 90 revolutions-per-minute. At the completion of each trial session, the

bicycle's drive train was returned to 4.27 gear-meters and the pedalling rate to 60 rpm, allowing for the return of the subject's HR below 100 bpm. Furthermore, if any subject exceeded their predetermined submaximal target HR during any of the trials, then the trial session was concluded prior to session completion by immediately returning the subject to the cool-down session. Values for HR and VO_2 were continuously calculated by the system computer and posted numerically at 30 second intervals during each trial. Each of the values from the final two minutes during each trial were averaged and considered the stable value at the respective work load.

Each subject was given verbal encouragement in regards to the following elements throughout each trial session: (1) avoidance of grip activity in the triathlon position; (2) maintenance of consistent hand position with each condition; (3) avoidance of resting the gas-exchange headgear in the forearms during the triathlon condition; and (4) maintenance of smooth, accurate pedalling cadence throughout each trial session. Additionally, each subject was given a verbal warning of upcoming pedalling rate changes at a point 30 seconds prior to each actual rate change.

Determinations and Data Analysis

Oxygen consumption was determined in terms of consumption per kg of body weight (ml/kg/min) and absolute consumption (L/min). Heart rate was determined in terms of beats per minute. The HR and VO_2 values were averaged during the final two minutes of each trial. These values were analyzed using two different analyses. First, HR, relative VO_2 values using lean body mass, and relative VO_2 values using total body mass (which were established during all three low gear ratio trials, as well as the values during 60

and 75 rpm trials of the high gear ratio) were analyzed with a 2 (handlebar format) x 5 (workload) repeated measures ANOVA. This analysis represented the workloads in an incremental fashion and omitted the final workload (90 rpm in the high gear ratio), due to the fact that six of the subjects could not achieve the highest workload without exceeding their predetermined submaximal target HR (85% MHR). A Newman-Keuls post hoc test was used in accordance with Thomas and Nelson (1990) to establish the location of significant differences.

Secondly, data from the nine subjects who completed all incremental workloads were analyzed using a 2 (handlebar format) x 2 (gear ratio) x 3 (pedalling rate) repeated measures ANOVA. Once again, a Newman-Keuls post hoc test was used to establish the location of differences.

CHAPTER IV

RESULTS

Descriptive data for age total body mass (TBM), lean body mass (LBM), and percent body fat were collected for each subject. Means and ranges are found in Table 5.1 below.

Table 5.1: Descriptive Data for all 15 Subjects.

Variable	Mean	Range
Age (years)	21.93	19 - 30
Total Body Mass (TBM; kg)	78.99	63.1 - 98.0
Lean Body Mass (LBM; kg)	66.05	56.85 - 84.96
% Body Fat (% of TBM)	16.18	8.4 - 26.1

Data from heart rate, relative VO₂ values using lean body mass (LBM VO₂), and relative VO₂ values using total body mass (TBM VO₂) were analyzed in separate ANOVA's. Each dependent variable was analyzed in a 2 (handlebar format) x 5 (workload) repeated measures ANOVA. Because all fifteen subjects were not able to successfully complete the cycling session at the highest workload, this workload was eliminated from this analysis. Results indicated no significant differences for handlebar format for each of the dependent variables (HR, LBM VO₂, and TBM VO₂). Furthermore, no significant interaction was observed between handlebar format and workload. However, significant

differences were found for workload in terms of HR, LBM VO₂, and TBM VO₂, F's (4, 56) = 133.12, 227.76, and 164.35, respectively; $P \leq 0.0001$.

A Newman-Keuls post-hoc test revealed significant differences between all workloads for each dependent variable, with exception to the comparison between workloads low-90 and high-75, as well as between workloads low-75 and high-60.

The second analysis of variance was performed on data from the nine subjects that completed all six work loads (low 60, 75, 90; and high 60, 75, 90). Data from each dependent variable was analyzed in a 2 (handlebar) x 2 (gear ratio) x 3 (pedalling rate) repeated measures ANOVA. As with the first analysis, no significant differences were found for handlebar position in terms of HR, LBM VO₂, and TBM VO₂. Furthermore, no significant interactions were seen between handlebar position and pedalling rate or gear ratio in terms of any dependent variable. However, results indicated significant differences for gear ratio in terms of HR, LBM VO₂, and TBM VO₂ F's (1, 8) = 103.7, 174.76, and 143.35, respectively, $P \leq 0.0001$. These results indicated that higher gear ratios produced higher values in dependent measures. Additionally, a significant main effect was found for pedalling rate in terms of HR, LBM VO₂, and TBM VO₂, F's (2, 16) = 105.31, 614.77, and 515.18, respectively, $P \leq 0.0001$. These results indicate that higher pedalling rates produce higher values in dependent measures. Furthermore, a significant interaction was observed between gear ratio and pedalling rate in terms of HR, LBM VO₂, and TBM VO₂, F's (2, 16) = 20.18, 33.47, and 22.30, respectively; $P \leq 0.0001$.

As with the first analysis, a Newman-Keuls post-hoc procedure revealed the locations of significant differences. Significant HR, LBM VO₂, and TBM VO₂ differences were discovered between all workloads (combinations of different

gear ratios and pedalling rates, as previously described), with two exceptions in terms of each dependent variable. In terms of each dependent variable, differences were not significant between workloads low-90 and high-75, and between workloads low-75 and high-60.

CHAPTER V

DISCUSSION AND CONCLUSIONS

Several different approaches to the testing of cycling performance have been proposed (Beasley et al., 1989; Coast & Welch, 1985; Faria et al., 1978; Faulkner et al., 1971; Hagberg et al., 1978; Hagberg et al., 1981; McCole et al., 1990; Nordeen-Snyder, 1977; Ryschon & Stray-Gunderson, 1991; Tanaka et al., 1987; and Whipp et al., 1972). A racing bicycle mounted on a wind trainer was used in the present investigation during the testing protocol. This selection was based on several factors: (1) the enhanced external validity provided by the opportunity for each subject to be tested on an actual racing bicycle ; (2) the variety of adjustments afforded by the system, including fore-aft handlebar and seat adjustments, as well as seat inclination; and (3) the positioning of the subject in a more comfortable performance-related position, when compared to a modified cycle ergometer.

