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Effect of the Cycle-Run Transition on Running Economy in Triathletes

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EFFECT OF THE CYCLE-RUN TRANSITION ON RUNNING ECONOMY IN TRIATHLETES

by

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Secondly, I wish to thank the TriKats triathlon club of Kalamazoo, Michigan for their participation and cooperation, without them this study would not have been possible, and finally The United States Triathlon Association for their aid and information.

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The purpose of this study was to investigate the effects of prior cycling on running economy (RE) during the running portion of a simulated Olympic distance triathlon. Six triathletes and one duathlete participated in four consecutive laboratory trials: (1) maximal treadmill tests, (2) independent 40km cycling trial (IC), (3) independent 10km treadmill running (IR) and (4) 40km cycling (TC) followed by a 10km treadmill run (TR). Pulmonary data were collected every minute using an automated breath-by-breath system and compared between the first and last ten minutes of each trial. The data showed a significant increase was seen in RE from IR (191.8 $\pm$11.1 ml of $O_2 \cdot min^{-1} \cdot km^{-1}$, 196.4 $\pm$ 8.5 ml of $O_2 \cdot min^{-1} \cdot km^{-1}$) to TR (223.0 $\pm$ 4.6 ml of $O_2 \cdot min^{-1} \cdot km^{-1}$, 219.4 $\pm$ 4.7 ml of $O_2 \cdot min^{-1} \cdot km^{-1}$). We concluded that prior cycling caused an increase in V_e, V_e/VO_2, and V_e/VCO_2 this in turn caused a decrease RE.

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INTRODUCTION

The emergence of the triathlon as an accepted multi-sport discipline, involving the consecutive events of swimming, cycling and running, forces the triathlete to face challenges unique in the world of sport. One of the most important determinants of triathlon success is the ability to link the three disciplines of a triathlon in an optimal way. The most critical aspects of the link are the transition between the events. Margaritis (1996) states that the physiological conditions in which the first transition is made can limit the performance in the subsequent two events. Hue, Le Gallies, & Chollet (1998) claim that the first transition is regarded as having a negligible effect on overall performance and that the second, cycle to run transition is considered more important to overall performance enhancement.

Millet & Vleck (2000) state the higher a competitor places in the field after the cycling session, the greater the importance to their final finishing position. This is supported by Hue, Le Gallies, & Prefaut (2001), which states that the athletes that show smaller increases in ventilation during the transition, perform better than their competitors that have a higher rate of ventilation. Hue, Le Gallies, Chollet, Boussana, & Prefant (1998) studied the effects of prior cycling on running and found higher running economy during the first few minutes (1 to 7) of running. Keider, Cundiff, Hammett, Cortes, & Williams (1988) also investigated the effects of prior cycling on running. Keider et al found higher oxygen consumption and ventilatory rates in the five triathletes tested. Millet, Millet, Hofmann, & Candau (2000) looked at the changes in running economy after cycling on subsequent running. Millet et al compared differences in changes in running economy variables between elite triathletes to amateur triathletes. These results stress the importance of the cycle to run transition to success in triathlon.

From existing research, it may be possible to decrease the effects of the cycle-to-run transition through training of the transition. This could greatly increase the quality of performance. Subjects will learn how their bodies respond to the transition and high intensity exercise. With this knowledge training regimens can be refined to improve performance. This study revisits Hue et al (1998) with the addition of a simulated triathlon and a counterbalance design. Few studies (Miura, Kitagawa & Ishiko, 1997, Millard-Stafford, Sparling, Rosskopf, Hinson & DiCarlo, 1990, Krieder, Boone, Thompson, Burkes & Cortes, 1988) have attempted to recreate a triathlon in the laboratory. These studies have reproduced the triathlon at submaximal (70% VO_2 max) intensities, not at a competitive intensity. To our present knowledge no research exists that permits the athlete to perform under racing conditions. The possibility of the affect of the transition is magnified by the skill level, experience of the athlete and physiology. Therefore the purpose of this study was to simulate the conditions of a cycle-run transition in a laboratory and investigate the affect of prior cycling on running economy during the run segment of the triathlon.

METHODS

Subjects

Subjects were recruited from the Kalamazoo Triathletes Club (the Trikats). E-mails were made to potential subjects. Subject profile is detailed in table 2.

Table 1. Subject profile.

Age	Height (cm)	Weight (kg)	$VO_{2\,max}$ (ml· kg^{-1}· min^{-1})
39	70	75.0	61.4
37	68	78.6	57.4
37	70	68.5	56.7
34	71	75.9	51.4
34	73	77.3	68.7
38	70	69.5	57.4
33	76	83.2	57.1

Subjects were screened for maximum oxygen consumption levels. Subjects with oxygen consumption levels of over 55 ml· kg^{-1}· min^{-1}, $\pm$ 1 met, were selected. All subjects have competed in a minimum of two triathlons or duathlons in the past 12 months. All subjects were injury free for the past six weeks, and currently training for future triathlons or duathlons. Subjects completed a Physical Activity Readiness Questionnaire to determine basic primary health. All subjects were informed of the purpose of the study and gave written consent in accordance to the Human Subjects Institutional Review Board at Western Michigan University before participation.

Trials

Each subject participated in a screening maximal treadmill test and three laboratory trials; independent 40km cycling trial (IC), independent 10km treadmill running trial (IR), 40km of cycling (TC) followed by 10km run (TR), the cycle-run transition trial. The subjects were randomly assigned to an order of which trials were completed in a counterbalanced design. Testing took place over four successive weeks, with one test performed per week on specific days as to minimize the effects of training on the results. Time commitment needed for each session varied by trial. Subjects were encouraged to continue training but not to compete during the duration of the study. Subjects were also discouraged from training on their specific testing day.

The maximal treadmill test (to volitional fatigue) was used to establish baseline VO_2 measures. The test was performed on a treadmill (Quinton model Q65, Bothell, WA, USA) where the speed began at 5.9km-h^{-1} (3 mph) at two degrees incline and increased every minute by 0.62 km-h^{-1} (1 mph) to a maximum of 18km-h^{-1} (11 mph). The speed then stayed constant and the incline was increased by one degree each minute until subjects could not run any longer.

The independent cycling trial (IC) was a cycle test performed on a cycle trainer (Minoura, Hyper-Mag, Gifu, Japan) with the subject's own cycle. The speed was self-selected by the subject as to represent race conditions and strive for their best time. The subjects rode for 40 km (24.8 miles); distance was recorded using a cyclocomputer (Cateye Cordless 7, Osaka, Japan). Running economy variables were collected breath-by-breath every minute during the first 10 km and during the final 10 km to allow the athletes to hydrate. The independent running trial (IR) was conducted on a treadmill. Subjects ran on a treadmill for 10 km (6.2 miles). The speed of the run was selected by the subject as to represent race condition and strive for their best time.

The cycle-run transition trial (TC and TR) consisted of 40km of cycling followed by 10km of running. This was a simulated cycle-run transition. Subjects rode for 40 kilometers exactly as for IC. After 40 km, subjects were given three minutes to dismount their bicycle, remove the breathing tube, change into their running shoes, hydrate, put the breathing tube back on and begin running on the treadmill. This is an approximation of the time of the cycle-run change during an official triathlon with extra time given in consideration for the breathing apparatus and allow for hydration. Subjects ran 10-kilometers exactly as for IR.

Gas Exchange Analysis

Data collection included gas exchange analysis using a breath by breath system, (Sensor Medics Vmax, Yorba Linda, CA, USA): tidal volume (V_t), minute ventilation (V_e), oxygen uptake (VO_2), carbon dioxide output (VCO_2), respiratory equivalent for oxygen (V_e/VO_2), respiratory equivalent for carbon dioxide (V_e/VCO_2), respiratory exchange ratio (RER), frequency of breathing (*f*) and heart rate (HR) every minute. Heart rate was measured using a Polar heart rate telemetry monitor (Polar target, Polar Electro. Oy, Finland). Subjects were asked every five minutes to rate their work effort using the Borg RPE (rate of perceived exertion) scale of 6 to 20. Location of data collection was the Exercise Physiology Laboratory at Western Michigan University.

Statistical Analysis

Running economy variables were analyzed by comparing V_t, V_e, VO_2, VCO_2, V_e/VO_2, V_e/VCO_2, RER, *f* and HR. Data from the first ten minutes of the independent trials and triathlon trials (IC, TC, IR and TR) were compared to the last ten minutes of IC versus TC, IR versus TR for analysis, a two-way analysis of variance (ANOVA) with repeated measures was used. Tukey's post-hoc test was performed to test where significance of effect occurs. Data comparisons between IC, TC, IR & TR were conducted using the statistical program for social sciences (SPSS) software package. Statistical significance was set at $P < 0.05$. All values are expressed as mean $\pm$ (σ). For this study, DiPrampero's formula for calculating the energy cost of running was used to compute RE: RE ($ml \cdot O_2 \cdot min^{-1} \cdot km^{-1}$) = VO_2 ($ml \cdot kg \cdot min^{-1}$)/ Speed ($km \cdot h^{-1}$) (Di Prampero, 1986).

RESULTS

Running Economy

The results from the independent (IR) and triathlon running (TR) trials showed a significant decrease ($P < 0.05$) between the first and last ten minutes in RE. These numbers were in agreement but lower than reported by Hausswirth et al (1996).

Figure 1 shows the change in RE between the first and last ten minutes of the independent run versus the triathlon run. For TR the first and last ten minutes were higher in comparison than in IR.

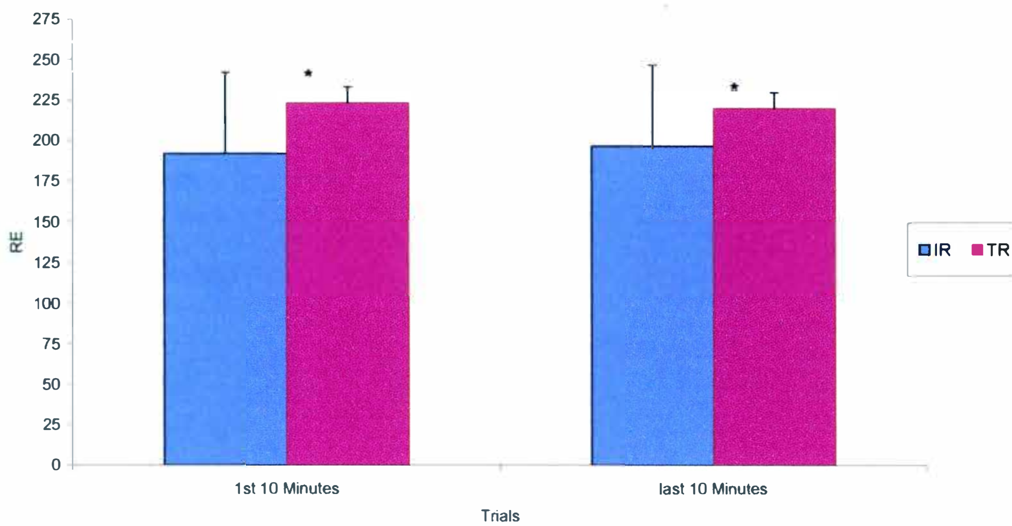

Figure 1. Running economy ($O_2 \cdot min^{-1} \cdot km^{-1}$) between the first and last ten minutes of trials IR and TR. * indicates significant increase from TR versus IR during the first and last ten minutes, ($P<0.05$).

