ABSTRACT

BORCHERS, Gregory E. Triathlon: the swim to bicycle transition. M.S. in Adult Fitness/Cardiac Rehabilitation, 1985. 63 p. (P. J. Buckenmeyer)

To examine the physiological characteristics of the swim to bicycle transition phase of triathlons, ten competitive male triathletes aged 22-28 performed a swim to bicycle transition (SBT) using tethered swimming as the pre-transition form of exercise. A control procedure (CP) using bicycling as the pre-transition form of exercise was also performed. Variables measured included VO₂, VE, RER and HR. During the 20 min of pre-transition exercise, subjects swam at a workload requiring 40.3 ml·kg·min⁻¹ and bicycled at a workload requiring 42.5 ml·kg·min⁻¹. The same workload was used for post-transition bicycling in both tests. VO₂ values were not sig. (p<0.05) different between tests. However, VE was sig. (p<0.05) elevated during bicycling as compared to swimming. During the third and final minute of the transition VO₂, VE, and HR dropped to values that were not sig. (p<0.05) different. With the onset of post-transition exercise VO₂ and HR returned to pre-transition values within 3 minutes for both tests. VE was sig (p<0.05) lower during post-transition bicycling in SBT as compared to CP. It was concluded that although statistically sig. differences did exist between the swim to bicycle transition and the control procedure, these differences did not appear to be large enough to warrant the development of specialized training programs to attempt to improve performance in the transition phase of triathlon competition. Based upon these findings, it is the recommendation of this study that triathletes could best improve their swim to bicycle transition performance by practicing and improving the techniques involved in the equipment changeover from swimming to bicycling and not from actually performing the transition between normal swimming and bicycling training sessions.
Triathlons: The swim to bicycle transition

A Thesis Presented

to

The Graduate Faculty

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of the requirements for the

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by

Gregory Eugene Borchers

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Candidate: Gregory Eugene Borchers

We recommend acceptance of this thesis in partial fulfillment of this candidate's requirements for the degree:

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The candidate has completed his or her oral report.

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Dedicated to those who have helped me learn how to learn.

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Triathlons are a form of endurance competition that have gained popularity within the last 10 years. The Hawaiian Ironman competition was the first widely publicized triathlon. It consisted of a 2.4 mile swim, a 110 mile bicycle ride, and 26.3 mile run. With the advent of shorter distance triathlons throughout the United States, the sport gained increasing popularity during the early 1980's. It has been estimated that 400,000 people participated in officially sanctioned triathlons during 1985 alone (Katovsky, 1985).

There is no single training program or method that is used by a majority of triathletes. Most triathletes use an individualized approach to training, attempting to develop a program that suits their own goals and time limitations. This large variation in training techniques is probably due to the scarcity of published research concerning training methods for triathletes. One aspect of triathlons that make them unlike almost any other sporting event is the transition from one form of endurance exercise to another without a rest period or decrease in intensity. Two transitions exist in triathlons. The first is from swimming to bicycling and the second from bicycling to running. The first transition involves a change from a primarily upper body activity to a lower body activity, and the second transition brings about changes in muscle group utilization patterns in the legs. This
study examines only the first transition, from swimming to bicycling. These transition phases are unique to the sport of triathlon and they provide an unprecedented challenge to the coach or physiologist developing a triathlon training program.

Statement of the Problem

Most training methods developed in the past to improve performance in the transition phase of triathlons have not been based upon data collected by qualified researchers. This study measured heart rate, oxygen uptake, minute ventilation, and respiratory quotient during two variations of the swim to bicycle transition period. The first transition was a swim to bicycle transition that attempted to reproduce competitive triathlon conditions. The second transition was a bicycle to bicycle procedure designed to reproduce the duration and pattern of intensity changes in the swim to bicycle transition, using only one mode of exercise (bicycling). The purpose of the second transition was to serve as a single exercise mode control for comparison to the swim to bicycle transition group. The purpose of this study was twofold; first to describe the physiological characteristics of the swim to bicycle transition phase of triathlons, and secondly to make practical recommendations concerning possible training methods for improving swim to bicycle transition performance. This study attempted to determine whether or not a triathlete could reproduce the physiological characteristics of the transition period for training purposes, by mimicking its pattern of intensity changes with a single mode of
exercise such as bicycling and whether or not there might be a need to do so.

**Need for the Study**

The lack of published research concerned with the characteristics of triathlon performance has led to an abundance of arbitrarily designed triathlon training programs. This study was intended to contribute to the data base necessary for more scientifically designed triathlon training programs.

**Null Hypothesis**

It was hypothesized that there would be no difference between the transition from swimming to bicycling and the control procedure (simulated transition) using bicycling alone.

**Assumptions**

The following assumptions were made concerning the study:

1. All subjects attained a true maximal VO₂ in both the tethered swim and bicycle ergometer max tests.
2. All subjects followed the dietary and activity level pre-test restrictions.
3. The bicycle ergometer and tethered swimming apparatus were calibrated correctly and provided reproducible and accurate workload measurements.
4. The physiological variables measured were not altered by psychological or environmental factors.
5. The subjects did not undergo a training effect as a result of the testing.

6. The dead space volume in the gas collection apparatus did not alter the oxygen uptake measurements.

**Delimitations**

The following delimitations were established for this study:

1. Subjects were limited to trained male college students 22-28 years of age from the University of Wisconsin-LaCrosse preparing for triathlon competition sometime in the three to four months following this study.

2. All subjects were free from symptomatic upper or lower body injuries.

3. Each subject completed all four tests within a two week period.

4. The subject's level of swimming and cycling experience was limited to non-elite levels.

**Limitations**

The identified limitations which were unable to be controlled for in this study included:

1. The subjects were volunteers; therefore, a random sample did not exist.

2. The subjects may have undergone a learning process through the course of the procedure.

3. Different fitness levels between subjects may have influenced the amount of recovery that occurred during the transition periods.
Definition of Terms

Maximal Oxygen Uptake - The maximal rate at which oxygen can be taken in, transported, and utilized by the body per minute. The power or capacity of the oxygen utilization system (Astrand & Rodahl 1977).

Relative Percentage VO₂ max - A percentage of a subject's known maximal oxygen uptake as previously measured for the specific exercise modality being performed (Astrand & Rodahl 1977).