A final design-related concern involved work load selection. The gear ratio selection was based on gear-meters (Konopka, 1981). The ratios were selected in a fashion that created sufficient gear-meter intervals between loads, while attempting to design the highest workload (high gear ratio and 90 rpm pedalling rate) at a level that would require each subject to perform below the 85% HR max value. The 85% HR max value was chosen in accordance with Powers and Howley (1990), who suggested that submaximal exercise testing is to be performed at work levels producing a HR between 60 and 85% of maximum HR. From earlier pilot work with non-cyclists, it was determined that this could be achieved with a gear ratio of 6.53 meters (52/17, chainring/rear sprocket).

Oxygen consumption comparisons were performed in terms of both lean body mass (LBM) and total body mass (TBM). Relative VO₂ values are derived in terms of LBM by McArdle et al. (1991), and in terms of TBM by Powers and Howley (1990). The LBM figures yielded higher VO₂ values than did the TBM figures. This was predictable, when using the same absolute VO₂ values from gas analysis procedures. Considering the fact that TBM values are larger than LBM values, the TBM values would produce smaller relative VO₂ values versus the LBM values, as depicted in equation 5.1, i.e.,

$$\text{Relative} = \frac{\text{Absolute VO}_2 \text{ (L/min)} \times 1000}{\text{Body mass (kg)}^*} \quad (5.1).$$

*either LBM or TBM

Another very important feature concerning cardiovascular measures could be identified. Values for HR, LBM VO₂, and TBM VO₂ were expected to increase incrementally with increases in workload. This increase occurred, but not following the expected order for workload. For example, the expected order (from lowest to highest workload) was low-60, -75, and -90, followed by high-60, -75, and -90. However, the actual order that cardiovascular values followed was: low-60, high-60, low-75, high-75, low-90, and high-90. Furthermore, both the analysis involving all fifteen subjects and the analysis involving the nine subjects who completed all six workloads produced the same workload order.

Although no differences were discovered between handlebar formats, differences were appreciated for workloads (different combinations of gear ratios and pedalling rates). As previously mentioned, differences were

observed in both analyses for HR, LBM VO₂, and TBM VO₂. Graphic representation of all mean data outcomes can be found in Appendix H. Differences were noted between each workload in terms of each cardiovascular measure, with only two exceptions: (1) the difference between values produced at workloads low-90 and high-75; and (2) the differences between values produced at workloads low-75 and high-60. These patterns suggested the interchangeability of the workloads associated with those similar values.

The patterns of ordered behavior for workloads were attributed to the fact that both pedalling rate and gear ratio have an impact on the subjects' cardiovascular performance while using a bicycle on a wind trainer. This fact could be useful to cyclists, non-cyclists, and investigators. To achieve evenly-spaced incremental workloads, an individual must avoid the selection of gear ratio-pedalling rate configurations which could produce similar cardiovascular outcomes (e.g., low-90 and high-75 workloads). Therefore, individuals must give consideration to both pedalling rate and gear ratio when designing workload increments for exercise testing and training that implement a racing bicycle / wind trainer system.

Another way to examine cardiovascular responses while using the bicycle/wind trainer format is by evaluating those responses in terms of gear ratio and pedalling rate independently. The results displayed predictable differences between dependent variable values at the two different gear ratios; as gear ratio increased, so did HR, LBM VO₂, and TBM VO₂ values. Although work rates (in terms of Watts) were not directly measured, the higher gear ratios were assumed to represent higher work rates. The fact that cardiovascular values increased with increases in work rates was consistent with the findings by other investigators (Coast & Welch, 1985; Whipp & Wasserman, 1972).

Another predictable outcome from the present investigation involved the significant increases in HR, LBM VO₂, and TBM VO₂ values with increases in pedalling rate. Thus, increases in pedalling rate suggested increases in workload. These expected results were consistent with outcomes reported by Coast & Welch (1985). These outcomes, along with outcomes concerning gear ratio, support the need for individuals to consider both gear ratio and pedalling rate when designing evenly-spaced incremental workloads for exercise on a bicycle/wind trainer system.

An increase in HR and oxygen consumption values was expected during cycling with the drop-style handlebar position versus the triathlon position, due to the increased gripping activity in the hands, as well as the increased isometric work of the triceps in the upper arm. These additional static activities were hypothesized to increase the peripheral resistance in the statically-active extremities (Bystrom & Kilbom, 1990), and increase the subject's overall cost of cardiovascular work (Faria et al., 1978; Sanchez et al., 1979). However, these additional activities in the subject's upper extremities during the drop position did not appear to have an impact on the subject's performance, when compared to the resting nature of the upper extremities in the triathlon position. This outcome could be either due to physiological similarities between the handlebar systems, or due to the various potential sources of error. These sources can be categorized in the following fashion: (1) error due to variability in equipment function; (2) error due to subject variability; and (3) error due to operation variability produced by the investigator during the testing process.

The physiological similarity between handlebar formats could also be attributed to insignificant differences in the upper extremity static work during both positions. The concept that this study suggests (gripping activity

associated with the drop position has no impact on HR and VO₂ values, when compared to the triathlon position) is consistent with Dlin et al (1990), who found that hand gripping activity during cycling has no influence on HR and blood pressure responses at equivalent, intermediate cycling workloads.

The outcomes from the present investigation agree with Johnson and Shultz (1990), who found no differences between cycling in both the drop-style and triathlon handlebar positions at 90 rpm pedalling rates and workloads at 80% maximum oxygen consumption. The only component in the investigation by Johnson and Shultz (1990) that was not supported by the present study deals with ventilatory function and ventilatory cost of work. One must question whether the lack of differences between the handlebar conditions in the present study was caused by a hindrance of ventilatory function, and thus an increase in the cost of ventilatory work associated with the triathlon position. Although the present investigation did not evaluate this question, one must consider any changes in ventilatory function as potentially contributory to this investigation's outcomes. This is especially true in light of previous studies which both identified the incidence of ventilatory muscle fatigue (Bye et al., 1984; Loke et al., 1982; & Martin et al., 1982) and established the impact of body position on ventilatory function (Craig, 1960; Walsh-Riddle et al., 1989; & Wasserman et al., 1973). Johnson and Shultz (1990) considered this question, along with the other measures performed in their study, and determined that triathlon handlebar use did not compromise ventilatory function, as evidenced by similarities between formats. Future investigations should attempt to prove the reliability of the findings by Johnson and Shultz (1990).