Running Trials

Changes in running times (fig. 2) seen between IR and TR revealed a significant increase (P <0.01) in overall running time during TR and a significant decrease in overall speed (fig. 3) for TR.

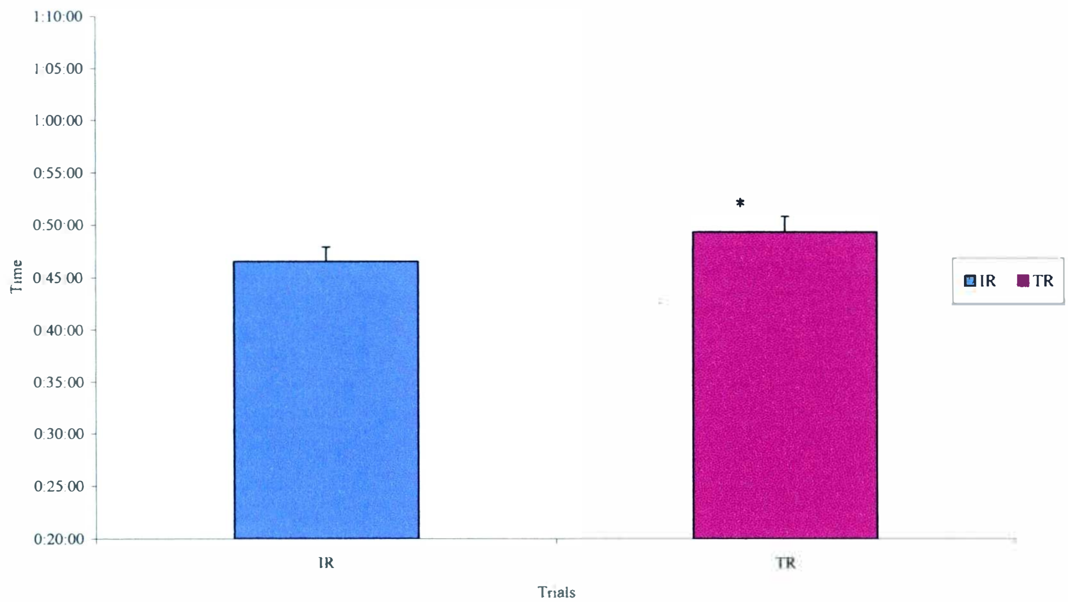

Figure 2. Mean running times between IR and TR. * indicates a significant increase in running time in TR versus IR, (P<0.01).

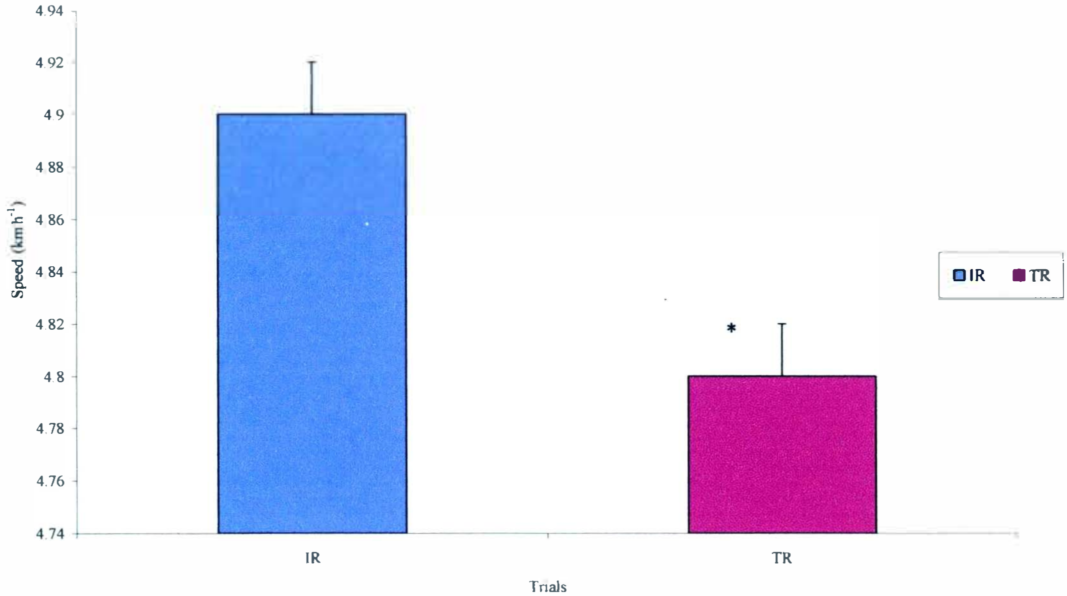

Figure 3. Mean running speeds between IR and TR. * indicates significant decrease in running speed in TR as compared to IR, (P<0.01).

Figure 4 shows VO_2 changes between running trials. A decrease was seen between TR compared to IR during the last ten minutes.

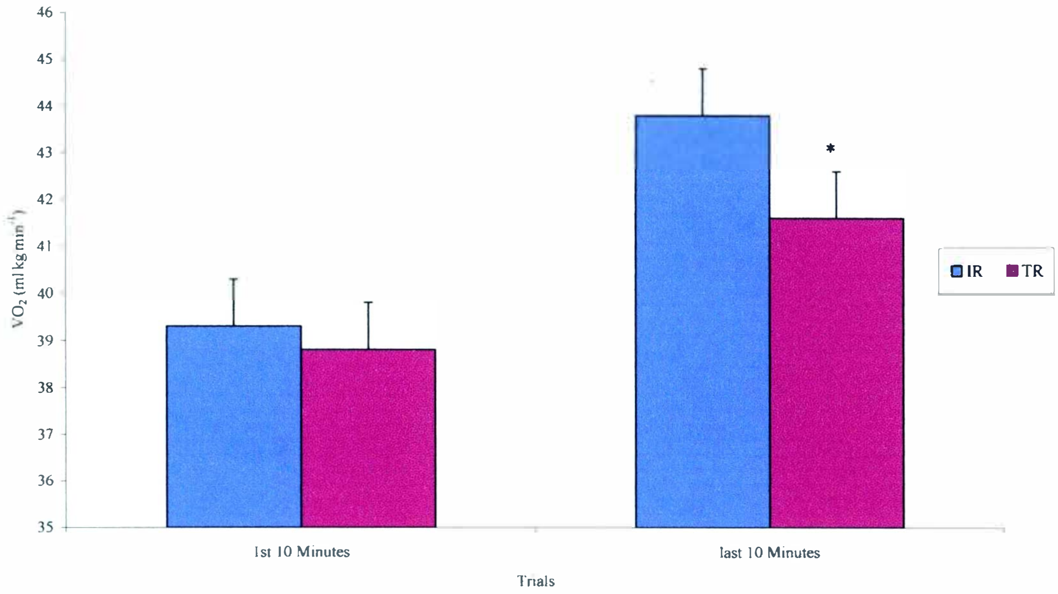

Figure 4. Oxygen consumption (ml· kg^{-1}· min^{-1}) between the first and last ten minutes of trials IR and TR. * indicates significant decrease seen in TR versus IR during the last ten minutes, ($P<0.05$).

Figure 5 represents the changes seen the respiratory equivalent for oxygen (V_e/VO_2) during the first and last ten minutes of IR and TR. V_e/VO_2 was higher in the first ten minutes of TR versus IR.

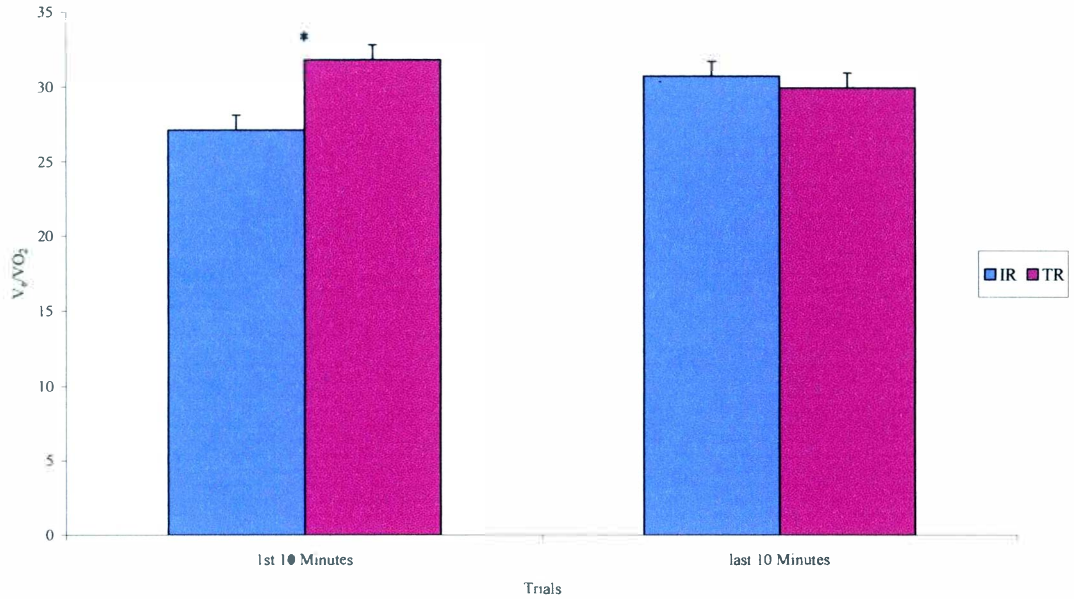

Figure 5. Respiratory equivalent for oxygen (V_e/VO_2) between the first and last ten minutes of trials IR and TR. * indicates significant increase during TR versus IR in the first ten minutes, ($P<0.05$).

Figure 6 illustrates the changes seen in the respiratory equivalent for carbon dioxide (V_e/VCO_2) during the first and last ten minutes of IR and TR. V_e/VCO_2 was greater during the first ten minutes of TR than in IR.