Steady State - A condition where oxygen uptake equals the oxygen requirement of the tissues (Astrand & Rodahl 1977). For the purposes of this study, a steady state was said to exist when the subject's heart rate fluctuated less than 5 beats per minute (Myers, Golding, & Sinning. 1973).

Triathlon - A multi-event endurance athletic event consisting of swimming bicycling and running, performed in that order (Edwards 1983).

Transition Period - The portion of a triathlon during which a triathlete changes events. Defined as the interval between the cessation of one event and the beginning of the next. For the purposes of this study, the word transition was used to describe only the swim to bicycle transition unless specified otherwise (Edwards 1983).

Tethered Swimming - Stationary swimming with the resistance to forward motion supplied by a harness and pulley system using a known resistance (Bonen et al., 1980).

Cross Training Effects - That portion of the training effects from a muscle group specific training program that manifest themselves as
increases in oxygen uptake during exercise of a different modality than that of the training program (Edwards, 1983).

**Training Effect** - Increases in oxygen uptake capacity as a result of training (Astrand & Rodahl, 1977).
CHAPTER II
REVIEW OF LITERATURE

Introduction

The physiological characteristics of differing forms of exercise have been studied for years. In particular, the comparison between upper and lower body exercise has been made numerous times (Reybrouck, Heigenhauser, & Faulkner, 1975, and Bergh, Kanstrap, & Ekblom, 1976). However, studies concerned with the interaction between upper and lower body exercise performed sequentially, as in triathlons, were not found in the literature.

This chapter will review the research that has been published concerning triathlon performance, and any additional literature pertaining to performance during the transition phase of triathlons. The chapter will be divided into the following sections; triathlon performance, specificity of testing and training, tethered swim testing, and bicycle ergometer testing.

**Triathlon Performance**

The relationship between triathlon performance and event specific maximal oxygen uptake was investigated in 1985 by Otto, Smith, Weatherwax, Southard, and Wygand. Novice triathletes were subjected to treadmill, bicycle, and arm cranking maximal graded exercise tests two weeks after a triathlon (1 mile swim, 28 mile ride, 6.2 mile run). When event specific maximal oxygen uptake ($\text{VO}_2\text{ max}$) was compared with the
corresponding time to completion for each segment of the triathlon, no high correlations were found. However, the correlation between treadmill VO$_2$ max and running times was significant \((p<0.05)\), \((r = -0.68)\). The authors concluded that factors other than metabolic capacity were involved in the performance of the swimming and bicycling events during the triathlon. Otto and associates (1985) conjecture that other factors influenced performance in unfamiliar events (i.e., swimming and bicycling) was supported by the finding of Katovsky that 54% of male triathletes were from a running background (1985).

In a similar study, also in 1985, Kohrt, Morgan, Bates, and Skinner examined the relationship between event specific VO$_2$ max, and corresponding time to completion in a triathlon (1.2 mile swim, 56 mile bike, 13.1 mile run). In addition, the relationship between the triathlete's event specific VO$_2$ max and treadmill max, was compared to established norms for both elite and recreational athletes, who specialized in only one activity. The triathletes' mean VO$_2$ max for tethered swimming was 86.8% of treadmill VO$_2$ max, and for bicycling 95.7% of treadmill VO$_2$ max. These proportions were in agreement with the findings of several other researchers using non-elite subjects (McConnel, Swett, Jeresaty, Missri, & Al-Hani, 1983; Stromme, Injer & Meen, 1977). It seems possible that when compared to other non-elite subjects, the well rounded nature of triathlon training programs do not drastically alter the proportions of swimming and bicycling VO$_2$ max, to those values obtained on a treadmill. Investigations concerned with the
best proportions of event specific $V_O_2_{max}$ for optimal triathlon performance were not found in the literature.

In an attempt to determine the predictors of triathlon success, Dengal, Flynn, Costill, Kirwin, Beltz, and Neufer (1986) examined the relationship between selected metabolic measurements and triathlon performance. The variables measured included oxygen uptake, minute ventilation, and heart rate. These variables were measured during maximal tests of treadmill running, bicycle ergometry, and free swimming. Maximal $V_O_2_{max}$ was found to be less related to performance time than performance economy for each of the three triathlon segments (1.2 mile swim, 56 mile bicycle, 13.1 mile run). The authors concluded that economy of effort during actual triathlon competition is a much better predictor of success than is laboratory determined max$V_O_2$.

In a study that examined lactate threshold in triathletes, Albrecht, Foster, Dickenson, and DeBever (1986) tested 9 triathletes using treadmill running, bicycle ergometry, and a swim bench apparatus to simulate the race conditions of a triathlon. Variables measured included oxygen uptake, blood lactate, ventilation, and perceived exertion. Lactate thresholds were determined using both blood lactate and ventilatory parameters. Lactate thresholds were determined to be 76.0% of $V_O_2_{max}$ for bicycling, 81.3% of $V_O_2_{max}$ for treadmill running, and 54.0% of $V_O_2_{max}$ for the swim bench. The authors concluded that laboratory determination of lactate threshold may underpredict the intensity of the triathlete's actual race pace.
The metabolic and energy demands of an actual triathlon competition (1 mile swim, 50 k ride, 20 k run) were studied by Woodard and Towne in 1983. Gas and venous blood samples were taken at the beginning and the end of each segment of the triathlon. Relative intensities during each of the segments were as follows; swimming 67.8% VO\textsubscript{2} max, bicycling 35.7% VO\textsubscript{2} max, and running 38.1% VO\textsubscript{2} max. VO\textsubscript{2} differences between triathlon segments were significantly different at the p<0.05 level. Respiratory exchange ratios (RER) were as follows; swimming 0.946, bicycling 0.844, and running 0.866. RER differences between segments were significant at the p<0.05 level. Blood lactate values (mEQ/L) show a dramatic elevation during swimming as compared to bicycling and running. The lactate values reported were as follows; swimming 9.24, bicycling 0.91, and running 0.63. The difference was significant at the p<0.001 level.