Although Johnson and Shultz (1990) tested elite cyclists and the present study utilized non-cyclists, the outcomes in both studies were similar.

Therefore, the results of the present study confer with Johnson and Shultz (1990), who established the following conclusions from their investigation: (1) the triathlon handlebar use was at least as efficient as the standard handlebar use; and (2) any physiological benefits attained with triathlon handlebar use would only enhance the already established aerodynamic benefits (if subtle differences existed). Future investigation should be conducted with elite cyclists to determine if pedalling rate or gear ratio changes have an impact on the differences between HR and oxygen consumption values attained in the triathlon versus drop-style handlebar positions during fixed, submaximal cycling work loads.

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APPENDIX A

TABLE A-1

HEART RATE DATA (HR; IN BEATS PER MINUTE)
ACROSS 10 TRIAL SESSIONS, AS A FUNCTION
OF HANDLEBAR STYLE FOR ALL 15 SUBJECTS.

Triathlon Style

Subject	HR1 (Low60)	HR2 (Low75)	HR3 (Low90)	HR4 (High60)	HR5 (High75)
1	98.0	113.0	132.5	136.0	156.0
2	119.5	122.5	127.5	120.5	134.5
3	124.0	136.0	152.0	127.0	145.0
4	99.0	114.0	139.5	102.0	120.0
5	107.0	118.0	139.0	125.5	136.5
6	98.0	108.5	119.0	106.0	121.5
7	122.5	139.0	172.5	137.0	157.5
8	115.0	125.5	150.5	131.5	151.5
9	113.5	122.0	131.0	122.0	133.5
10	121.0	136.0	157.5	126.0	152.0
11	108.5	120.5	140.0	117.5	151.5
12	123.5	140.0	158.0	133.5	159.0
13	121.0	139.0	164.0	130.0	160.0
14	109.0	125.5	145.5	124.5	148.5
15	118.5	145.0	164.5	148.0	175.5

Drop-Style

Subject	HR6 (Low60)	HR7 (Low75)	HR8 (Low90)	HR9 (High60)	HR10 (High75)
1	104.5	119.5	146.0	108.0	127.5
2	120.0	140.0	142.0	130.0	141.5
3	120.0	144.0	156.0	139.5	157.5
4	92.5	105.0	126.0	98.5	121.5
5	115.5	126.5	140.5	123.5	140.5
6	93.5	104.5	126.5	116.0	129.5
7	120.0	144.5	159.0	129.0	156.5
8	122.0	133.5	156.5	128.5	147.0
9	114.0	121.0	134.5	119.5	136.0
10	122.0	137.5	156.5	137.0	157.0
11	112.5	120.5	134.5	128.0	155.0
12	130.5	148.0	169.0	137.5	160.0
13	127.0	137.5	165.5	126.0	155.5
14	104.5	116.0	137.5	122.0	152.5
15	118.0	136.0	170.5	127.0	152.0

TABLE A-2

LEAN BODY MASS OXYGEN CONSUMPTION DATA
(LBM VO₂; in ml/kg/min) ACROSS 10 TRIAL SESSIONS,
AS A FUNCTION OF HANDLEBAR STYLE
FOR ALL 15 SUBJECTS.

Triathlon Style

Subject	LBM1 (Low60)	LBM2 (Low75)	LBM3 (Low90)	LBM4 (High60)	LBM5 (High75)
1	18.09	24.01	30.36	29.30	36.16
2	24.11	28.49	33.81	26.52	33.44
3	19.60	24.40	31.33	24.00	31.64
4	19.60	23.59	31.00	19.69	26.51
5	18.94	25.00	32.47	23.41	29.46
6	15.65	22.05	24.87	19.37	25.23
7	20.55	26.43	35.51	22.06	29.55
8	20.45	25.57	32.56	25.00	32.67
9	18.77	23.51	29.51	23.58	29.96
10	18.33	23.11	32.92	22.60	32.90
11	23.00	28.06	33.56	29.64	40.84
12	22.35	31.00	41.85	29.72	42.13
13	20.85	27.17	37.21	26.41	36.69
14	20.30	28.14	36.10	26.15	37.27
15	23.22	30.60	36.37	30.38	38.43

Drop-Style

Subject	LBM6 (Low60)	LBM7 (Low75)	LBM8 (Low90)	LBM9 (High60)	LBM10 (High75)
1	20.57	25.58	33.09	21.17	30.34
2	29.83	33.38	37.52	31.65	36.53
3	20.16	24.37	33.39	25.14	34.21
4	11.92	17.42	23.89	20.19	26.80
5	18.05	25.68	34.12	24.90	33.37
6	17.09	24.21	29.28	20.00	24.77
7	19.20	25.10	33.10	23.98	31.43
8	19.92	24.86	31.13	24.11	30.76
9	18.98	24.13	31.67	22.97	29.78
10	19.87	25.75	33.09	23.57	32.20
11	20.91	26.54	30.38	26.31	35.76
12	24.15	32.04	42.52	28.95	39.92
13	21.00	27.74	37.63	24.54	34.12
14	20.89	28.05	35.83	25.17	35.80
15	22.87	28.48	36.70	26.19	34.00

TABLE A-3

TOTAL BODY MASS OXYGEN CONSUMPTION DATA
(TBM VO₂; in ml/kg/min) ACROSS 10 TRIAL SESSIONS,
AS A FUNCTION OF HANDLEBAR STYLE FOR ALL
15 SUBJECTS.