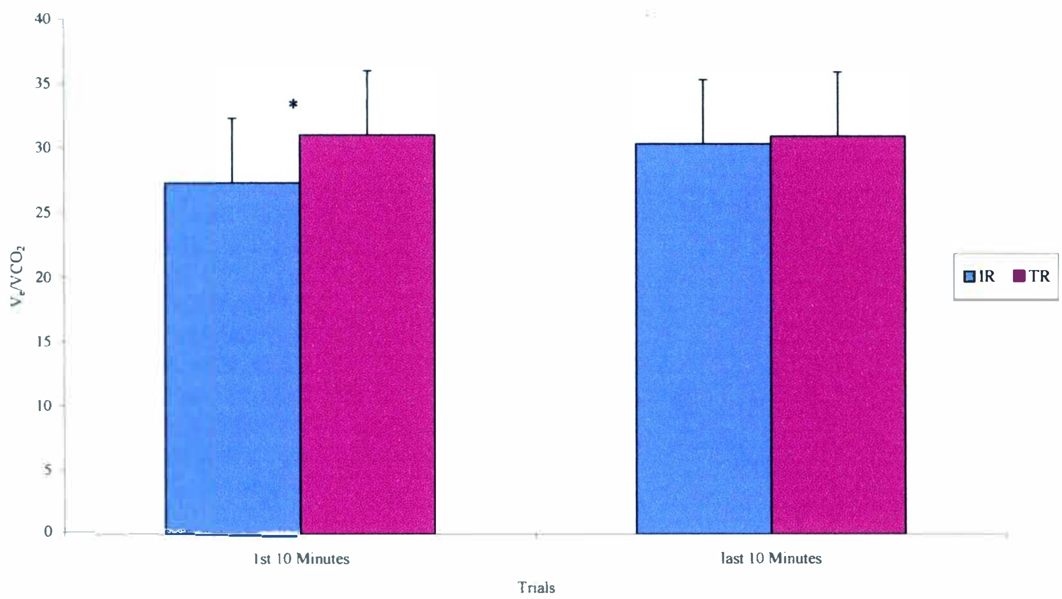

Figure 6. Respiratory equivalent for carbon dioxide (V_e/VCO_2) between the first and last ten minutes of trials IR and TR. * indicates significant increase seen during the first ten minutes of TR versus IR, ($P<0.05$).

Figures 7, 8 & 9 represent the changes seen in minute ventilation (V_e), tidal volume (V_t) and breathing frequency (*f*) between the first and last ten minutes of IR and TR. No significant changes were seen in V_e, while a decrease in V_t was witnessed in the first and last ten minutes of TR versus IR and an increase in *f* was recorded in the first ten minutes of TR.

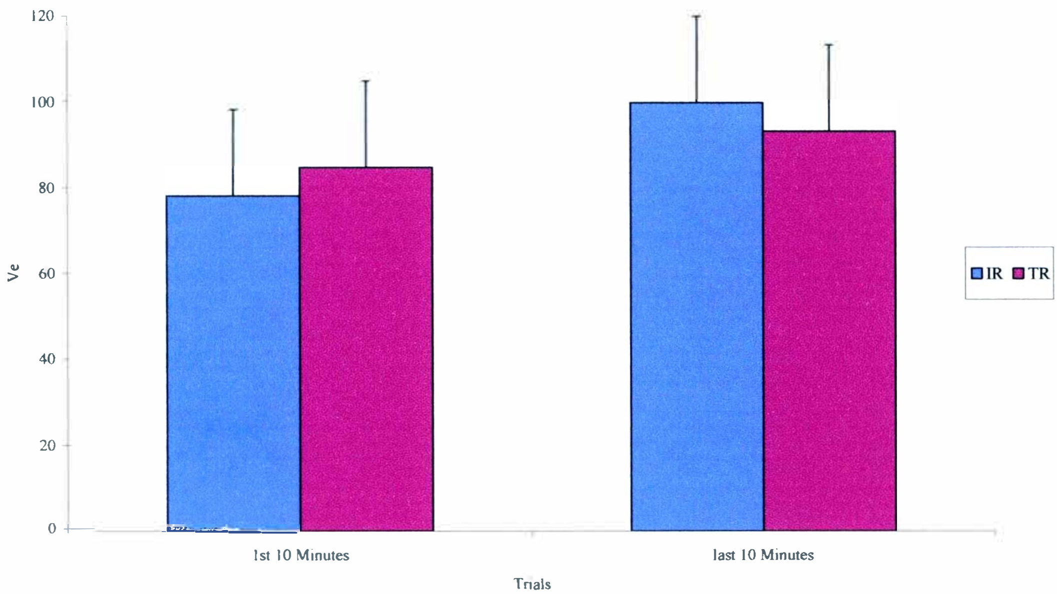

Figure 7. Minute ventilation ($l \cdot min^{-1}$) between the first and last ten minutes of trials IR and TR. no significant difference was found between TR and IR, (P<0.05).

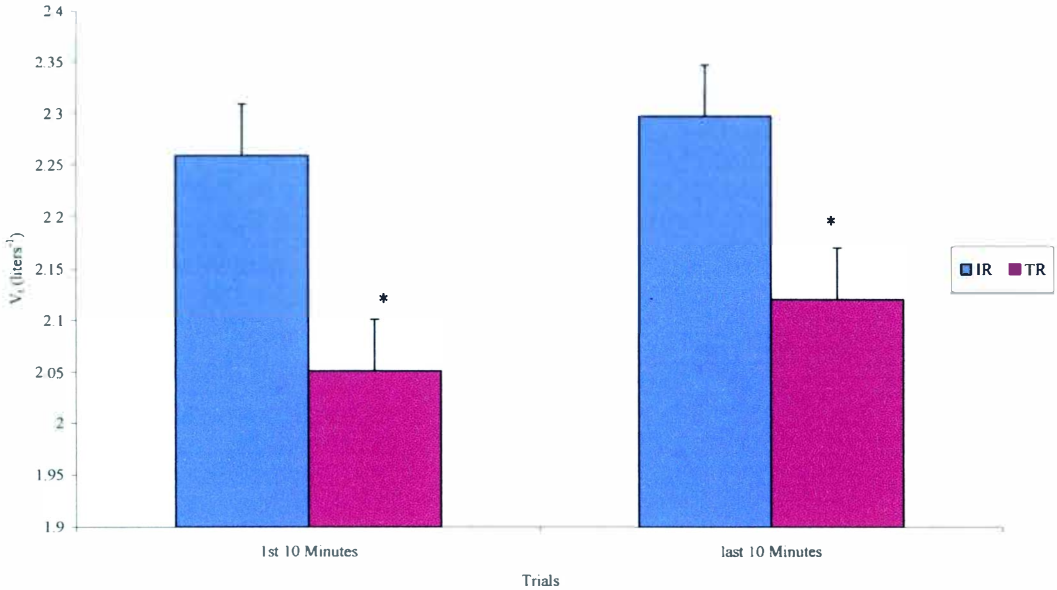

Figure 8. Tidal Volume (l) between the first and last ten minutes of trials IR and TR. * indicates the significant decreases seen during the first and last ten minutes of TR versus IR, (P<0.05).

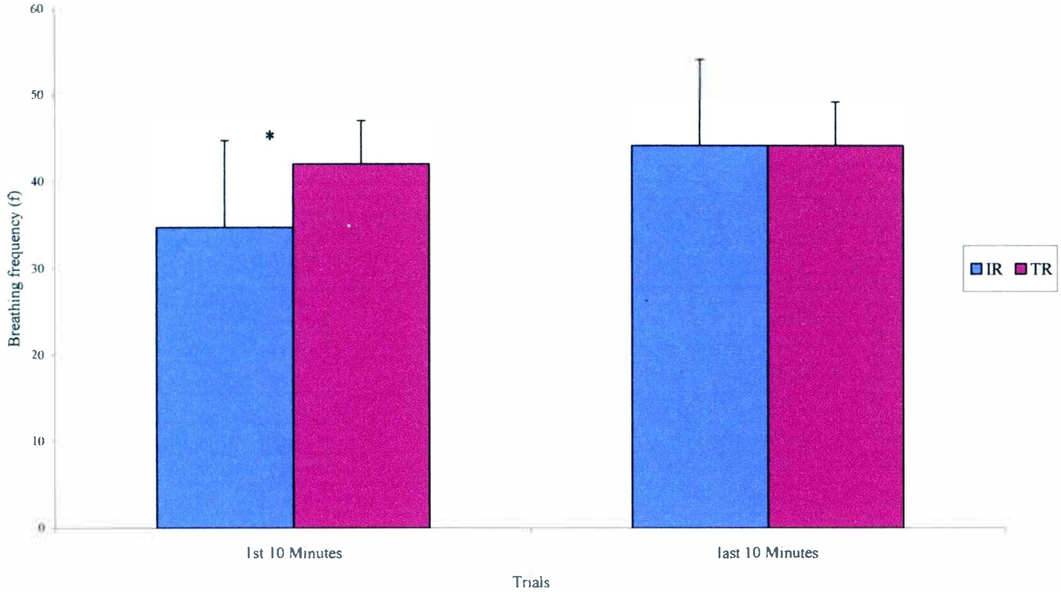

Figure 9. Breathing frequency (*f*) between the first and last ten minutes of trials IR and TR. * indicates significant increase in TR versus IR during the first ten minutes, (P<0.05).

Figure 10 explains the changes seen in heart rates (HR) between the first and last ten minutes of IR and TR. HR was lower during the last ten minutes of TR versus IR.

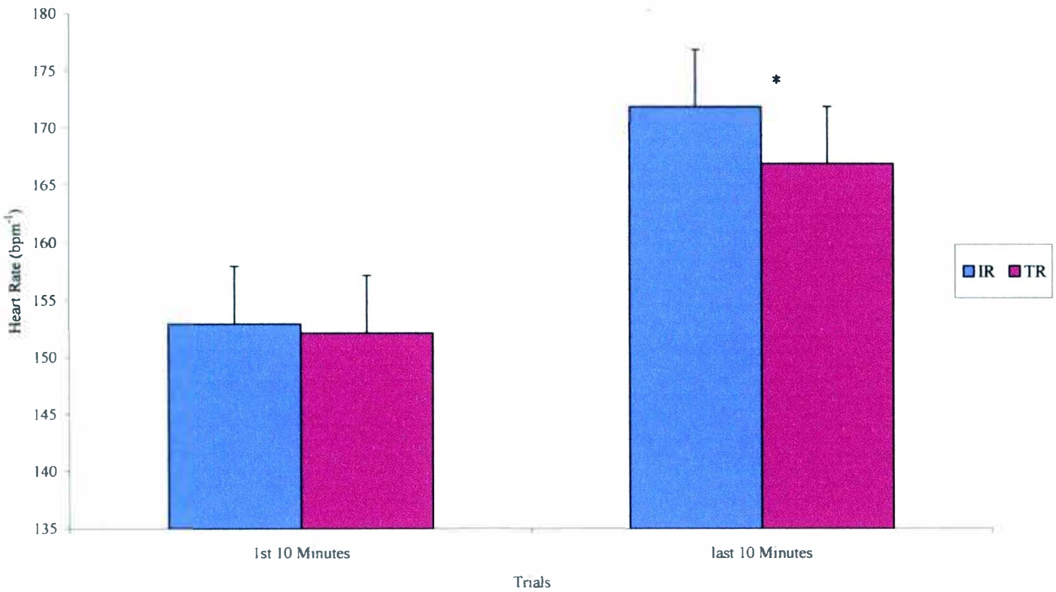

Figure 10. Heart rate (beats·min^{-1}) between the first and last ten minutes of trials IR and TR. * indicates the significant decrease witnessed during the last ten minutes of TR versus IR, (P<0.05).