The findings of Woodard and Towne (1980) were in agreement with LaVoie, who in 1982 found that in male college students swimming at 70% of event specific VO\textsubscript{2} max, lactate and pyruvate were significantly (p<0.05) elevated as compared to bicycling values. Lavoie also found that plasma free fatty acids, glycerol, and glucose were not significantly different between the two modes of exercise (p<0.05). Lavoie (1982) concluded that there was a higher level of carbohydrate utilization in swimming than in bicycling at the same relative work intensity, but cautioned that the utilization of intramuscular triglycerides may have been a factor. It was suggested that these results could have been due to a different training state of the muscles used, and/or to a different fiber type recruitment pattern.
In the only study found that indirectly observed the physiological characteristics of transition periods, the physiological responses to 5 hours of stationary cycling immediately followed by 3 hours of treadmill running were examined (O'Toole, Hiller, Douglas, Pisarello, & Mullen, 1985). The variables measured included VO$_2$, HR, stroke volume, and cardiac output. Variables were measured 5 min after the onset of each form of exercise, and every 30 minutes thereafter. No significant (p<0.05) differences were found in any of the values for males. However, during the first five minutes of each form of exercise, the values for females were significantly (p<0.05) different from those measured 30 minutes into the tests and at the end of each segment. The authors concluded that female triathletes required longer than 5 minutes to reach steady state.

**Specificity of testing and training**

It has been stated that the type of test is an important factor that must be taken into consideration when evaluating the maximal oxygen uptake of specifically trained athletes (Stromme et al., 1977). It has been demonstrated that training in one mode of exercise produces increases in VO$_2$ max only during testing in that mode of exercise, and at the same time, smaller non-significant increases when tested in other modes of exercise (Magel, Foglia, McArdle, Gutin, Pechar, & Katch, 1975; Gergley, McArdle, DeJesus, Toner, Jacobowitz, & Spina, 1984).

The question of whether or not triathletes incur a cross-training effect between different modes of training was examined by Korht, O'Conner, and Skinner, (1986). Eight male and six female triathletes
participated in a training study to monitor adaptations to triathlon
training in three sports. Training schedules were left to the
individual's discretion but recorded weekly. Maximal pre and post-tests
for treadmill running, bicycling, and tethered swimming were performed.
Variables reported include oxygen uptake and blood lactate. The
training improvement over the seven months of the study was significant
(p<0.05) only for bicycling (4.9% increase in VO_2max). The authors
concluded that since the subjects put more time into bicycling, that
training improvements were dependent on training volume. This study was
in support of the concept of training specificity since equal
improvement was not demonstrated in all three testing modes.

An exception to the studies refuting the existence of a significant
cross training effect was found by McArdle, Magel, Delio, Tone, and
Chase in 1978. Experimental subjects (N = 11) ran in an interval
training program at 85% VO_2 max 3 times per week for 20 minutes. This
training program produced a significant (p < 0.05) increase in treadmill
VO_2 max (6.3%). At the same time, a significant (p< 0.05) increase in
tethered swim VO_2 max was observed (2.6%). This increase was observed
even though no swim training had taken place. The authors concluded
that while their results supported the concept of specificity of
training, it was possible that running at that intensity and duration
may produce a generalized training adaptation. More in-depth studies
into the general training effects of specific training modes, otherwise
known as "cross training effects" were not found in the literature.
However, the findings of McArdle et al. (1978), suggested that
intensity, duration, and the amount of muscle mass involved, may be factors in producing a cross training effect.

**Tethered Swim Testing**

The use of a restraining device to allow a measurable resistance to be applied to a stationary swimmer was first described by Cureton in 1930. Magel and Faulkner examined the practicality of tethered swim testing using a discontinuous protocol and found it to be satisfactory (1967). The test retest reliability of tethered swimming with triathlete subjects has been shown to be 0.97 (Kohrt et al., 1985). Maximal oxygen uptakes as measured during free, tethered, and flume swimming, have been found to be essentially identical \(r = 0.99\), (Bonen, Wilson, Yarkony, & Belcastro, 1980). Triathletes have been tested for oxygen uptake during swimming by several researchers (Henry, 1985). In summary, tethered swimming tests utilizing continuous, (Bonen et al., 1980) and discontinuous (Magel and Faulkner, 1967) protocols have been found to be highly accurate and reliable models of free swimming.

**Bicycle ergometer testing**

The use of bicycle ergometers as a testing mode for cyclists was found to be well accepted in the literature. However, a great deal of controversy did exist concerning protocols for the testing of experienced and elite cyclists. Controversy surrounds both the equipment characteristics and the procedure to be used, particularly pedalling cadence and body position.
In untrained college males, it has been found that no significant differences \((p<0.05)\) existed between \(\text{VO}_2\) max values obtained using three differently equipped ergometers; a standard bicycle ergometer, a toeclip equipped ergometer, and an ergometer equipped with toeclips and dropped handlebars (Bateman, 1983). In contrast, it has been demonstrated that the use of dropped handlebars and toeclips resulted in higher \(\text{VO}_2\) max values in experienced cyclists (Faria, Dix, & Frazier, 1978; Ribisl, Rejeski, Brodowicz & King, 1982). These findings suggest that experienced cyclists benefit from the use of dropped handlebars and toeclips, while inexperienced cyclists may not gain the same benefits. The mechanisms for these results are not clearly stated in the literature.

There is little agreement in the literature concerning an optimal pedalling cadence for testing. It appears that the goals of the testing and the level of cycling experience of the subjects are the best determinants of optimal pedalling cadence for testing. Faria, Sjoraard and Bonde-Peterson (1982), studied the energy expenditure and efficiency of different pedalling cadences at a constant power output. Elite subjects were studied \((N = 4)\) utilizing 60, 100, and 130 rpm cadences at constant workloads of 800 and 1300 kpm. It was found that gross pedalling efficiency did not change at the higher workloads. Based on this finding, the authors concluded that in skilled cyclists benefits may be realized by high pedalling cadences at high power outputs.

The conclusions of Faria et al. (1982), were indirectly supported by the finding that graded exercise test using a 60 rpm pedalling
cadence produced the highest VO$_2$ max in competitive cyclists when compared to 90 and 120 rpm tests (Buchannon & Weltman 1985). The studies of Faria et al. (1982), and Buchannon and Weltman (1985), supported the idea that while 60 rpm may be valuable for testing purposes because of its inefficiency and resultant high energy cost, 90 rpm may be beneficial in actual competition, where high efficiency and low energy costs are a primary concern. In addition it has been reported that in experienced cyclists perceived exertion is lower at 90 rpm than at 60 rpm for both high and low power outputs (Faria, 1984; Ribišl et al., 1984). It was also found that 91 rpm was the most mechanically efficient pedalling cadence for experienced cyclists (Hagberg, Grese, Spitznagel, & Mullen, 1981).