Triathlon Style

Subject	TBM1 (Low60)	TBM2 (Low75)	TBM3 (Low90)	TBM4 (High60)	TBM5 (High75)
1	16.55	21.97	27.77	26.80	33.08
2	20.49	24.21	28.74	22.54	28.43
3	16.38	20.40	26.19	20.06	26.45
4	17.68	21.28	27.96	18.35	23.91
5	16.67	22.00	28.57	20.60	25.92
6	13.57	19.16	21.56	16.80	21.87
7	16.46	21.17	28.32	17.67	23.67
8	16.77	20.97	26.70	20.50	26.79
9	14.94	18.71	23.49	18.77	23.84
10	16.79	21.17	30.15	20.70	30.13
11	17.36	21.18	25.34	24.88	30.84
12	19.32	26.80	36.18	25.99	36.41
13	19.04	24.81	39.99	24.12	33.51
14	16.63	23.04	29.56	21.47	30.53
15	17.13	22.58	26.83	22.42	28.36

Drop-Style

Subject	TBM6 (Low60)	TBM7 (Low75)	TBM8 (Low90)	TBM9 (High60)	TBM10 (High75)
1	18.82	23.42	30.27	19.36	27.75
2	25.36	28.37	31.89	26.90	31.05
3	16.86	20.37	27.58	21.01	28.60
4	10.76	15.72	21.55	18.21	23.99
5	15.88	22.60	30.03	21.91	29.37
6	14.82	20.98	25.21	17.34	21.47
7	15.37	20.10	26.51	19.21	25.18
8	16.34	20.38	25.53	19.77	25.23
9	15.11	17.71	25.21	18.28	23.71
10	18.21	23.59	30.31	21.58	29.48
11	15.79	20.04	22.94	19.86	27.00
12	20.87	27.69	36.45	25.02	34.38
13	19.18	25.33	34.37	22.41	33.16
14	17.12	21.34	29.36	20.61	29.32
15	16.88	21.02	27.08	19.32	25.09

TABLE A-4

HEART RATE DATA (HR; IN BEATS PER MINUTE) ACROSS
12 TRIAL SESSIONS, AS A FUNCTION OF HANDLEBAR
STYLE, GEAR RATIO, AND PEDALLING
RATE FOR 9 SUBJECTS.

Triathlon Style

Subj.	HR1 (Low60)	HR2 (Low75)	HR3 (Low90)	HR4 (High60)	HR5 (High75)	HR6 (High90)
1	98.0	113.0	132.5	136.0	156.0	170.0
2	119.5	122.5	127.5	120.5	134.5	143.0
3	124.0	136.0	152.0	127.0	145.0	171.0
4	99.0	114.0	139.5	102.0	120.0	156.0
5	107.0	118.0	139.0	125.5	136.5	157.5
6	98.0	108.5	119.0	106.0	121.5	135.5
7	122.5	139.0	172.5	137.0	157.5	179.5
8	115.0	125.5	150.5	131.5	151.5	179.0
9	113.5	122.0	131.0	122.0	133.5	147.0

Drop-Style

Subj.	HR7 (Low60)	HR8 (Low75)	HR9 (Low90)	HR10 (High60)	HR11 (High75)	HR 12 (High90)
1	104.5	119.5	146.0	108.0	127.5	159.5
2	120.0	140.0	142.0	130.0	141.5	151.5
3	120.0	144.0	156.0	139.5	157.5	180.0
4	92.5	105.0	126.0	98.5	121.5	155.0
5	115.5	126.5	140.5	123.5	140.5	164.0
6	93.5	104.5	126.5	116.0	129.5	150.5
7	120.0	144.5	159.0	129.0	156.5	180.0
8	122.0	133.5	156.5	128.5	147.0	178.5
9	114.0	121.0	134.5	119.5	136.0	150.5

TABLE A-5

LEAN BODY MASS OXYGEN CONSUMPTION DATA
(LBM VO₂; in ml/kg/min) ACROSS 12 TRIAL SESSIONS,
AS A FUNCTION OF HANDLEBAR STYLE, GEAR RATIO,
AND PEDALLING RATE FOR 9 SUBJECTS.

Triathlon Style

Subj.	LBM1 (Low60)	LBM2 (Low75)	LBM3 (Low90)	LBM4 (High60)	LBM5 (High75)	LBM 6 (High90)
1	18.09	24.01	30.36	29.30	36.16	41.69
2	24.11	28.49	33.81	26.52	33.44	43.05
3	19.60	24.40	31.33	24.00	31.64	43.19
4	19.60	23.59	31.00	19.69	26.51	36.94
5	18.94	25.00	32.47	23.41	29.46	36.97
6	15.65	22.05	24.87	19.37	25.23	33.43
7	20.55	26.43	35.51	22.06	29.55	41.95
8	20.45	25.57	32.56	25.00	32.67	41.84
9	18.77	23.51	29.51	23.58	29.96	38.06

Drop-Style

Subj.	LBM7 (Low60)	LBM8 (Low75)	LBM9 (Low90)	LBM10 (High60)	LBM11 (High75)	LBM12 (High90)
1	20.57	25.58	33.09	21.17	30.34	39.92
2	29.83	33.38	37.52	31.65	36.53	44.11
3	20.16	24.37	33.39	25.14	34.21	46.04
4	11.92	17.42	23.89	20.19	26.80	37.81
5	18.05	25.68	34.12	24.90	33.37	42.75
6	17.09	24.21	29.28	20.00	24.77	35.56
7	19.20	25.10	33.10	23.98	31.43	41.77
8	19.92	24.86	31.13	24.11	30.76	42.90
9	18.98	24.13	31.67	22.97	29.78	39.17

TABLE A-6

TOTAL BODY MASS OXYGEN CONSUMPTION DATA
(TBM VO₂; in ml/kg/min) ACROSS 12 TRIAL SESSIONS,
AS A FUNCTION OF HANDLEBAR STYLE, GEAR RATIO,
AND PEDALLING RATE FOR 9 SUBJECTS.

Subj.	TBM1 (Low60)	TBM2 (Low75)	TBM3 (Low90)	TBM4 (High60)	TBM5 (High75)	TBM6 (High90)
1	16.55	21.97	27.77	26.80	33.08	38.13
2	20.49	24.21	28.74	22.54	28.43	36.59
3	16.38	20.40	26.19	20.06	26.45	36.10
4	17.68	21.28	27.96	18.35	23.91	33.32
5	16.67	22.00	28.57	20.60	25.92	32.53
6	13.57	19.16	21.56	16.80	21.87	28.98
7	16.46	21.17	28.32	17.67	23.67	33.60
8	16.77	20.97	26.70	20.50	26.79	34.32
9	14.94	18.71	23.49	18.77	23.84	30.29