Figure 11 shows no difference in respiratory exchange ratio (RER) between the first and last ten minutes of both IR and TR.

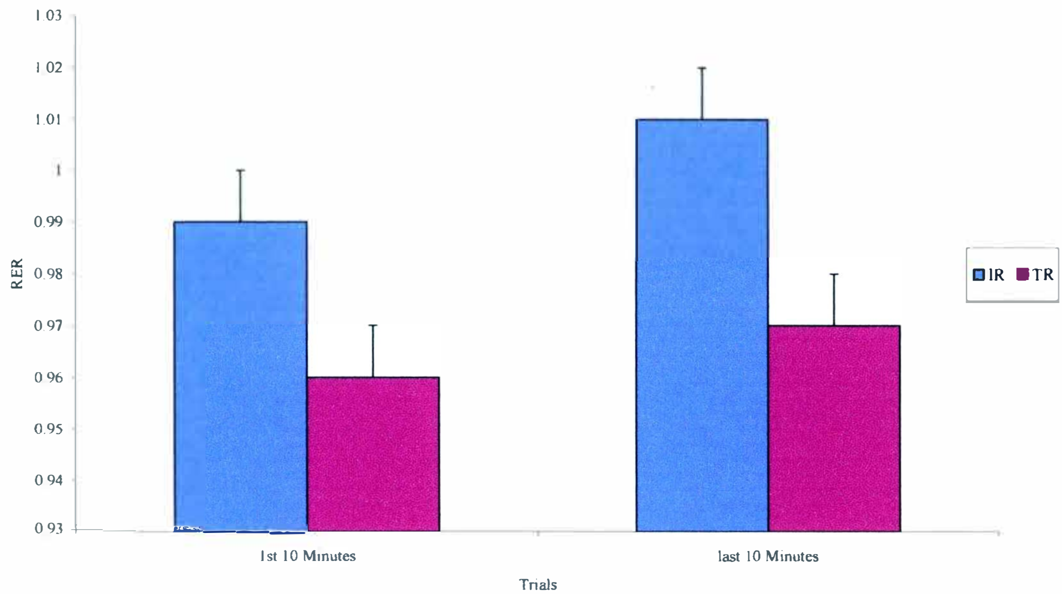

Figure 11. Respiratory exchange ratio (VCO_2/VO_2) between the first and last ten minutes of trials IR and TR. No significant difference was found between TR and IR, ($P<0.05$).

Cycling Trials

Figure 12 displays the cycling times of the independent cycling (IC) and triathlon cycling (TC) trials. Cycling time for TC was higher against IC.

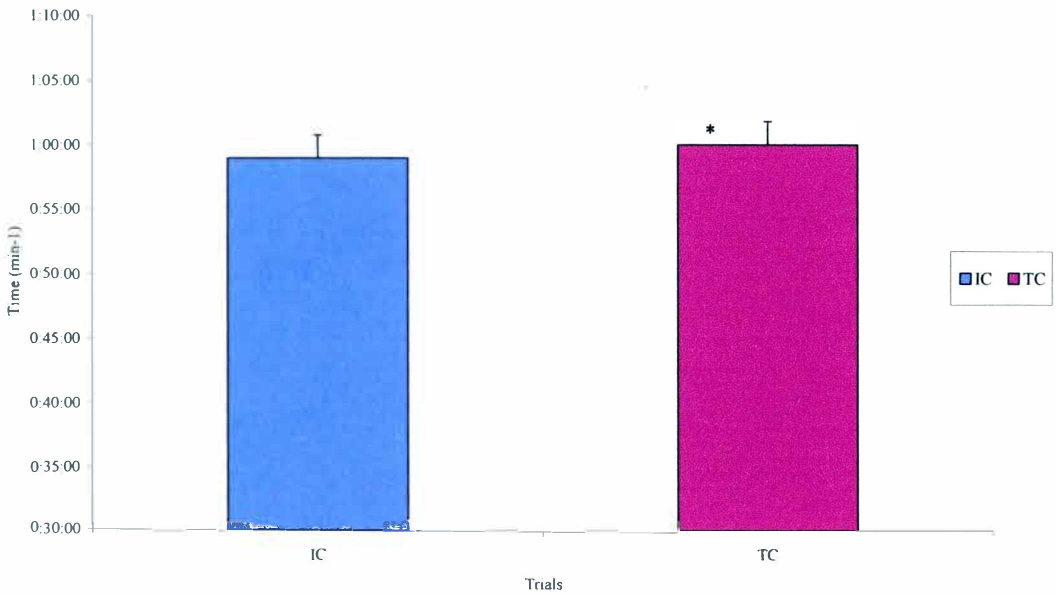

Figure 12. Mean cycling times between IC and TC. * indicates significant increase in cycling time in TC versus IC, (P<0.01).

Figure 13 shows the cycling speeds seen in the IC and TC trials. TC speeds were slower than seen during IC.

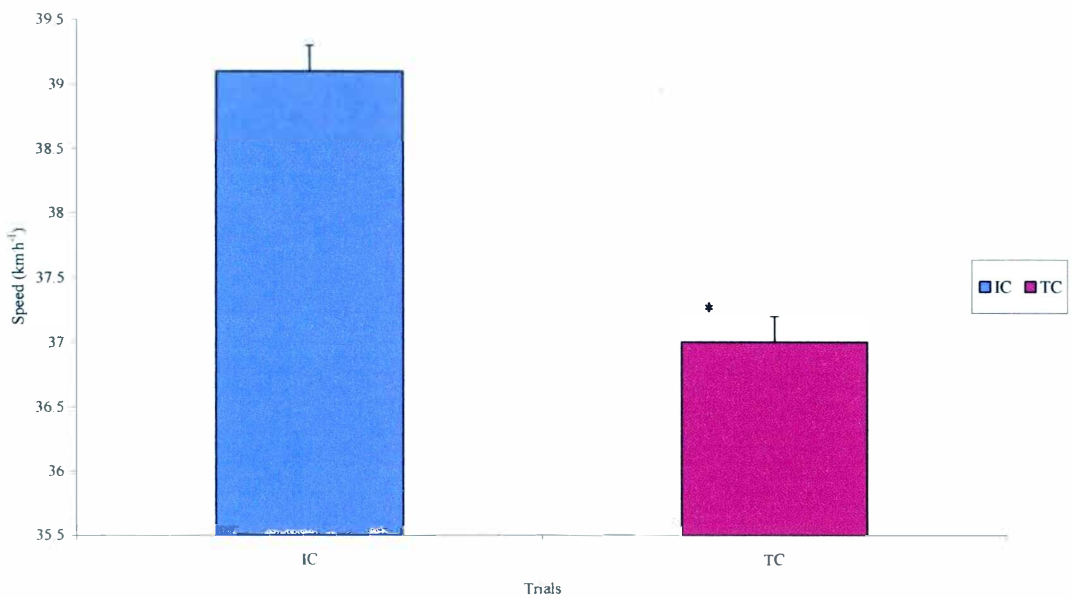

Figure 13. Mean cycling speeds ($k \cdot mh^{-1}$) between trials IC and TC. * indicates a significant decrease in cycling speed seen in TC versus IC, (P<0.01).

Figure 14 reveals the changes seen in oxygen consumption between the first and last ten minutes of IC and TC. An increase was seen in VO2 between both the first and last ten minutes of TC to IC.

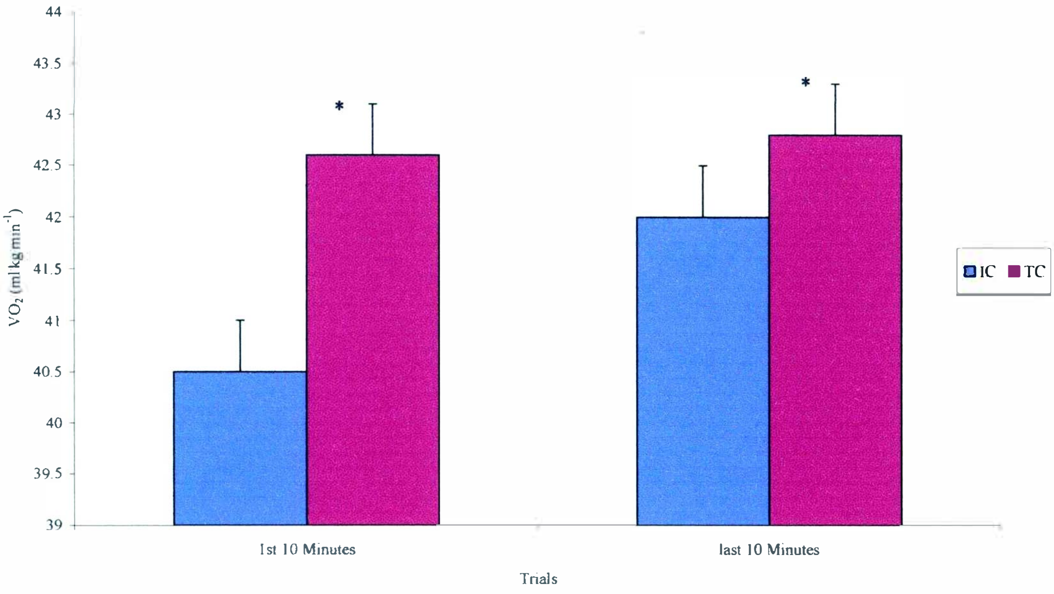

Figure 14. Oxygen consumption (VO_2 ml· kg^{-1}· min^{-1}) between the first and last ten minutes of trials IC and TC. * indicates the significant increase witnessed during the first and last ten minutes of TC versus IC during, (*P*<0.05).

Figure 15 exhibits the changes in respiratory equivalent for oxygen (V_e/VO_2) during the first and last ten minutes of IC and TC. An increase in V_e/VO_2 was observed in both the first and last ten minutes of TC over IC.