Summary

It has been found that event specific oxygen uptake is somewhat related to performance in the bicycling and running segments of triathlons, while not related at all to performance in the swimming event (Kohrt et al., 1985; Otto et al., 1985). During triathlon competition substrate utilization was found to be different in swimming as compared to bicycling. Swimming resulted in increased mobilization of glucose, while fat metabolism was higher in bicycling and running (Woodard & Towne, 1983). Female triathletes were found to differ from men only in their increased length of time from the onset of exercise to the attainment of steady state. (O'Toole et al., 1985).

The literature is in agreement concerning the use of tethered swimming tests as an accurate model for free swimming (Magel et al.,
1975; Bonen et al., 1980; McArdle et al., 1978). Testing experienced subjects on bicycle ergometers yielded the highest VO₂ max values when subjects pedalled at 60 rpm (Buchannon & Weltman, 1980). Steady-state cycling was found to be most efficient at 91 rpm (Hagberg et al., 1981).

Studies using a combination of these two modes of testing to simulate the transition period of triathlons could not be found in the literature. However, it seems likely that an accurate model could be produced by combining these two modes.
CHAPTER III
INTRODUCTION

It has been stated that in evaluating the oxygen uptake of specifically trained athletes, it is preferable that the testing mode be identical to the specific sport activity (Stromme et al., 1977). A peculiarity of this study was the need to design the test so as to replicate two specific activities, and the transition from one to the other. To accurately represent the transition phase of triathlons, two well-established and accepted testing modalities were combined.

The activities of the subjects during the transition period were closely modeled after those occurring in triathlon competition. After leaving the water, subjects towelled dry, changed into cycling clothes, and then briefly ran to simulate the distance from the swim exit area to the bicycle staging area that typically exists during race conditions.

Subject Selection

The ten subjects that participated in this study were trained male college students aged 22-28 from the University of Wisconsin-LaCrosse. All subjects had previously competed in at least one triathlon, and were presently training for triathlon competition within three to four months of the study. As determined prior to the study, all subjects were training at least five times per week for 20 minutes, at an intensity high enough to produce a training effect (Astrand &
Rodahl, 1977; ACSM guidelines, 1986). Subjects were recruited through word of mouth and "call for participants" flyers.

Each subject had participated in at least one swim to bike transition during triathlon competition. Prior to testing all individuals were allowed to familiarize themselves with the tethered swim apparatus and the transition process while connected to the gas collection equipment. All subjects were required to read and sign informed consent and willingness to participate forms (see Appendix A). Subjects were instructed not to exercise on the day of the test and not to eat during the four hours prior to the test.

Instrumentation

Tethered Swimming. The tethered swim apparatus as described by Magel et al. (1977), was designed so as to place a measurable resistance to forward movement upon a stationary swimmer, with minimum interference of the swimmer's natural swim stroke. A waist belt with a quick release buckle attached the swimmer to the resistance. A 6.3 mm diameter nylon cord was passed through three pulleys to a bucket containing known amounts of water (see Appendix B). The nylon cord was attached to the swimmer in such a manner that it did not hinder either swim stroke or body alignment of the subject (see Appendix C). The resistance to the swimmer was changed by adding or removing measured amounts of water from the bucket.

Bicycle Ergometer. A Monark 868 bicycle ergometer, equipped with a racing seat, toe clips and dropped handlebars was used during the bicycle portion of the tests. The toe clips, racing seat and dropped
handlebars provided a familiar body position and pedalling motion for the subjects, all of whom were experienced bicycle riders. It has been demonstrated that in untrained subjects, no significant difference in oxygen uptake measurement exists between standard bicycle ergometers with upright handlebars and platform pedals, and dropped handlebar, toeclip-equipped bicycle ergometers (p < 0.05) (Bateman, 1983).

Heart Rate Monitoring. Radio Telemetry provided a convenient solution to the need for a lightweight and unobtrusive heart rate monitoring method. The transmitter was connected to the subject with an extended lead wire system (see Appendix D). Electrodes were placed on the subjects prior to their entry into the water during the swim to bicycle transition test. Lead wires were clipped to the subjects immediately after they exited the water. This method provided satisfactory EKG tracings for the determination of heart rate during the transition and post-transition bicycling phases of the tests. Electrodes were secured to the subjects with surgical tape to minimize movement artifact.

Gas Analysis. Expired gases were analyzed using a computerized portable open circuit gas analyzer (Beckman MMC). The Beckman gas analyzers (OM-11 and LB-2) were calibrated with a calibration gas previously assayed using the Scholander technique. Gas samples were automatically analyzed at the end of every minute throughout all of the tests.

Subjects breathed through a one way valve and mouthpiece (Hans Rudolph), attached to flexible plastic gas collection tubing. During the maximal swimming and swim to bicycle transition tests a scuba type mouthpiece with flexible rubber inlet and outlet tubing replaced the
Hans Rudolph valve and tubing (see Appendix E). The two gas collection systems were similar in diameter and length and pilot testing did not demonstrate any apparent differences between them for the variables measured in this study.

**Experimental Procedure**

Each subject underwent four tests; maximal bicycling, maximal swimming, swim to bicycle transition, and a simulated transition utilizing a "bicycle to bicycle" procedure. The simulated transition will henceforth be referred to as the "control procedure". The maximal bicycle and swimming tests were necessary to determine the equalized relative workloads utilized in the swimming and bicycling portions of the transition tests.

**Maximal Bicycle Tests.** A maximal bicycle test protocol using two minute stages with 180 kpm increases at the end of each stage was used in the maximal bicycle tests. Subjects pedalled at 60 rpm. Buchannon and Weltman (1980) determined that these workloads and pedalling cadence were optimal for testing experienced cyclists.

**Maximal Swimming Tests.** Discontinuous protocols for maximal tethered swimming tests were developed by Magel and Faulkner in 1967, and Bonen et al., in 1980. The procedure used in this study was a continuous protocol similar to that utilized by Henry (1985). The initial workload was determined from a practice session in which water was added to the bucket in 0.5 pound increments until enough resistance was present to allow the swimmer to perform a comfortable front crawl stroke with normal stroke mechanics. The test started with a three minute warm-up
stage at the initial workload. At the end of the warm-up and each minute thereafter, one pound of water was added to the bucket.