Drop-Style

Subj.	TBM7 (Low60)	TBM8 (Low75)	TBM9 (Low90)	TBM10 (High60)	TBM11 (High75)	TBM12 (High90)
1	18.82	23.42	30.27	19.36	27.75	36.51
2	25.36	28.37	31.89	26.90	31.05	37.50
3	16.86	20.37	27.58	21.01	28.60	38.48
4	10.76	15.72	21.55	18.21	23.99	35.61
5	15.88	22.60	30.03	21.91	29.37	37.62
6	14.82	20.98	25.21	17.34	21.47	30.83
7	15.37	20.10	26.51	19.21	25.18	33.46
8	16.34	20.38	25.53	19.77	25.23	35.18
9	15.11	17.71	25.21	18.28	23.71	28.00

APPENDIX B

TABLE B-1
 MEANS AND STANDARD DEVIATIONS FOR HEART RATE
 (HR), LEAN BODY MASS OXYGEN CONSUMPTION
 (LBM VO₂), AND TOTAL BODY MASS OXYGEN
 CONSUMPTION (TBM VO₂) FOR ALL
 15 SUBJECTS

Format	Variable	Mean	Std Deviation
Tri	HR 1	113.2000000	9.4260278
	HR 2	127.0000000	11.3845133
	HR 3	146.2000000	15.3678700
	HR 4	125.8000000	11.6646597
	HR 5	146.8333333	15.1559355
Drop	HR 6	114.4333333	11.2056533
	HR 7	128.9333333	13.9870689
	HR 8	148.0333333	14.8810362
	HR 9	124.6666667	10.9864635
	HR 10	145.9666667	12.4649031
Tri	LBM 1	20.2450000	2.2432241
	LBM 2	26.0753333	2.7557702
	LBM 3	33.2953333	3.9232947
	LBM 4	25.1886667	3.5473388
	LBM 5	42.1300000	5.0023792
Drop	LBM 6	20.3606667	3.8019590
	LBM 7	26.2220000	3.6771888
	LBM 8	33.5426667	4.3235294
	LBM 9	24.5893333	3.0647873
	LBM 10	32.6526667	2.8692016
Tri	TBM 1	17.0520000	1.6801837
	TBM 2	21.9633333	2.1094707
	TBM 3	28.4900000	4.5542821
	TBM 4	21.4446667	3.0128270
	TBM 5	28.2493333	4.1733208
Drop	TBM 6	17.1580000	3.2419399
	TBM 7	21.9106667	3.3999842
	TBM 8	28.2860000	4.0923462
	TBM 9	20.7193333	2.5801480
	TBM 10	27.6520000	3.6180760

TABLE B-2

MEANS AND STANDARD DEVIATIONS FOR HEART RATE (HR), LEAN BODY MASS OXYGEN CONSUMPTION (LBM VO₂), AND TOTAL BODY MASS OXYGEN CONSUMPTION (TBM VO₂) FOR ALL 9 SUBJECTS WHO COMPLETED ALL WORKLOADS

Format	Variable	Mean	Std Deviation
Tri	HR 1	110.722222	10.5656019
	HR 2	122.111111	10.2279573
	HR 3	140.388889	15.9878426
	HR 4	123.055556	12.2307104
	HR 5	139.555556	13.8956928
	HR 6	159.833333	15.9785012
Drop	HR 7	111.333333	11.6350763
	HR 8	126.500000	15.3582226
	HR 9	143.000000	12.5349511
	HR 10	121.388889	12.5044437
	HR 11	139.722222	12.5202614
	HR 12	163.277778	12.9400326
Tri	LBM 1	19.528889	2.2618214
	LBM 2	24.783333	1.8834211
	LBM 3	31.268889	3.0103050
	LBM 4	23.658889	3.1363651
	LBM 5	30.513333	3.4032117
	LBM 6	39.680000	3.4291799

TABLE B-2
(cont'd)

Format	Variable	Mean	Std Deviation
Drop	LBM 7	19.5244444	4.6662059
	LBM 8	24.9700000	4.0354523
	LBM 9	31.8877778	3.7806407
	LBM 10	23.7900000	3.5325911
	LBM 11	30.8877778	3.6229814
	LBM 12	41.1144444	3.2883549
Tri	TBM 1	16.6122222	1.8820851
	TBM 2	21.0966667	1.6301380
	TBM 3	26.5888889	2.4972007
	TBM 4	20.2322222	3.0150488
	TBM 5	25.9955556	3.3238461
	TBM 6	33.7622222	2.9478033
Drop	TBM 7	16.5911111	3.9262878
	TBM 8	21.0722222	3.5878363
	TBM 9	27.0866667	3.2126002
	TBM 10	20.2211111	2.8758236
	TBM 11	26.2611111	3.1052111
	TBM 12	34.7988889	3.4696161

APPENDIX C

TABLE C-1

MEAN DEPENDENT MEASURE VALUES ACCORDING
TO WORKLOAD FOR ALL SUBJECTS

*Workload (Gear Ratio/Pedalling Rate) Rank
According to mean HR*

<u>Work Load*</u>	<u>Mean HR_bpm</u>
Low 60	113.8176
High 60	125.2333
Low 75	127.9667
High 75	146.4000
Low 90	147.1167

*Workload (Gear Ratio/Pedalling Rate) Rank
According to mean LBM VO₂*

<u>Work Load*</u>	<u>Mean Lean VO₂ ml/kg/min</u>
Low 60	20.1297
High 60	24.8880
Low 75	26.1487
Low 90	33.4190
High 75	33.0890

TABLE C-1
(cont'd)

<i>Workload (Gear Ratio/Pedalling Rate) Rank According to mean TBM VO₂</i>	
<u>Work Load*</u>	<u>Total VO₂</u> ml/kg/min
Low 60	17.1050
High 60	21.0820
Low 75	21.4885
High 75	27.9507
Low 90	28.3880

TABLE C-2

MEAN DEPENDENT MEASURE VALUES IN TERMS OF
GEAR RATIO AND PEDALLING RATE FOR 9 SUBJECTS
WHO COMPLETED ALL WORKLOADS

<i>Gear Ratio/Pedalling Rate According to mean HR</i>	
<u>Work Load*</u>	<u>Mean HR bpm</u>
Low 60	111.0278
High 60	122.2222
Low 75	124.3056
High 75	139.6389
Low 90	141.6944
High 90	161.5556

<i>Gear Ratio/Pedalling Rate According to mean Lean VO₂</i>	
<u>Work Load*</u>	<u>Mean Lean VO₂ ml/kg/min</u>
Low 60	19.5267
High 60	23.7244
Low 75	24.8767
High 75	30.7006
Low 90	31.5783
High 90	40.3972