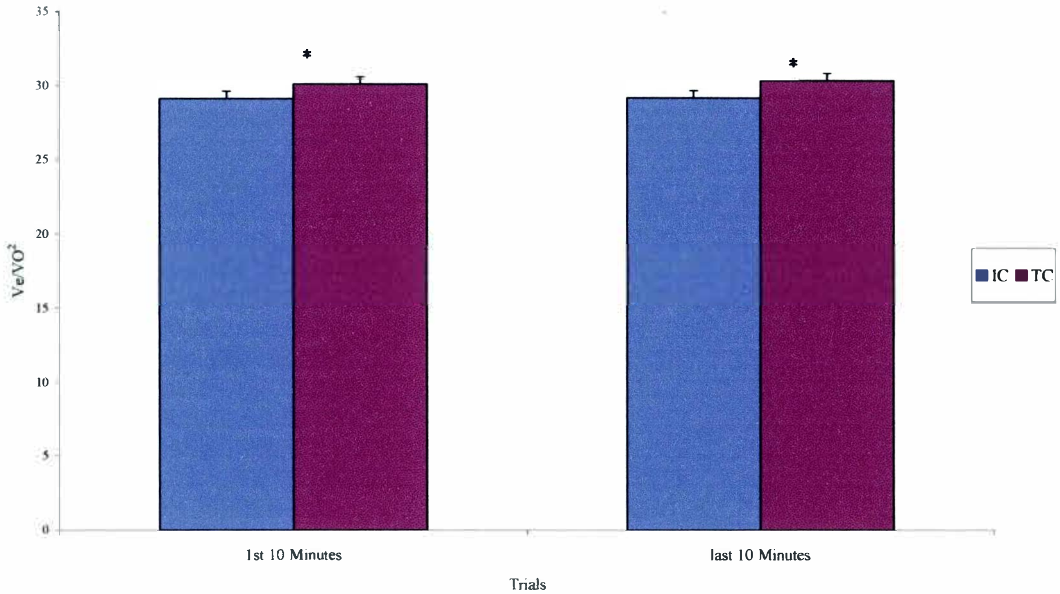

Figure 15. Respiratory equivalent for oxygen (V_e/VO_2) between the first and last ten minutes of trials IC and TC. * indicates a significant increase seen in both the first and last ten minutes during TC versus IC, ($P<0.05$).

Figure 16 shows the change in respiratory equivalent for carbon dioxide (V_e/VCO_2) during the first and last ten minutes of IC and TC. An increase in V_e/VCO_2 was witnessed in both the first and last ten minutes of TC over IC.

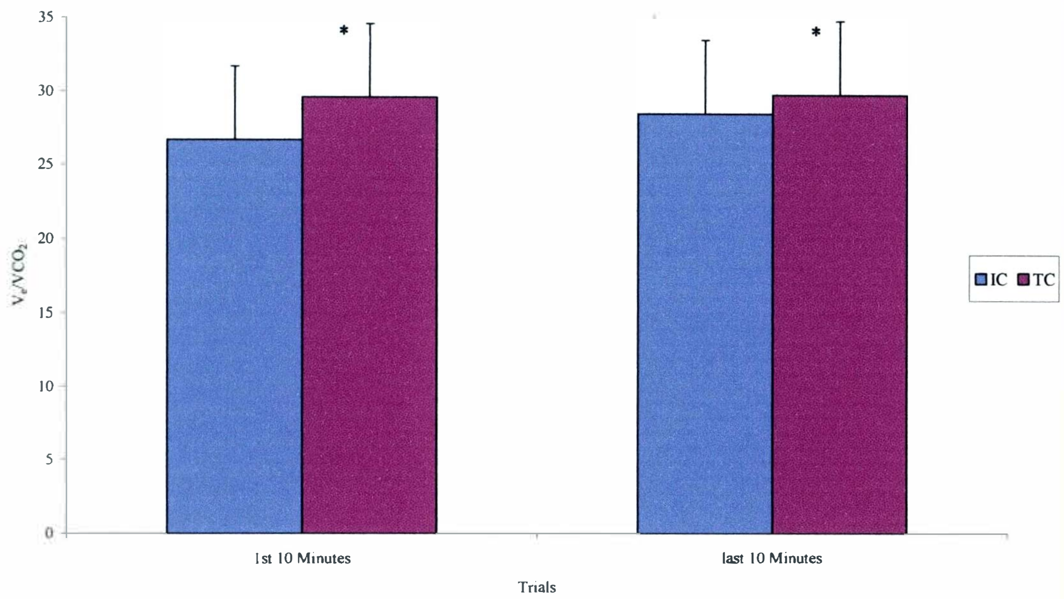

Figure 16. Respiratory equivalent for carbon dioxide (V_e/VCO_2) between the first and last ten minutes of trials IC and TC. * indicates a significant increase seen in both the first and last ten minutes during TC versus IC, ($P<0.05$).

Figure 17 displays minute ventilation (V_e) between the first and last ten minutes of IC and TC. An increase in V_e occurred during both the first and last ten minutes of TC opposed to IC.

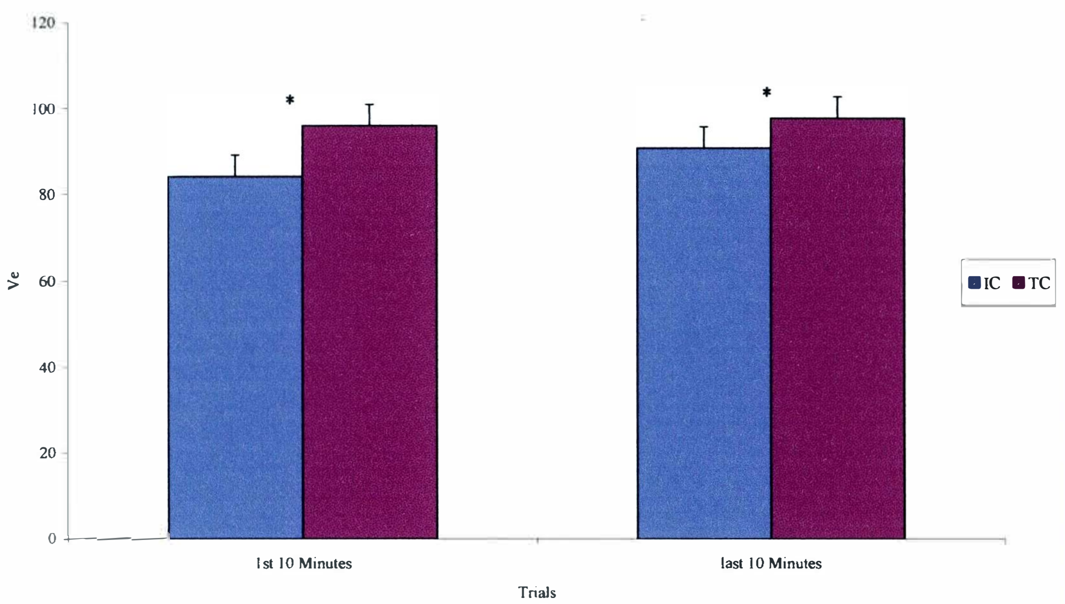

Figure 17. Minute ventilation ($l \cdot min^{-1}$) between the first and last ten minutes of trials IC and TC. * indicates a significant increase seen in both the first and last ten minutes during TC versus IC, (P<0.05).

Figure 18 presents tidal volume (V_t) values between the first and last ten minutes of IC and TC. A decrease was seen V_t in the first ten minutes of TC versus IC.

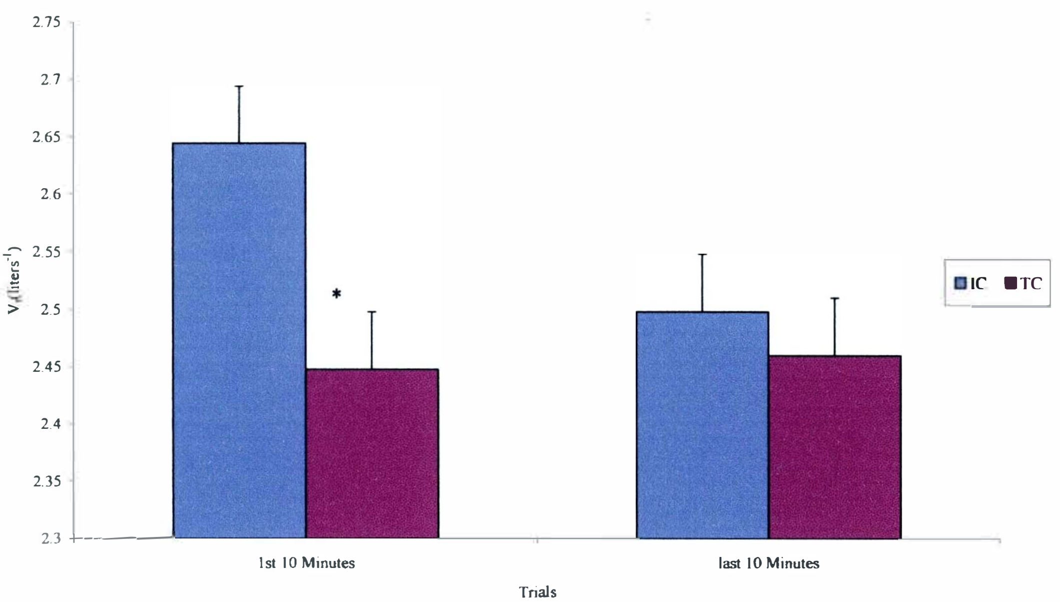

Figure 18. Tidal Volume (l) between the first and last ten minutes of trials IC and TC. * indicates the significant decrease witnessed during the first ten minutes of TC versus IC, (P<0.05).

Figure 19 shows the changes seen in breathing frequency between the first ten minutes of IC compared to TC. An increase in *f* occurred between both the first and last ten minutes of TC as compared to IC.