When the swimmer could no longer maintain a fixed position over a predetermined mark on the pool bottom, a plastic pole was used to signal the swimmer that the test was almost over. At this time, the swimmer began to sprint and attempted to return to the original mark on the pool bottom. The swimmer terminated the test upon voluntary exhaustion, or the test was stopped when the subject no longer provided enough force to hold the bucket off the floor.

**Transition Test.** To replicate the transition phase of a triathlon, subjects swam for twenty minutes with the tethered swim apparatus set at 60% of their swim VO$_2$ max. They then climbed out of the pool, and ran back and forth between two lines 15 feet apart to simulate the approximate 30 yard distance that exists between the swimming exit and the bicycle equipment area that exists during competition. Next, the subjects towelled dry, changed into cycling clothes, and began to ride the bicycle ergometer. The subjects rode the bicycle ergometer at 60% of their bicycle VO$_2$ max with a 90 rpm pedalling cadence until they had reached a steady state heart rate and VO$_2$. The gas collection was continuous with 60 second measurement intervals throughout the transition period. Heart rates were determined at the end of each minute from a ten second EKG tracing. The duration of the transition period was held to exactly three minutes for each of the subjects. Each subject began all activities within the transition phase at the same time interval.
Control Procedure (simulated transition test). As previously stated, one of the objectives of this study was to determine whether or not the physiological responses to the swim to bicycle transition phase could be reproduced using the bicycle ergometer as the only mode of exercise. This procedure served as the control for statistical purposes, and the data were compared to the swim to bicycle transition test.

The purpose of this portion of the testing was to determine if the energy requirements and HR response to a swim to bicycle transition could be replicated with a single form of exercise. Subjects exercised on a bicycle ergometer at 60% of their bicycle VO\(_2\) max with a 90 rpm pedal cadence for ten minutes, and then underwent a transition procedure that was identical to the one performed in the swim to bicycle transition test, including a change of shoes and towelling dry. After completing the transition phase, subjects resumed bicycling at the same workload and cadence until steady state VO\(_2\) and HR was observed.

**Statistical Analysis**

Oxygen uptake, minute ventilation, and respiratory exchange ratio from all three segments of both the transition and the simulated transition were compared using the two sample hypothesis testing method for dependent samples. Heart rate data were compared across each minute after the onset of the transition, because no HR data were available for the swimming portions of the tests.

The independent variable was the form of exercise preceding the transition period in the control procedure and swim to bicycle transition (either swimming or bicycling). The mean, standard
deviation, were computed for each variable in all three segments of both tests. All differences were accepted as significant at the p < 0.05 level.
CHAPTER IV
RESULTS AND DISCUSSION

This chapter presents the results and discussion of the variables measured, trends observed, and significant differences calculated. Comparisons of the data from the swim to bicycle transition and the control procedure are also covered in this section. Practical concerns and comparisons to other published results are addressed.

Maximal bicycle ergometer testing

Maximal oxygen uptake (VO₂) values for the bicycle ergometer (BE) ranged from 55.4 ml·kg·min⁻¹ to 73.0 ml·kg·min⁻¹. The mean maximal VO₂ for BE was 63.34 ml·kg·min⁻¹ with a standard deviation of 5.41 ml·kg·min⁻¹. This value was higher than any other reported BE VO₂ max for triathletes in the literature. A comparison of BE VO₂ max values for subjects in the present study compared to BE VO₂ max values reported by other researchers is presented in Table 1. The values for BE VO₂ max in other triathlete samples suggest that the subjects in this study were highly trained in cycling as compared to other triathlete subjects in published studies.
Table 1. Comparison of bicycling VO₂ max values of triathlete subjects in published research.

<table>
<thead>
<tr>
<th>Study</th>
<th>Sex</th>
<th>Age</th>
<th>N</th>
<th>Max VO₂ ml·kg·min⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Albrecht et al., (1986)</td>
<td>-</td>
<td>-</td>
<td>9</td>
<td>56.3</td>
</tr>
<tr>
<td>Dengal et al., (1986)</td>
<td>male</td>
<td>-</td>
<td>11</td>
<td>63.1</td>
</tr>
<tr>
<td>Henry (1985)</td>
<td>male</td>
<td>19-32</td>
<td>16</td>
<td>56.5</td>
</tr>
<tr>
<td>Korht et al., (1985)</td>
<td>-</td>
<td>29.5</td>
<td>13</td>
<td>57.9</td>
</tr>
<tr>
<td>Otto et al., (1985)</td>
<td>-</td>
<td>27.3</td>
<td>9</td>
<td>55.0</td>
</tr>
<tr>
<td>Present Study (1986)</td>
<td>male</td>
<td>22-28</td>
<td>10</td>
<td>63.3</td>
</tr>
</tbody>
</table>

Maximal tethered swim testing

Maximal tethered swim (TS) oxygen uptake (VO₂) ranged from 44.6 ml·kg·min⁻¹ to 60.6 ml·kg·min⁻¹. The mean maximal VO₂ for tethered swimming was 52.9 ml·kg·min⁻¹ with a standard deviation of 4.59 ml·kg·min⁻¹. This was higher than the values reported by other researchers for tethered swimming (Henry, 1985; Korht et al., 1985). However, Dengal, et al. (1985) found higher values for free swimming in triathlete subjects. The comparison between the results of this study and others may have been influenced by the numerous biomechanical...
differences between tethered swimming and free swimming that have been previously discussed by Magel and Faulkner, (1967). A comparison of swimming VO2 max among studies using triathlete subjects (including the present study) is presented in Table 4-2.

Table 2. Comparison of swimming VO2 max values of triathlete subjects in published research.