TABLE C-2
(cont'd)

<i>Gear Ratio/Pedalling Rate According to mean Total VO₂</i>	
<u>Work Load*</u>	<u>MeanTotal VO₂</u> ml/kg/min
Low 60 (1)	16.6017
High 60 (4)	20.2267
Low 75 (2)	21.0844
High 75 (5)	26.1283
Low 90 (3)	26.8378
High 90 (6)	34.2806

* Workload nomenclature in Appendix C refers to the following:

-Low vs. High: gear ratio;

Low = 42/17 (5.27 meters); High = 52/17 (6.53 meters)

-Pedalling rate: 60, 75, and 90 rpm

APPENDIX D

TABLE D-1
2 (HANDLEBAR) X 5 (WORKLOAD) ANOVA FOR HR.
Univariate Tests of Hypotheses for Within Subject Effects

Source	DF	Type III SS	Mean Square	F Value	PR > F
HBTYPE	1	13.50000000	13.50000000	0.18	0.6797
Error	14	1063.05000000	75.93214286		
WLOAD	4	24855.176666	6213.7941666	133.12	0.0001
Error	56	2614.0233333	46.67898810		
HBTYPE * WLOAD	4	66.416666667	16.604166667	0.49	0.7452
Error	56	1909.28333333	34.09434524		

TABLE D-2

2 (HANDLEBAR) X 5 (WORKLOAD) ANOVA FOR LBM VO₂.

Univariate Tests of Hypotheses for Within Subject Effects

Source	DF	Type III SS	Mean Square	F Value	PR > F
HBTYPE	1	1.41523267	1.41523267	0.13	0.7237
Error	14	152.29793733	10.87842410		
WLOAD	4	3798.73310267	949.68327567	227.76	0.0001
Error	56	233.49847733	4.16961567		
HBTYPE * WLOAD	4	7.6958440000	1.9239610000	0.81	0.5252
Error	56	133.32133600	2.38073814		

TABLE D-3

2 (HANDLEBAR) X 5 (WORKLOAD) ANOVA FOR TBM VO₂.

Univariate Tests of Hypotheses for Within Subject Effects

Source	DF	Type III SS	Mean Square	F Value	PR > F
HBTYPE	1	3.25606667	3.25606667	0.38	0.5480
Error	14	120.27773333	8.59126667		
WLOAD	4	2780.14451067	695.03612767	164.37	0.0001
Error	56	236.80104933	4.22859017		
HBTYPE * WLOAD	4	3.78299333	0.94574833	0.46	0.7670
Error	56	115.93200667	2.07021440		

APPENDIX E

TABLE E-1
2 (HANDLEBAR) X 2 (GEAR RATIO) X 3 (PEDALLING RATE)
ANOVA FOR HR.

Univariate Tests of Hypotheses for Within Subject Effects

Source	DF	Type III SS	Mean Square	F Value	PR > F
HBTYPE	1	68.48148148	68.48148148	0.71	0.4228
Error	8	767.601851185	95.95023148		
GEARRAT	1	6455.78703704	6455.78703704	103.70	0.0001
Error	8	498.04629630	62.25578704		
PEDRATE	2	22161.22685185	11080.61342593	105.31	0.0001
Error	16	1683.56481481	105.22280093		
HBTYPE * GEARRAT	1	24.08333333	24.08333333	0.19	0.6717
Error	8	996.08333333	124.51041667		
HBTYPE * PEDRATE	2	63.22685185	31.61342593	2.43	0.1194
Error	16	207.81481481	12.98842593		
GEARRAT * PEDRATE	2	338.22685185	169.11342593	20.18	0.0001
Error	16	134.06481481	8.37905093		
HBTYPE * GEARRAT * PEDRATE	2	29.26388889	14.63194444	1.23	0.3196
Error	16	190.94444444	11.93402778		

TABLE E-2
2 (HANDLEBAR) X 2 (GEAR RATIO) X 3 (PEDALLING RATE)
ANOVA FOR LBM VO₂.

Univariate Tests of Hypotheses for Within Subject Effects

Source	DF	Type III SS	Mean Square	F Value	PR > F
HBTYPE	1	5.63526759	5.63526759	0.41	0.5399
Error	8	109.95954074	13.74494259		
GEARRAT	1	1064.89960093	1064.89960093	174.76	0.0001
Error	8	48.7477407	6.09347176		
PEDRATE	2	3737.79617963	1868.89808981	614.77	0.0001
Error	16	48.64007037	3.04000440		
HBTYPE * GEARRAT	1	0.97280093	0.97280093	0.07	0.7920
Error	8	104.70740741	13.08842593		
HBTYPE * PEDRATE	2	4.59563519	2.29781759	1.75	0.2061
Error	16	21.05448148	1.31590509		
GEARRAT * PEDRATE	2	98.90679074	49.45339537	33.47	0.0001
Error	16	23.64105926	1.47756620		
HBTYPE * GEARRAT * PEDRATE	2	0.64442407	0.32221204	0.61	0.5586
Error	16	8.48669259	0.53041829		

TABLE E-3
2 (HANDLEBAR) X 2 (GEAR RATIO) X 3 (PEDALLING RATE)
ANOVA FOR TBM VO₂.

Univariate Tests of Hypotheses for Within Subject Effects

Source	DF	Type III SS	Mean Square	F Value	PR > F
HBTYPE	1	2.27940833	2.27940833	0.22	0.6510
Error	8	82.59715000	10.32464375		
GEARRAT	1	778.75740833	778.75740833	143.35	0.0001
Error	8	43.45921667	5.43240208		
PEDRATE	2	2673.61578519	1336.80789259	515.18	0.0001
Error	16	41.51721481	2.59482593		
HBTYPE * GEARRAT	1	0.52780093	0.52780093	0.05	0.8320
Error	8	87.87399074	10.98424884		
HBTYPE * PEDRATE	2	3.15140000	1.57570000	1.61	0.2310
Error	16	15.67606667	0.97975417		
GEARRAT * PEDRATE	2	67.03002222	33.51501111	22.30	0.0001
Error	16	24.04837778	1.50302361		
HBTYPE * GEARRAT * PEDRATE	2	0.31505185	0.15752593	0.24	0.7920
Error	16	10.64968148	0.66560509		

APPENDIX F

APPENDIX F

NEWMAN KEULS ANALYSIS FOR WORKLOAD COMPARISONS

The following comparisons provide two tables per dependent variable (differences & studentized values) in terms of each of the following independent variables:

A. For the 2 (Handlebar) x 5 (Workload) ANOVA

independent variable: Workload

B. For the 2 (Handlebar) x 2 (Gear Ratio) x 3 (Pedalling Rate) ANOVA

independent variables: Gear Ratio & Pedalling Rate

Note: No post-hoc analyses were conducted for the independent variable = handlebar, due to no significant dependent variable differences in terms of this variable in either ANOVA.