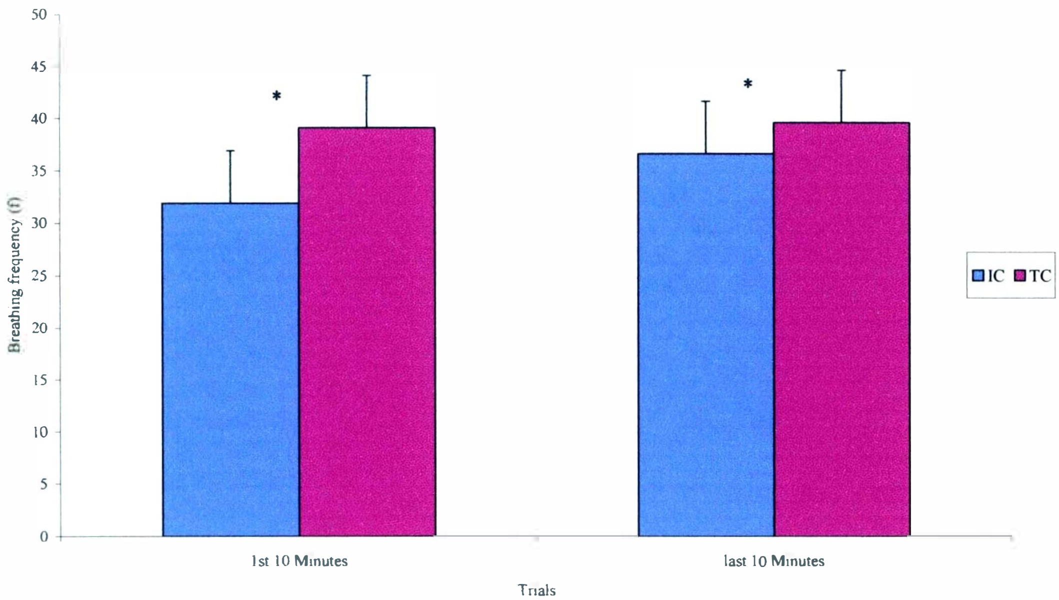

Figure 19. Breathing frequency (*f*) between the first and last ten minutes of trials IC and TC. * indicates a significant increase seen in both the first and last ten minutes during TC versus IC, (P<0.05).

Figure 20 reveals the changes seen in heart rate (HR) between the first and last ten minutes of IC and TC. An increase in HR was witnessed during the first ten minutes of TC as compared to IC.

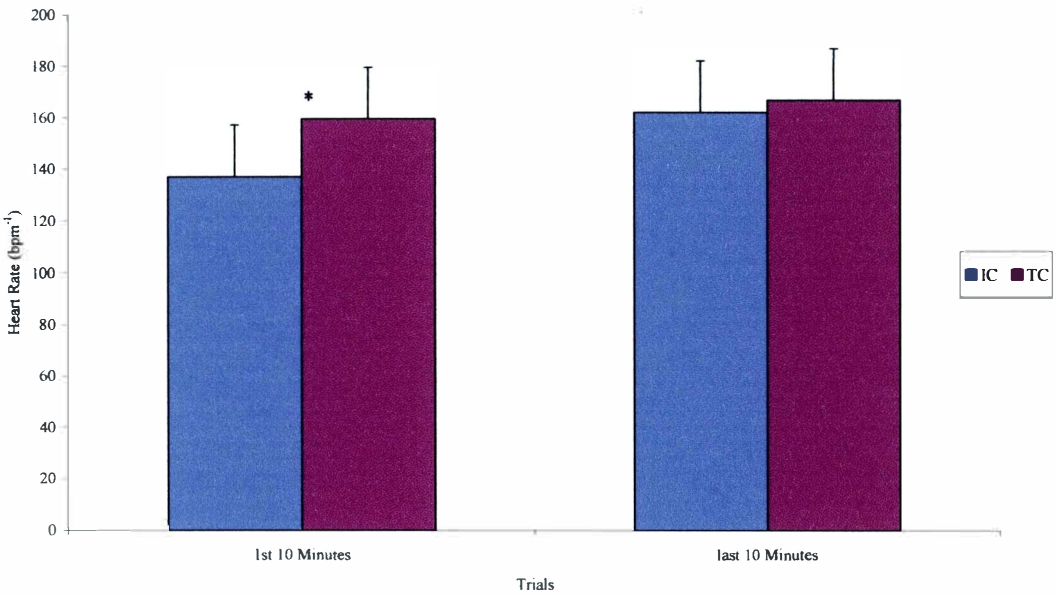

Figure 20. Heart rate (beats·min^{-1}) between the first and last ten minutes of trials IC and TC. * indicates a significant increase that was witnessed during the first ten minutes of TC versus IC, (P<0.05).

Figure 21 depicts the changes in the respiratory exchange ratio (RER) between the first and last ten minutes of IC and TC. A decrease in RER was seen the first ten minutes between IC as compared to TC.

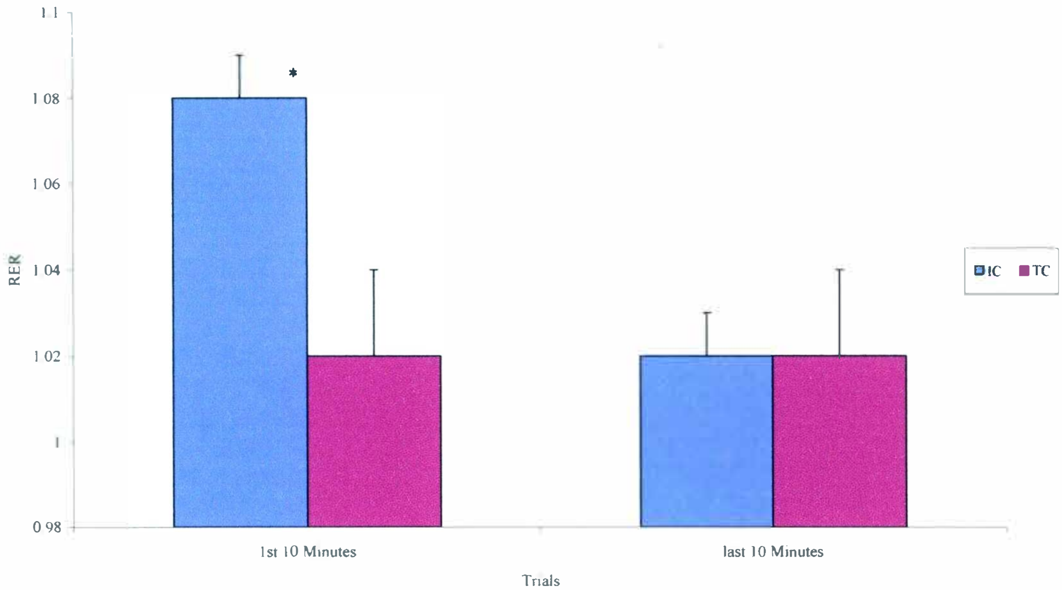

Figure 21. Respiratory exchange ratio (VCO_2/VO_2) between the first and last ten minutes of trials IC and TC. * indicates the significant decrease seen during the first ten minutes of TC versus IC, ($P<0.05$).

DISCUSSION

This study revealed a significant decrease in RE between the independent (IR) and triathlon running trials (TR). RE values for TR were 31.2 ml of $O_2 \cdot min^{-1} \cdot km^{-1}$ higher during the first ten minutes than in IR and 23 ml of $O_2 \cdot min^{-1} \cdot km^{-1}$ during the last ten minutes of IR. Hausswirth et al (1996) reported a change of 35 ml of $O_2 \cdot min^{-1} \cdot km^{-1}$ post cycling. The decrease in economy reveals the effect of prior activity on RE. Percentages of $VO_{2\,max}$ used during IR and TR were 71.4% and 71.0% respectively. These values were lower than reported by Hue et al (1997) 77.6%, 83.2% and Keider et al (1988) 73 and 78%. Mean RE, $V0_2$ and V_t between IR and TR were in agreement with prior research, (Hausswirth et al 1996 and Hue et al 1998).

Mean VO_2 showed a decrease from the first ten minutes of the independent run to the first ten minutes of the triathlon run (39.3 ± 5.6 ml$\cdot$ $kg^{-1} \cdot min^{-1}$ to 38.8 ± 5.2 ml$\cdot$ $kg^{-1} \cdot min^{-1}$). This decrease in VO_2 from the first ten minutes of the independent run to the first ten minutes of the triathlon run versus VO_2 mean is thought to be related to the cycling portion which caused a decrease in aerobic metabolism and hence a decrease in RE (DeVito et al 1995). This decrease could potentially prevent the best possible performance because triathlon training promotes adaptations which improve VO2 max instead of anaerobic capacity (Schneider et al 1990).

Mean VO_2 values collected during 40 km cycling, IR and TR correspond to 71.6%, 71.4% and 71.0% of $VO_{2\,max}$ respectively. Also Hue et al (1998) reported a decrease in submaximal VO_2 between treadmill running and cycling, (71.9% of $VO_{2\,max}$ run and 66.8% of $VO_{2\,max}$ cycle) that difference was witnessed as well (42.8 ± 0.9, 41.6 ±0.8 ml· kg^{-1}· min^{-1} for TC and TR respectively). This decrease may be related to the subject's ability to self-select their running pace and not a pre-selected speed, suggesting the athletes were saving themselves during the course of the triathlon since the subjects were in a 'base' training period.

It should be noted that the correlation between $VO_{2\,max}$ to performance is not as clear as in other single endurance sports. O'Toole (1987) reported a male triathlete finished the Ironman triathlon in Hawaii in less than 12 hours with a $VO_{2\,max}$ of 52.2 ml· kg^{-1}· min^{-1}. While $VO_{2\,max}$ values as high as 84.5 ml· kg^{-1}· min^{-1} for males and 80.0 ml· kg^{-1}· min^{-1} for females have been reported, (O'Toole, 1987), this shows other physiological factors are as important if not more so than $VO_{2\,max}$ in a multiple discipline event such as a triathlon.

Mean running times were 0:46:52 ± 0:07:59 (h:min:s) for IR and 0:49.17 ± 0:08:23 (h:min:s) for TR, mean running speeds were 4.87 ± 0.77 km·h^{-1} for IR and 4.81 ± 0.78 km·h^{-1} for TR. Mean cycling times were 0:58:56 ± 7:57:0 (h:min:s) for IC and 0:59:57 ± 6:50:1 (h:min:s). Mean cycling speeds were 39.1 ± 4.75 km·h^{-1} for IC and 37.0 ± 4.04 km·h^{-1} for TC. The difference between the triathlon running speeds and independent running speeds show the athlete's control of the running speed may have had an affect on the decrease of oxygen consumption (VO_2), heart rate (HR), minute ventilation (V_e), tidal volume (V_t) and breathing frequency (*f*). This may have been the strategy of the athletes to conserve energy to enable finishing the trial.

The minute ventilation (V_e) values showed no difference between both independent and triathlon running trials. The cycling trials revealed significant increases in both time periods for triathlon cycling over independent cycling. The higher values for V_e during the cycling trials over the running trials were not in agreement with previous research (Hue et al 1998, Keider et al 1998, Boussana et al 2003). Boussana et al (2003) theorized that the crouched position would provoke a decrease in respiratory muscle performance. Boussana et al found a significant decrease in inspiratory muscle performance and that the performance was not reversed by the subsequent run. The amount of decrease in V_e was not in agreement with Boussana et al and does not seem to indicate a decrease in respiratory muscular performance after cycling. This discrepancy may indicate the athlete's desire to run at a pace in order to finish the trials.