<table>
<thead>
<tr>
<th>Study</th>
<th>Sex</th>
<th>Age</th>
<th>N</th>
<th>Max VO2 (method) ml·kg·min⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dengal et al., (1986) (free swim)</td>
<td>male</td>
<td>-</td>
<td>11</td>
<td>56.7</td>
</tr>
<tr>
<td>Henry (1985) (tethered swim)</td>
<td>male</td>
<td>19-32</td>
<td>16</td>
<td>51.5</td>
</tr>
<tr>
<td>Korht et al., (1985) (tethered swim)</td>
<td>-</td>
<td>29.5</td>
<td>13</td>
<td>52.5</td>
</tr>
<tr>
<td>Present Study (1986) (tethered swim)</td>
<td>male</td>
<td>22-28</td>
<td>10</td>
<td>52.9</td>
</tr>
</tbody>
</table>

The tethered swim VO2 max values found in this study did not rank as highly as compared to the values obtained by others using triathlete subjects. This was in contrast to the results of comparing BE VO2 max values in which the subjects in this study ranked highly. This suggests that the subjects in this study were not as highly trained in swimming.
as they were in bicycling, in comparison to other triathlete subjects studied in the literature.

**Swimming max VO₂ vs. Bicycling max VO₂**

Maximal VO₂ for tethered swimming was 16% less than VO₂ max for bicycle ergometry. The differences ranged from 7.2% less in a subject who had prior competitive swim experience, to 22.2% less in a subject fairly new to serious swim training. This pattern of differences was in agreement with the results of previous studies utilizing triathlete subjects and swimmers of different backgrounds and skill levels. (Dengal et al., 1986; Korht et al., 1985; Lavoie, 1983; Magel & Faulkner, 1967).

**The control procedure**

The following sections will discuss the results of the swim to bicycle transition, and the control procedure (which was different only in that bicycling was the mode of exercise used both before and after the transition phase). For clarity of discussion, the term "pre-transition" will be applied to minutes 0-20 of the tests. The term "transition phase" will be applied to minutes 21, 22 and 23. Minutes 24-28 of the tests will be referred to as the "post transition" segment of the tests.

The results of utilizing the same mode of exercise before and after the transition phase were not unusual. Subjects cycled during the
pre-transition segment at a workload requiring 42.5 ml·kg·min⁻¹. This value was 67.2% of their max VO₂ for bicycling. After going through the transition phase, subjects reached a steady state heart rate at the same workload with an average VO₂ of 43.0 ml kg min and 67.9% of bicycling VO₂ max. This pattern of VO₂ changes is depicted in Fig. 1. The subjects' recovery rate after the transition was rapid. VO₂ reached a low of 15.3 ml·kg·min⁻¹ (24.5% of BE VO₂ max) during the third minute of the transition phase. After two minutes of post transition bicycling, the subjects had returned to within 0.74 ml·kg·min⁻¹ of their pre-transition VO₂ for the same workload. This rapid return to steady state VO₂ upon the resumption of exercise may have been due to the subjects' high max VO₂ values for bicycling.

Expired minute ventilation (VE) exhibited a pattern of changes similar to those of VO₂ during the pre-transition and post-transition segments of the control procedure. The pattern of VE changes is depicted in Fig. 2. Pre-transition VE was 77,862 ml min and post transition VE reached 72,755 within two minutes of the start of post-transition bicycling. This was 7% lower than pre-transition values. VE dropped sharply at the onset of the transition phase, and reached a low value of 33,127 ml·min⁻¹ before rapidly increasing with the onset of post-transition bicycling.
Figure 1

VO2 vs. minutes

- - - = swim to bicycle transition
--- = control procedure

Rest 5 10 15 20 25 30 35 40 45

5 10 15 20 25 30 35 40 45
Respiratory exchange ratio (RER) reached a steady state value within 7 minutes of the onset of pre-transition cycling. As depicted in Fig. 3, RER values gradually declined after reaching an initial steady state and then reached a second stable range of values during minutes 16-20 of the test. At the onset of the transition phase, RER increased and peaked in the second minute of the transition period at 0.933. This rise in RER corresponded to a decrease in VO₂. The rise in RER during the transition phase may have been due to the decrease in VO₂ and its mathematical influence on RER (the ratio of oxygen consumption to carbon dioxide production). The changes in RER did not appear to be caused by an increase in VCO₂, only a lag in its rate of decline as compared to VO₂. A precise explanation for these changes in RER could not be found in the literature. However, it is tempting to speculate that the rapid decline in VE, as previously mentioned, may have hindered the body's ability to remove CO₂ thereby causing the lag in the decrease in VCO₂ as compared to the decrease in VO₂.

Heart rate (HR) changes are depicted in Fig. 4. The heart rate responses, as would be expected, paralleled the VO₂ response throughout the tests.

As can be seen in the figures depicting the control procedure, physiological response were relatively consistent. The oxygen uptake followed a predictable fall and rise pattern through the transition phase of the test, and returned to pre-transition values very rapidly with the onset of post transition cycling exercise. Within the transition phase HR and VE also followed this pattern of a decrease
Figure 3

RER

△△ = swim to bicycle transition

----- = control procedure
followed by a return to pre-transition values. The RER response though not completely understood, may have been influenced by the changes seen in $V_F$ during the transition phase. In summary, the physiological response to the control procedure were not unusual or different from what would be expected.

**The swim to bicycle test**

The transition from tethered swimming to bicycling produced a pattern of changes strikingly similar to those of the control procedure. The subjects swam at a workload that required a mean $VO_2$ of 40.3 ml·kg·min$^{-1}$ (see Fig. 1) This corresponded to 76.0% of their tethered swim $VO_2$ max. During the transition, $VO_2$ dropped to 20.9 ml·kg·min$^{-1}$ in the last minute of the transition phase. Within two minutes of the onset of post-transition bicycling, $VO_2$ had returned to 39.6 ml·kg·min$^{-1}$ which was within 6.0% of the pre-transition values for bicycling at the same workload during the control procedure. This difference was not significant ($p < .05$).

As depicted in figure 2, minute ventilation followed a pattern of changes similar to those for $VO_2$. A rapid decline in $V_F$ at the onset of the transition was followed by a rapid return to pre-transition values after the onset of post-transition bicycling.

RER reached a steady state in the first ten minutes of tethered swimming. At the beginning of the transition phase, RER increased to a peak value of 0.923 during the third minute of the transition phase. In the post-transition period RER immediately dropped and then began to rise slowly (see Fig. 3). The mechanisms for these changes could not be
Figure 4

[Graph showing heart rate (HR) over time with annotations]

ΔΔ = swim to bicycle transition
--- = control procedure
determined from the data, but may have been influenced by the changes in VE and VO2 as previously discussed for the control procedure.