For each studentized value table, the recorded values are the result of the following calculation (Thomas & Nelson, 1990):

$$E = \frac{MSw}{n}$$

$$\text{Studentized value} = \frac{\text{Difference}}{E}$$

-MSw was taken from each corresponding ANOVA

Studentized values were compared to a value derived from Table A7 in Thomas and Nelson (1990).

TABLE F-1

**NEWMAN-KEULS POST-HOC ANALYSIS FOR WORK-
LOAD COMPARISONS IN TERMS OF HR. FROM
2 (HANDLEBAR) X 5 (WORKLOAD) ANOVA**

Differences (Mean HR Data; in beats per minute)

(*differences which are significant; Compared to Table A7, Thomas & Nelson, 1990)

	147.12	146.4	127.97	125.23	113.82	
147.19 Low 90	—	0.7167	19.15	21.8834	33.300	
146.4 High 75		—	18.4333	21.1667	32.5833	
127.97 Low 75			—	2.7334	14.15	
125.23 High 60				—	11.4166	
113.82 Low 60					—	

Studentized Values

$$E = 11.9825$$

	147.12	146.4 2 Steps	127.97 3 Steps	125.23 4 Steps	113.82 5 Steps	
147.12	—	0.0598	1.5982	1.8263	2.7791	
146.4		—	1.5384	1.7665	2.7192	
127.97			—	0.2281	1.1809	
125.23				—	0.9528	
113.82					—	

TABLE F-2

NEWMAN-KEULS POST-HOC ANALYSIS FOR WORK-
LOAD COMPARISONS IN TERMS OF LBM VO₂. FROM
2 (HANDLEBAR) X 5 (WORKLOAD) ANOVA

Differences (Mean LBM VO₂ Data; in ml/kg/min)
(*differences which are significant; Compared to Table A7, Thomas & Nelson, 1990)

	33.089	33.419	26.149	24.888	20.130	
33.089 Low 90	—	0.3300	6.9403*	8.0100*	12.9593*	
33.419 High 75		—	7.2703*	8.5310*	13.2911*	
26.149 Low 75			—	1.2607	13.2893*	
24.888 High 60				—	4.7583*	
20.130 Low 60					—	

Studentized Values

E = 0.527

	33.089	33.419 2 Steps	26.149 3 Steps	24.888 4 Steps	20.130 5 Steps	
33.089	—	0.63	13.17	15.56	24.59	
33.419		—	13.80	16.19	25.22	
26.149			—	2.39	25.22	
24.888				—	9.03	
20.130					-----	

TABLE F-3

**NEWMAN-KEULS POST-HOC ANALYSIS FOR WORK-
LOAD COMPARISONS IN TERMS OF TBM VO₂. FROM
2 (HANDLEBAR) X 5 (WORKLOAD) ANOVA**

Differences (Mean TBM VO₂ Data; in ml/kg/min)

(*differences which are significant; Compared to Table A7, Thomas & Nelson, 1990)

	28.39	27.95	21.49	21.08	17.11	
28.39 Low 90	—	0.44	6.90*	7.31*	11.28*	
27.95 High 75		—	6.46*	6.87*	10.85*	
21.49 Low 75			—	0.41	4.38*	
21.08 High 60				—	3.98*	
17.11 Low 60					—	

Studentized Values

$$E = 0.2819$$

	28.39	27.95 2 Steps	21.49 3 Steps	21.08 4 Steps	17.11 5 Steps	
28.39	—	1.55	24.48	25.92	40.03	
27.95		—	22.92	24.37	38.47	
21.49			—	1.44	15.55	
21.08				—	14.11s	
17.11					—	

TABLE F-4

NEWMAN-KEULS POST-HOC ANALYSIS FOR GEAR
RATIO COMPARISONS IN TERMS OF HR. FROM
2 (HANDLEBAR) X 2 (GEAR RATIO) X
3 (PEDALLING RATE) ANOVA

Differences (Mean HR Data, in bpm)
(*differences which are significant; Compared to Table A7, Thomas & Nelson, 1990)

	161.56	141.70	139.64	124.31	122.22	111.03
161.56 High 90	—	19.86*	21.92*	37.25*	39.33*	50.53*
141.70 Low 90		—	2.06	17.39*	19.47*	30.67*
139.64 High 75			—	15.33*	17.42*	28.61*
124.31 Low 75				—	2.08	13.28*
122.22 High 60					—	11.19*
111.03 Low 60						—

Studentized Values E = 2.63

	161.56	141.70 2 Steps	139.64 3 Steps	124.31 4 Steps	122.22 5 Steps	111.03 6 Steps
161.56	—	7.55	8.34	14.1	14.96*	19.21
141.70		—	0.78	6.61	7.40	11.66
139.64			—	5.83	6.62	10.88
124.31				—	0.79	5.05
122.22					—	4.26
111.03						—

TABLE F-5

NEWMAN-KEULS POST-HOC ANALYSIS FOR GEAR
RATIO COMPARISONS IN TERMS OF LBM VO₂.
FROM 2 (HANDLEBAR) X 2 (GEAR RATIO) X
3 (PEDALLING RATE) ANOVA

Differences (Mean LBM VO₂ Data; in ml/kg/min)
(*differences which are significant; Compared to Table A7, Thomas & Nelson, 1990)

	40.40	31.58	30.70	24.88	23.72	19.53
40.40 High90	—	8.82*	9.70*	18.86*	20.26*	25.36*
31.58 Low90		—	0.88	6.70*	7.85*	12.05*
30.70 High75			—	5.82*	6.98*	11.17*
24.88 Low75				—	1.15	5.32*
23.72 High60					—	4.20*
19.53 Low60						—