Ventilatory equivalent for oxygen (V_e/VO_2) is a measure of ventilation during steady state exercise. V_e/VO_2 will remain relatively unchanged during steady state exercise as it is a reflection of minute ventilation and breathing frequency. While there were no significant changes seen in V_e during the running trials, the increase seen in f during the first ten minutes of the triathlon run decreased RE. The increases in f and V_e/VO_2 witnessed between the first ten minutes of the triathlon run show the added demands of prior cycling on running economy as indicated by larger minute ventilation values and may indicate some respiratory muscle fatigue. Boutelier (1998) reported that increases in f and V_e are indirect signs of respiratory muscle fatigue caused by activation of pulmonary J receptors resulting in hyperventilation.

The decrease seen in mean heart rate (HR) values from the first ten minutes of the triathlon run as compared to the independent run may have been related to the slower running speed during the transition. The decrease seen in HR from the previous cycling trial reveals the affect of the transition suggests HR values returned to baseline. Hausswirth et al (1996) heart rate increased +6.8%, Hue et al (1998, 1999, 2001) heart rates increased +5.6%, +5.9% and +6.8% respectively and Millet et al (2000) heart rates increased +6.3 % after cycling. Hausswirth et al (1996) suggested that HR peaked faster as compared to an independent run because of the prior cycling which may have induced higher blood catecholamine release and decreased stroke volume (Wells et al 1987).

The respiratory equivalent for carbon dioxide (V_e/VCO_2) will remain relatively unchanged during steady state exercise. During an intense exercise, or a triathlon, V_e/VO_2 will increase and V_e/VCO_2 will not show a noticeable increase. This is related to the enhanced CO_2 production during cellular respiration and an increase in V_e. Significant increases seen in the last ten minutes of both cycling trials and in the triathlon run show the athletes were performing in their anaerobic threshold.

The changes witnessed in RE between IR and TR can be related to a number of physiological reasons. The first cause may be dehydration and thermoregulation as suggested by several studies (Guezennec et al., 1986, Douglas and Hiller, 1989, Hue et al., 1998). Although hydration levels were not measured, the increase witnessed in V_e from TC to TR and HR between IR and TR may be related to respiratory and cardiovascular drift, which is identified by dehydration and increased body temperature.

The second cause behind the change in RE could be substrate depletion. Muscle glycogen depletion has been cited (Armstrong et al 1977) during a triathlon causing a shift in energy substrate usage from carbohydrate to fat oxidation. As seen in Hue, the lack of change in RER in this study does not support this.

A third contributor may be the performance level of the subjects. VO_2 changes witness between IR and TR were not in agreement with current research (10.3% increase in the first ten minutes, 6.8% increase during the last ten minutes), which revealed $VO_{2\,max}$ changes of 13% as reported by O'Toole and Douglas (1989) in amateur triathletes. The changes witness here are closer in agreement to those found be Hue et al (1989) of 6-7% increase in VO_2. These changes may be related to the stage of training of the athletes during the time of the study. The athletes in this study were in a 'base' training program at the time of the research. The subjects were not in competitive training and this may have contributed to the percentage increases seen here.

In conclusion, the changes seen in RE from prior cycling, including increases in *f*, V_e/VO_2 and V_e/VCO_2 are in agreement with previous research (Hue et al 1998, Boussana et al 2003, Hue et al 2001, Hue et al 1999). Triathletes should gradually increase running pace after the cycle-run transition to lessen the effects of prior cycling. Training for triathlons should stress transitions, swim-cycle and cycle-run, in order to condition the triathlete to the complexities of these transitions and to improve their abilities to perform at or below their anaerobic threshold. More research is needed to determine the best training modalities for these athletes. Long term studies focusing on the changes and adaptations to these training methods are needed to verify these methods.

APPENDIX A

HSIRB APPROVAL

WESTERN MICHIGAN UNIVERSITY

Human Subjects Institutional Review Board

Centennial
1903-2003 Celebration

Date: October 15, 2004

To: Timothy Michael, Principal Investigator
Mark Ricard, Co-Principal Investigator
James Swanson, Student Investigator for thesis

From: Amy Naugle, Ph.D., Interim Chair

Re: HSIRB Project Number: 04-08-01

This letter will serve as confirmation that your research project entitled "Effects of the Cycle-Run Transition on Running Economy of Triathletes" has been **approved** under the **full** category of review by the Human Subjects Institutional Review Board. The conditions and duration of this approval are specified in the Policies of Western Michigan University. You may now begin to implement the research as described in the application.

Please note that you may **only** conduct this research exactly in the form it was approved. You must seek specific board approval for any changes in this project. You must also seek reapproval if the project extends beyond the termination date noted below. In addition if there are any unanticipated adverse reactions or unanticipated events associated with the conduct of this research, you should immediately suspend the project and contact the Chair of the HSIRB for consultation.

The Board wishes you success in the pursuit of your research goals.

Approval Termination: September 15, 2005

Walwood Hall, Kalamazoo, MI 49008-5456
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APPENDIX B

REVIEW OF LITERATURE

History of the Triathlon

The triathlon was developed by Jack Johnstone and Don Shanahan and sponsored by the San Diego Track Club in 1973. The event consisted of 6 miles of running, 5 miles of cycling, and 500 yards of swimming. The first competition was on September 25, 1974 in Mission Bay San Diego, California and had 46 competitors. The event grew and four years later the Ironman triathlon began and has become the premier event for triathletes. The modern triathlon has evolved into a variety of distances (table 1) and debuted as an

Table 2. Distances of popular triathlon races. All distances in kilometers.

Distances (km)	*Swim*	*Bike*	*Run*
Ironman	3.8	180	42
Olympic	1.5	40	10
Sprint	0.75	20	5

Olympic sport at the Sydney 2000 Olympic games. Hilliard (1988) stated there are over 2,000,000 triathletes competing yearly worldwide testifying to the sports popularity.

The following review of related literature is a brief history of the research of running economy and the cycle to run transition of a triathlon. Similar studies on running economy and triathlons will be reviewed as well. The review concludes with a brief analysis of the cost of energy expenditure.

Review of Running Economy

Running economy (RE) is defined as the aerobic demand needed at a given running speed, and is considered a determinant of distance running performance. The variables that comprise RE are: breathing frequency, the number of breaths per minute (*f*), minute ventilation, the volume of air breathed per minute (V_e), oxygen uptake or consumption, the volume of oxygen consumed (VO_2), carbon dioxide output, volume of carbon dioxide produced (VCO_2), respiratory equivalent for oxygen, ratio of air breathed per minute to oxygen consumed (V_e/VO_2), respiratory equivalent for carbon dioxide, ratio of air breathed per minute to carbon dioxide produced (V_e/VCO_2) and respiratory exchange ratio, the ratio of carbon dioxide produced to oxygen consumed (RER).

Hausswirth and Lehenaff (2001) state to be a valid measure of RE, calculation of RE relies upon measurements obtained in stable submaximal metabolic conditions, where VO_2 is truly representative of energy expenditure per unit of time. The classical method of calculating RE was developed by Di Prampero (1986) with the following equation: $Cr\ (RE) = (VO2\text{-}VO2\ rest) \cdot Speed^{-1}$, And is expressed in ml O_2/kg/m, speed in m/sec and VO_2 in ml O_2/kg/min.

Morgan, Martin, Krahenbuhl (1989) attempted to define the measurement running economy. The contribution of energy expenditure of both aerobic and anaerobic metabolism to the overall energy cost of running has been questioned. Using Brooks and Fahey's (1984) claim of postexercise oxygen consumption being an inadequate measure of energy metabolism during intense exercise, Morgan states that the estimation of anaerobic contribution during highly intensive exercise is unsubstantiated at best and is based upon knowledge of the amount of ATP, creatine phosphate, muscle glycogen, lactate, intracellular water and the amount of muscle mass used in the exercise (Astrand & Rodahl 1986). Substantiating the running economy can be achieved by measuring the steady state VO_2 for a standardized running speed to compute indirect calorimetry. This conclusion is based upon two hypotheses; 1) the ATP requirement derives completely from cellular respiration and not from phosphagen catabolism or anaerobic deterioration of carbohydrate and 2) the insignificance of protein and amino acid contribution to energy necessities (Brooks and Fahey 1984). Margarita et al (1963) supports this idea during submaximal exercise. The aerobic demand of running at high intensities may be underestimated because of the contribution of anaerobic metabolism adding a portion of useful energy to the active muscles (Bransford & Howley 1977). Also of note, is that protein catabolism increases during prolonged intense exercise in glycogen-depleted individuals (Lemon & Mullin 1980; White & Brooks 1981). Morgan believes that given the short duration of submaximal running tests (between 6 to 10 minutes) that these questions would not cause an error of any significance.

Pate, Nacera, Bailey, Bartoli, Rowell, 1992 have shown that individual variances in RE are related to physiological and biomechanical factors. Increases in oxygen cost during extensive exercise may be related to metabolic, circulatory, ventilatory and thermoregulatory adaptations. Gradual increases seen in heart rates during extensive running at constant speed are a sign of circulatory adaptations. Heart rate increases to maintain cardiac output and oxygen supply to working muscles (Davies & Thompson 1986).

The most prominent theory behind the changes seen in running economy is thermoregulation and dehydration. During exercise, thermoregulation initiates sweat production, which can lead to unintentional dehydration. The dehydration from the increase body temperature indirectly increases heart rate and breathing frequency. Weight loss witnessed at triathlons signifies a dehydrated state and may require emergency medical attention. Therefore maintaining an adequate level of hydration during a race is an essential determinant of success in a triathlon.

Morgan et al (1989) suggests that fatigue caused by long duration running may adversely impact the aerobic demand of running. Existing research studying the metabolic and biomechanical costs of extensive high intensity runs has yielded ambiguous results. Cavanaugh et al (1985) is one example of research that shows worsened economy in elite runners with a few days of competition, while Martin et al (1987) saw no change in economy in non-elite runners one day after an intense training run.

Dressendorfer (1991) found a significant reduction in VO_2 max after running a half marathon at intensities equal to 74% of VO_2 max. Xu & Montgomery (1995) reported decreases in running economy, less than reported by Dressendorfer, after 90 minutes of running at intensities of 65% and 80% of VO_2 max. Dressendorfer perform the running trials on a treadmill in a climate control environment, while Xu performed two running trials on an outdoor 400m track. These differences in conditions can explain these discrepancies.

Review of the cycle-run transition.

The running segment of the triathlon elicits feelings and complications not encountered during an isolated run. Triathletes contended with many physiological responses during and after a triathlon. Thermoregulation and dehydration are the most prominent factors affecting triathletes (Van Resberg et al 1986). During the triathlon, thermoregulation requires the production of sweat which may be hampered by the athlete's level of hydration. This could lead to dehydration and a drift in body temperature (Nadel et al 1980; Nielsen 1984) and an increase in heart rate (Sawka 1984).