Although heart rate (HR) data was not available for the tethered swim portion of the test, HR values were obtained immediately after the tethered swim and monitored until the end of the tests (minutes 20-28). The HR data did demonstrate trends that were similar to those observed for VE and VO2. These changes in the heart rate data are presented in Fig. 5.

Physiological responses during the swim to bicycle transition test maintained a pattern similar to those that occurred during the control procedure. HR VO2 and VE all responded to the transition phase with the familiar decrease then increase, finally returning to pre-transition values within the first two to three minutes of post-transition bicycling. The pattern of changes in RER were also very similar to those observed in the control procedure.

In summary, the variables in the swim to bicycle transition test exhibited patterns very similar to those observed in the control procedure. The statistical and practical significance of the differences that did exist will be discussed in the next section of this chapter. However, it may be generalized that the pattern of changes which occurred across the transition was similar in both the control procedure and the swim to bicycle transition test.

Swim to bicycle results compared to control procedure results

In comparing the results of the swim to bicycle transition test to the control procedure, a two tailed t-test was performed on the data
points for each corresponding minute between the tests. Statistical analyses were made for VO\textsubscript{2}, HR, VE, RER and work efficiency on the bicycle ergometer. The results were accepted as significant at the 95% confidence interval. All further references to significant differences imply a statistically significant difference at the p < 0.05 level.

Oxygen uptake data showed a significant difference during minutes 2, 21 22 and 23 of the tests. In the early minutes of the tests the VO\textsubscript{2} while bicycling (the control procedure) were higher than the initial VO\textsubscript{2} for swimming. It was apparent in this finding that adaptation to swimming was slower than adaptation to cycling. This may have been related to the subjects' relatively higher fitness level in bicycling as compared to swimming as was previously discussed. These differences are illustrated in Fig. 1.

During minutes 21 22 and 23 of the tests (the transition phase) the difference between the VO\textsubscript{2} values for the swim to bicycle test and the control procedure were significantly different. In the last minute of pre-transition exercise (minute 20 of the tests) the VO\textsubscript{2} for the control procedure (bicycling) was higher than the VO\textsubscript{2} (swimming) of the swim to bicycle test. Although this difference was not significant, it is helpful in illustrating the changes that occurred across the transition. During the first minute of the transition VO\textsubscript{2} for both the swim to bicycle test and the control procedure decreased. The control procedure elicited a significantly higher VO\textsubscript{2} (13.0%) compared to the swim to bicycle test value. During the second and third minutes of the transition phase the opposite occurred, with the control procedure VO\textsubscript{2}
values being 15.0% and 14.6% lower than the swim to bicycle test VO₂ values, respectively. With the resumption of exercise in the first minute of the post-transition phase (bicycling), the VO₂ values increased, with control procedure values increasing more rapidly than swim to bicycle test values. In the first minute of post-transition bicycling, the control procedure had a significantly higher (13.4%) VO₂ as compared to the swim to bicycle test value. However, after two minutes of post-transition bicycling there were no significant differences in VO₂ between the tests.

As demonstrated in Fig. 1, the VO₂ values of the control procedure decreased more rapidly and reached lower values during the transition phase than did the swim to bicycle test VO₂ values. With the resumption of exercise (cycling) the control procedure demonstrated a more rapid increase in VO₂ as compared to the swim to bicycle test values.

During minutes three, four, and five of the test RER was significantly lower in the swim to bicycle test as compared to the control procedure. These lower RER values for swimming during the initial phase of exercise are in disagreement with the results of Lavoie et al. (1982), who found higher RER values for the first 5 minutes of cycling. The reason for this discrepancy may have been caused by differences in the testing protocols.

In the 24th minute of the test (the first minute after the transition), the RER values for the swim to bicycle test were significantly higher (5.5%) than the control procedure values. RER data are illustrated in Fig. 3.
Minute Ventilation (VE) as illustrated in figure 2, demonstrated a significantly different relationship between the control procedure and the swim to bicycle test at numerous points, as well as a consistent trend throughout the tests. During the first 20 minutes of the test VE was higher for the control procedure (bicycling) as compared to the swimming portion of the swim to bicycle test. At the onset of the transition (minutes 21, 22, and 23 of the test) VE values fell for both tests and reached low values that were not significantly different during the final minute of the transition (minute 23 of the test). These results were consistent with those of Magel et al., (1967) who found that VE values for tethered swimming were significantly less (p<.05) than those for running at the same oxygen uptakes.

Interestingly, the VE values for the bicycle portion of the swim to bicycle transition test remained significantly lower than the values for the same segment of the control procedure. Although the magnitude of the difference was not as great as the difference between VE values during the swimming and bicycling segments, it was statistically significant. The mechanism behind the failure of VE values for bicycling to rise above those for swimming during the bicycling phase of the swim to bicycle transition was not apparent in the data, nor was there any information in the literature to provide plausible explanations for this trend. A possible factor in this trend could be the work efficiency differences between swimming and bicycling as mentioned by Lavoie, (1982). Another factor could be the thermoregulatory differences between swimming and bicycling which have
been stated to alter bloodflow to the skin thereby having a secondary effect on bloodflow to the working muscle and cardiac output (Holmer, 1974). These relationships and their influence on the swim to bicycle transition phase of triathlon performance merit further study.

Heart rate (HR) data was collected from the end of minute 20 (the beginning of the transition phase) to the end of the tests at minute 28. No comparisons could be made using swimming HR and bicycling HR as swimming HR data was not available. However, HR values from the minute immediately following the swimming portion of the swim to bicycle test (minute 21) were significantly lower than those found in the same minute of the control procedure. This difference is supported by the findings of previous studies comparing swimming HR with cycling HR (Kohrt et al., 1985; Dengal, 1986). Control procedure HR was significantly higher in the final minute of the transition (minute 23 of the test) as compared to the swim to bicycle test values. The HR values for both tests paralleled those for VO2 as depicted in Fig. 4.

Work efficiency for cycling was calculated by the method of Gaesser and Brooks (1975) for post-transition cycling in both tests (minute 24–28 of the tests). Cycling efficiency was significantly lower in the first minute following the transition phase (minute 24 of the test) for the swim to bicycle test as compared to control procedure values. As illustrated in figure 5, efficiency quickly became similar in minutes 25–26 of the test.
Figure 5

% Efficiency

△△ = swim to bicycle transition
○○ = control procedure

minutes

Rest  5  10  15  20  21  22  23  24  25  26  27  28

20  25  30  35  40
DISCUSSION

In the present study VO₂ max values for cycling and swimming were similar to those reported for other highly trained triathletes (Dengal, et al., 1986; Kohrt, 1985). However, since data were not obtained during the peak of the triathlon season, these values may not reflect the highest training state of the triathletes in this study.