Studentized Values E = 0.8228

	40.40	31.58 2 Steps	30.70 3 Steps	24.88 4 Steps	23.72 5 Steps	19.53 6 Steps
40.40	—	10.72	11.78	18.86	20.27	25.36
31.58		—	1.07	8.14	9.55	14.65
30.70			—	7.08	8.48	13.58
24.88				—	1.40	6.50
23.72					—	5.10
19.53						—

TABLE F-6

NEWMAN-KEULS POST-HOC ANALYSIS FOR GEAR
 RATIO COMPARISONS IN TERMS OF TBM VO₂.
 FROM 2 (HANDLEBAR) X 2 (GEAR RATIO) X
 3 (PEDALLING RATE) ANOVA

Differences (Mean TBM VO₂ Data; in ml/kg/min)
 (*differences which are significant; Compared to Table A7, Thomas & Nelson, 1990)

	34.28	26.84	26.13	21.08	20.23	16.60
34.28 High 90	—	7.44*	8.15*	13.20*	14.05*	17.68*
26.84 Low 90		—	0.71	5.75*	6.61*	10.24*
26.13 High 75			—	5.04*	5.90*	9.53*
21.08 Low 75				—	0.86	4.48*
20.23 High 60					—	3.63*
16.60 Low 60						—

Studentized Values E = 0.7769

	34.28	26.84 2 Steps	26.13 3 Steps	21.08 4 Steps	20.23 5 Steps	16.60 6 Steps
34.28	—	9.58	10.49	16.99	18.09	22.76
26.84		—	0.91	7.41	8.51	13.18
26.13			—	6.49	7.60	12.26
21.08				—	1.10	5.77
20.23					—	4.67
16.60						—

TABLE F-7

NEWMAN-KEULS POST-HOC ANALYSIS FOR PEDAL.
RATE COMPARISONS IN TERMS OF HR. FROM
2 (HANDLEBAR) X 2 (GEAR RATIO) X
3 (PEDALLING RATE) ANOVA

Differences (HR Data in bpm)

(*differences which are significant; Compared to Table A7, Thomas & Nelson, 1990)

	161.56	141.70	139.64	124.31	122.22	111.03
161.56 High 90	—	19.86*	21.92*	37.25*	39.33*	50.53*
141.70 Low 90		—	2.06	17.39*	19.47*	30.67*
139.64 High 75			—	15.33*	17.42*	28.61*
124.31 Low 75				—	2.08	13.28*
122.22 High 60					—	11.19*
111.03 Low 60						—

Studentized Values

E = 3.4193

	161.56	141.70 2 Steps	139.64 3 Steps	124.31 4 Steps	122.22 5 Steps	111.03 6 Steps
161.56	—	5.81	6.41	10.89	11.50	14.78
141.70		—	0.60	5.09	5.70	8.97
139.64			—	4.48	5.09	8.37
124.31				—	0.61	5.05
122.22					—	4.26
111.03						—

TABLE F-8

NEWMAN-KEULS POST-HOC ANALYSIS FOR PEDAL
RATE COMPARISONS IN TERMS OF LBM VO₂.
FROM 2 (HANDLEBAR) X 2 (GEAR RATIO) X
3 (PEDALLING RATE) ANOVA

Differences (LBM VO₂ Data in ml/kg/min)

(*differences which are significant; Compared to Table A7, Thomas & Nelson, 1990)

	40.40	31.58	30.70	24.88	23.72	19.53
40.40 High 90	—	8.82*	9.70*	18.86*	20.26*	25.36*
31.58 Low 90		—	0.88	6.70*	7.85*	12.05*
30.70 High 75			—	5.82*	6.98*	11.17*
24.88 Low 75				—	1.15	5.32*
23.72 High 60					—	4.20*
19.53 Low 60						—

Studentized Values

E = 0.5812

	40.40	31.58 2 Steps	30.70 3 Steps	24.88 4 Steps	23.72 5 Steps	19.53 6 Steps
40.40	----	15.17	16.68	26.70	28.69	35.91
31.58		—	1.51	11.53	13.51	20.74
30.70			—	10.02	12.00	19.23
24.88				—	1.98	9.21
23.72					—	7.22
19.53						—

TABLE F-9

NEWMAN-KEULS POST-HOC ANALYSIS FOR PEDAL.
RATE COMPARISONS IN TERMS OF TBM VO₂.
FROM 2 (HANDLEBAR) X 2 (GEAR RATIO) X
3 (PEDALLING RATE) ANOVA

Differences (TBM VO₂ Data in ml/kg/min)

(*differences which are significant; Compared to Table A7, Thomas & Nelson, 1990)

	34.28	26.84	26.13	21.08	20.23	16.60
34.28 High 90	—	7.44*	8.15*	13.20*	14.05*	17.68*
26.84 Low 90		—	0.71	5.75*	6.61*	10.24*
26.13 High 75			—	5.04*	5.90*	9.53*
21.08 Low 75				—	0.86	4.48*
20.23 High 60					—	3.63*
16.60 Low 60						—

Studentized Values

E = 0.5369

	34.28	26.84 2 Steps	26.13 3 Steps	21.08 4 Steps	20.23 5 Steps	16.60 6 Steps
34.28	-----	13.85	15.18	24.58	26.19	32.93
26.84		—	1.32	10.72	12.31	19.07
26.13			—	9.39	10.36	17.74
21.08				—	1.60	8.35
20.23					—	6.75
16.60						—

APPENDIX G

Figure G-1: Graphic representation of 2 (handlebar)
X 5 (workload) ANOVA in terms of mean HR.

Figure G-2: Graphic representation of 2 (handlebar)
X 5 (workload) ANOVA in terms of mean LBM VO₂.

Figure G-3: Graphic representation of 2 (handlebar)
X 5 (workload) ANOVA in terms of mean TBM VO₂.

Figure G-4: Graphic representation of 2 (handlebar) X 2 (gear ratio) X 3 (pedalling rate) in terms of mean HR.

Figure G-5: Graphic representation of 2 (handlebar) X 2 (gear ratio) X 3 (pedalling rate) in terms of mean LBM VO₂.

Figure G-6: Graphic representation of 2 (handlebar) X 2 (gear ratio) X 3 (pedalling rate) in terms of mean TBM VO₂.