Endurance activities generates lower haematocrit levels and is usually caused by an increase in plasma volume (Convertino 1991). Performance in triathlons appears to be contradictory related the haematocrit after each segment and rest (Nagao et al 1991). The decrease of blood viscosity assists capillary circulation (Selby and Eichner 1994) and oxygen transport to active muscle.

The triathlon can elicit a severe state of dehydration that at times requires medical attention (Van Resberg et al 1986). This amount of bodyweight loss constitutes that the athlete's are hypohydrated and haemodilute during the competition (O'Toole and Douglas 1995). This is often related to the inability of the athlete to maintain adequate hydration levels and/or by the specific environmental conditions.

Maintaining a normal body temperature relating to adequate hydration levels is seen as an important determining factor of triathlon success (Keider et al 1995).

Boone and Kreider (1986) were among the first to study the change in RE after cycling. Their study examined the change in RE from running for 5 minutes at 9.6 km after cycling for 3 minutes at 80% of maximal heart rate as compared to a run of equal duration using physically active subjects and no triathletes. Boone and Keider found that RE increased during the transition run.

Hausswirth, Bigard, Berthelot, Thomaidis & Guezennec (1996) found running economy decreased after a triathlon and 2 hours and 15 minutes of running of the same duration. Their study found significantly greater values for heart rate, pulmonary ventilation and weight loss. This study was performed overground and not in laboratory.

Millet et al (2000) found a difference in RE between elite and mid-level triathletes. Millet also found that the RE for respiratory muscle significantly increased more for mid-level triathletes as compared to elite level triathletes.

Hausswirth et al (1999) studied the effects of cycling alone or drafting on a subsequent running. This is important because of the legalization of drafting in some triathlon competitions can affect the outcome of a race. Hausswirth found that ventilation, VO2, and heart rate were significantly lower when drafting as compared to cycling alone and that running post-cycling significantly improved running speed when drafting. USA Triathlon (USAT) defines a drafting zone as a rectangular area seven (7) meters long and two (2) meters wide surrounding each bicycle. The longer sides of the zone begin at the leading edge of the front wheel and run backward parallel to the bicycle; the front wheel divides the short side of the zone into two equal parts. It is without question that drafting is a definite advantage to any triathlete.

The transition from cycling to running during a triathlon places multiple physiological demands upon the cardiovascular system that has been shown to increase oxygen cost, minute ventilation, breathing frequency and heart rate during the transition (Hue et al. 1998). Performing the events consecutively intensifies the demands placed upon the athlete. The most common factors are changes in thermoregulation and dehydration; substrate usage; lower ventilatory efficiency and/or exercise induced hypoxaemia; and the level of performance of the athletes.

Boussana et al, found that moderately intense exercise (75% $VO_{2\,max}$), not performed to exhaustion, induces a decrease in respiratory muscle performance. Respiratory muscle fatigue was found to occur during prior cycling in a simulated transition. The level of fatigue was neither reversed nor deteriorated by the successive run. V_e, V_e/VO_2, V_e/VCO_2, f and heart rate were shown to be significantly increased after prior cycling. It is thought that the body position of cycling, crouched position, may be more constraining than running for respiratory muscle performance.

The transition from cycling to running is characterized by increased ventilatory responses that can differ between athletes (Hue, Le Gallais and Prefaut 2000). The athletes that have little hyperventilation perform better than those who have greater hyperventilation. Hue (1999) showed that the transition itself was the most prominent cause of the increased ventilatory response.

Future research should focus on the transition from both a competitive and training view point. Training studies should focus on which methods provide the best chances for competitive success. The focus should be on whether training one discipline at a time or a multiple transitions has the greatest affect on finishing position. This can enable athletes to center their training on the best available methods.

Long-term studies are needed to track physiological changes to training and which methods of training better enable success in competition. Studies on racing strategies (drafting, post-transition running pace) are needed to help athletes prepare for competition.

Gender differences in physiological and biomechanical affects of triathlon and transitions are needed as well. Few studies exist showing the differences between male and female triathletes.

BIBLIOGRAPHY

Hilliard, D. C. (1988) Finisher, competitors, and pros: a description and speculative interpretation of the triathlon scene. *Play Culture*, 1, 300-313.

Morgan, D. W., Martin, P. E., Krahenbuhl, G, S. (1989). Factors affecting running economy. *Sports Medicine*, 7, 310-330.

Pate, R. R., Nacera, C. A., Bailey, S. P., Bartoli, W. P., Rowell, K. E. (1992). Physiological, anthropomertic, and training correlates of running economy. *Medicine and Science in Sports Medicine*, 24, 1128-1133.

Dressendorfer, R. H. (1991). Acute Reduction in maximal oxygen uptake after long-distance running. *International Journal of Sports Medicine*, 12, 30-33.

Xu, F., Montgomery, D. L. (1995) Effect of prolonged exercise at 65% and 80% of VO_2max on running economy. *International Journal of Sports Medicine*, 16, 309-315.

Hausswirth, C., Bigard, A. X., Berthelot, M., Thomaidis, M., Guezennec, C. Y. (1996) Variability in energy cost of running at the end of a triathlon and a marathon. *International Journal of Sports Medicine*, 17, 572-579.

Margaritis, I. (1996) Factors limiting the performance of a triathlon. *Canadian Journal of Applied Physiology*, 21, 1-15.

Hue, O., Le Gallies, D., Chollet, D. (1998) The influence of prior cycling on biomechanical and cardiorespiratory response profiles during running in triathletes. *European Journal of Applied Physiology*, 77, 98-105.

Di Prampero, P. E. (1986) The energy cost of human locomotion on land and in water. *International Journal of Sports Medicine*, 7, 55-72.

O'Toole, M. L., Hiller, W.D.B., Crosby, L.O., Douglas, P.S. (1987) The Ultraendurance triathlete: a physiological profile. *Medicine and Science in Sports Medicine*, 19, 45-50.

Hue, O., Le Gallais, D., Boussana, A., Chollet, D., & Prefaut, C. (1999) Ventilatory responses during experimental cycle-run transition in triathletes. *Medicine and Science in Sports and Exercise*, 31 (10), 1422-1428.

Hausswirth, C., Lehenaff, D., Dreano, P., & Savonen, K. (1998) Effects of cycling alone or in a sheltered position on subsequent running performance during a triathlon. *Medicine and Science in Sports and Exercise*, 31 (4), 599-604.

Schneider, D. A., LaCroix, K. A., Atkinson, G. R., Troped, P. J., & Pollack, J. (1989) *Medicine and Science in Sports and Exercise*, 22 (2), 257-264.

Hue, O., Le Gallais, D., Prefaut, C. (2001) Specific pulmonary responses during the cycle-run succession in triathletes. *Scandinavian Journal of Medicine and Science in Sports*, 11, 355-361.

O'Toole, M. L., Douglas, P.S. (1995) Applied physiology of triathlon. *Sports Medicine*, 19 (4), 251-267.

Millet, G.P., Millet, G.Y., Hofmann, M.D., & Candau, R.B. (1999) Alterations in running economy and mechanics after maximal cycling in triathletes: influence of performance level. *International Journal of Sports Medicine*, 21, 127-132.

Boussana, A., Galy, O., Hue, O., Matecki, S., Varray, A., Ramonatxo, M., & Le Gallais, D. (2003) The effects of prior cycling and a successive run on respiratory muscle performance in triathletes. *International Journal of Sports Medicine*, 24, 63-70.

Farber, H.W., Schaefer, E.J., Franey, R., Grimaldi, R., & Hill, N.S. (1991) The endurance triathlon: metabolic changes after each event and during recovery. *Medicine and Science in Sports and Exercise*, 23 (8), 959-965.

Millet, G.P., Vleck, V.E. (2000) Physiological and biomechanical adaptations to the cycle to run transition in Olympic triathlon: review and practical recommendations for training. *British Journal of Sports Medicine*, 34, 384-390.

Hausswirth, C. Lehenaff, D. (2001) Physiological demands of running during long distance runs and triathlons. *Sports Medicine*, 31 (9), 679-689.

Morgan, D.W., Martin, P.E., Baldini, F.D., & Krahenbuhl, G.S. (1990) Effects of a prolonged maximal run on running economy and running mechanics. *Medicine and Science in Sports and Exercise*, 22 (6), 834-840.

Roalstad, M.S. (1989) Physiological testing of the ultraendurance triathlete. *Medicine and Science in Sports and Exercise*, 21 (5), S200-S204.

Brisswalter, J., LeGros, P., & Durand, M. (1996) Running economy, preferred step length correlated to body dimensions in elite middle distance runners. *The Journal of Sports Medicine and Physical Fitness*, 36, 7-15.

Bassett, Jr, D., R., & Howley, E.T. (2000) Limiting factors for maximum oxygen uptake and determinants of endurance performance. *Medicine and Science in Sports and Exercise*, 32 (1), 70-84.

Kreider, R.B., Cundiff, D.E., Hammett, J.B., Cortes, C. W., & Williams, K.W. (1988) Effects of cycling on running performance in triathletes. *Annals of Sports Medicine*, 3 (4), 220-225.

Convertino, V.A. (1991) Blood volume: its adaptations to endurance training. *Medicine and Science in Sports and Exercise*, 23 1338-1348.

Boone, T., Kreider, R.B. (1986) Bicycle exercise before running: effect on performace. *Annals of Sports Medicine*, 3, 25-29.

Van Resburg, J.P., Kielbock, A.J., & Vanderlinde, A. (1986) Physiological and biochemical changes during a triathlon competition. *International Jounral of Sports Medicine*, 7, 30-35.

Nadel, E.R., Fortney, S.M., Wenger, C.B. (1980) Effect of hydration state on circulatory and thermal regulations. *Journal of Applied Physiology*, 49, 430-437.

Nielsen, B. (1984) The effect of dehydration on circulation and temperature regulation during exercise. *Journal of Thermal Biology*, 9, 107-112.

Sawka, M.N., Francesconi, R.P., Young, A.J. (1992) Influence of hydration level and body fluids on exercise performance in the heat. *Journal of the American Medical Association*, 252, 1165-1169.

Selby, G.B., Eichner, E.R. (1994) Hematocrit and performance: the effect of endurance training on blood volume. *Semin Hematol*, 31, 201-205.

Nagao, N., Imai, Y., Arie, J. (1991) Energy intake profile in the triathlon competition by means of cluster analysis. *Journal of Sports Medicine and Physical Fitness*, 32, 201-205.

DeVito, G., Bernadi, M., Sproviero, E., Figura. F. (1995) Decrease of endurance during olympic triathlon. *International Journal of Sports Medicine*, 16, 24-28.