During the swim to bicycle transition test, all variables quickly reached steady state as was expected. This steady state was consistent for all variables up until the onset of the transition phase (minute 21 of the test). With the beginning of the transition phase VO₂, HR, and VE began to decrease rapidly. This is consistent with the characteristics of recovery from exercise as outlined by Astrand and Rodahl (1977). During the initial steady state portion of both the control procedure and swim to bicycle tests (minutes 0-20) VO₂ values were not significantly different. However, the swimmers swam at 76.0% of the tethered swimming VO₂ max during the swim to bicycle test while they cycled at 67.9% of their BE VO₂ during the control procedure. They also cycled at 67.9% of their BE VO₂ max during the post transition (minutes 24-28) portion of both tests. This is similar to the pattern of intensities shown for actual triathlon competition by Town and colleagues (1983).

RER values remained elevated and increased slightly during the transition phase (minutes 21-23) for both tests. The mechanisms for this result may have involved the rapid decline in VE that occurred with the onset of the transition phase and/or the increased lactate and
pyruvate production associated with prolonged swimming as reported by Lavoie (1982).

Work efficiency values for post-transition bicycling were significantly different only in the first minute of post-transition exercise (minute 24 of the test). In minute 24, the work efficiency during the swim to bicycle test was 2.6% lower than the efficiency for the control procedure in minute 24. This may have been due to a "warm up" time needed by the bicycling muscles of the swim to bicycle test subjects. In contrast, the control procedure tests provided 20 minutes of bicycling prior to the transition thereby allowing the muscles in these tests to return to steady state much more efficiently than during the swim to bicycle test. In practical terms this decreased efficiency would seem to mean very little to the competitive triathlete. As illustrated in figure 5, the efficiency values quickly became almost identical within two minutes of the onset of post-transition bicycling. With only a 2.6% difference in efficiency during one minute of the test, the possible effects of this decrease on triathlon performance times would seem to be minimal.

Although they were statistically different at times, the physiological changes that occurred during the swim to bicycle test appear to be similar to those that occurred during the control procedure. It appeared that switching from swimming to bicycling as it occurs in a triathlon, may have a great deal of physiological similarity to undergoing a similar change of intensities using bicycling as the only mode of exercise. It also seemed apparent that the physiological
differences that did exist were not large enough or unique enough to warrant a specialized training program for attempting to improve performance in the swimming to bicycling transition phase of triathlons. In order to best improve swim to bicycle transition performance, triathletes should consider practicing and improving the skills and techniques involved in the equipment changeover from swimming to bicycling as opposed to actually performing the transition between normal swimming and bicycling training sessions.
Ten competitive male triathletes aged 22 to 23 participated in this study. Four tests were administered including maximal tethered swimming and bicycling, as well two submaximal tests that (1) replicated a swim to bicycle transition, and (2) served as a control for comparative purposes. Physiological parameters measured during the tests were the following: oxygen uptake, expired minute ventilation, respiratory exchange ratio, and heart rate. In addition, mechanical work efficiencies were calculated for post-transition portions of the tests.

Statistical analysis of the data included means and standard deviations for each variable, and two way t-tests for significant differences at the 95% confidence interval. T-tests were made comparing all variables across each corresponding minute of the swim to bicycle test and the control procedure.

Similar trends were observed for the variables in both the swim to bicycle transition and the control procedure. During the pre-transition phase of the tests, an adaptation and then steady state response was observed. In the transition phase variables followed a pattern indicative of a recovery response, reaching lowest values during the final minute of the transition. With the onset of post-transition exercise, the observed responses were similar to those seen at the onset
of pre-transition exercise. These trends suggest that the swim to bicycle test was not different enough from the control procedure to warrant the development of specific training programs for the swim to bicycle transition.

Conclusions

Based on the results of this study and considering the limitations involved, the following conclusions were reached.

1. In the first minute of post transition bicycling (minute 24 of the tests) several variables showed significant differences between the swim to bicycle test and the control procedure.

2. A significantly (p<0.05) higher VO$_2$ was observed in minute 24 of the control procedure as compared to the swim to bicycle transition test.

3. Work efficiency was lower for the first minute of post-transition bicycling in the swim to bicycle transition test, as compared to the control procedure.

4. Minute ventilation was significantly (p<0.05) lower for swimming as compared to bicycling at the same oxygen uptake.

The differences observed in this study were demonstrated to be statistically significant, therefore, the null hypothesis was rejected.
Recommendation for further study

A great deal of further research is needed in the area of triathlon performance. Recommendations for further study include:

1. A similar study of the bicycle to run transition could provide information complimentary to that presented here.

2. Additional research in the area of performance intensities during actual triathlon competitions could provide information valuable to the development of triathlon training programs.

3. Cross-training effects and specificity of training need to be more accurately quantified.

4. The relationship of triathlon performance to training methods needs to be more firmly established.
References Cited


APPENDIX A

INFORMED CONSENT

FORM
Triathlon Transition Test

Informed Consent

I, ________________, am volunteering to participate in a research study that is designed to measure the physiological characteristics of the transition phase of a simulated triathlon.

I understand that I will perform a series of tests with a tethered swimming apparatus and a bicycle ergometer. Every effort will be made to minimize discomfort and risk. However, I understand that just as with any form of exercise, there are potential risks. These may include; light headedness, fainting, arm, leg or chest discomfort, and very rarely heart attack or sudden death.

I understand that I may withdraw from the study at any time if I so desire.

To my knowledge, I am not limited by any condition(s) that would affect my ability to participate in this study.

_____________________________

witness

_____________________________

name

_____________________________

date

_____________________________

date
APPENDIX B

TETHERED SWIM BELT
APPENDIX C

TETHERED SWIM APPARATUS
APPENDIX D

GAS COLLECTION SYSTEM
APPENDIX E

EKG TRANSMITTER
APPENDIX G
HEADGEAR
APPENDIX F

HEADGEAR AND MOUTHPIECE