IMPACT OF THREE DIFFERENT CYCLING RACING STRATEGIES DURING A SHORT-COURSE TRIATHLON

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By

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ABSTRACT

Race strategies appear to be an important issue to maximize performance in any athletic event. Little is known about the effectiveness of racing strategies in triathlon competition. Therefore, the purpose of this study is to investigate the effect of three different cycling strategies on the total combined performance of cycling and running portions of a short-course triathlon. Eight trained triathltes (7 males, 1 female, age= 32.6 ± 3.9 yrs) performed a preliminary set of tests: a peak oxigen consumption (VO_2) test on a motorized treadmill, a 750m maximum exercise intensity swim test and a 40km Time Trial (TT). Each triathlete also randomly performed 3 different protocols simulating triathlon competitions, where the intensity during the cycling course was manipulated based on the avergage workload obtained during the 40km TT. The pace for the first race strategy (PO-100) was the same power output averaged by each triathlete during the 40km TT, the second trial (PO-95) was 5% slower pace than the first one, and the third race strategy (PO-90) pace was 10% slower than the first one. The swimming portion of each trial was held constant at a pace 5% slower than their 750m maximun swim test time. The running portion was performed at maximum voluntary speed. Total time to complete the cycling plus running portion as well as blood lactate concentrations (La), VO_2 and heart rate (HR) were measured. The time to complete the combined bike and run portions of the experimental trials was significantly ($p < 0.05$) lower for PO-100 (3368 ± 283 sec) when compared to both PO-95

(3416 ± 311 sec) and PO-90 (3483 ± 340 sec). In addition La (4.0 ± 1.1 vs. 4.8 ± 1.0 and 5.5 ± 1.5 mM respectively) and VO_2 (44.8 ± 5.8 vs. 49.8 ± 6.2 and 47.9 ± 6.6 ml/kg/min^{-1}) were also significanlty different between trials. This data demonstrates that in order to maximize performance during a short-course triathlon, the bike portion should be performed at an exercise intensity the same as that elicited during a 40km TT.

Dedicated to Mary M. Yost and my loving family

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CHAPTER 1

INTRODUCTION

The triathlon involves the interaction of three aerobic disciplines swimming, cycling, and running, and requires that these events be completed in sequence. Millet [16] refers to a triathlon as "one sport, three disciplines and two transitions". Among several overall triathlon distances, short-course triathlons are the most popular and preferred by athletes. A short-course triathlon consists of 750 meters swimming, 20km of cycling, and 5km running. Location and measurement of distance vary from race to race, as a result organizers may modify the standard distance, increasing/reducing one or more portions. Regardless, the sequence of a triathlon is the same: swim, cycle, and run in succession. Although there are transition periods between each event, these are of short duration and typically represent less than 2% of total finish time. Short course triathlons have an average duration of 60–90 minutes. The proportion of time spent in each discipline is approximately: 13% swimming, 50% cycling, 35% running, and 2% transitions.

Studies have analyzed the physiological effects of training and competing in triathlons, [10, 17, 18, 21, 22] providing useful information that has helped coaches and athletes to improve athletic performance. However, physiological parameters represent just one of several factors that help to explain the complexity of performance during a triathlon. Billet et al.[16] suggested that more research is required on the effects of varying conditions (i.e. distance, terrain and weather) during the cycling portion of a triathlon in relation to the physiological stress of the subsequent run. Hausswirth et al.[8] demonstrated that during a short distance triathlon, under drafting conditions, running at a steady state is less difficult than performed after cycling under non-drafting conditions. Smith[23] obtained preliminary power output data in the field for elite athletes during a draft-legal World Cup event; he reported that athletes perform the bike portion of a triathlon at variable power outputs (rather than steady state). Ramsay et al. [19] demonstrated that varying the exercise intensity during 1 hour of cycling, has no effect on subsequent 10km running time. Although there weren't significant differences between the two levels of independent variable (variable pace and steady state pace), results may not predict the same outcome during a triathlon race, because the swimming segment was not implemented. Nevertheless, these data[19, 23] support the hypothesis that the conditions under which the cycling portion of a triathlon is performed may affect running and overall performance during a triathlon.

One might question why most studies tend to focus on cycling intensity as a race strategy alternative, and swimming and running strategies seem to be less important. There are multiple conditions that may help to explain this emphasis. The swimming event is performed in open water conditions. Thus, race conditions vary according to water temperature, direction of currents, characteristics of the start line, and the outline of the course. Each of these conditions is well known to influence performance and is highly variable during a race. Besides the present ecological conditions involved with swimming, athletes do not have means to monitor exercise intensity in efforts to pace themselves. Due to these ecological and technical characteristics, investigators find it difficult to manipulate the swimming portion of a triathlon to simulate race conditions. Concerning the running event, exercise intensity and run time are easy to assess. However, running represents the last portion of a race and is significantly influenced by the other two events. Consequently, the cycling portion of a triathlon has typically been utilized to examine race conditions. Cycling involves less complex ecological conditions and exercise intensity can be easily assessed employing heart rate monitors, odometers, speedometers, and devices that measure power. Cycling is the discipline that requires the most time to be completed; performance in this event may have the most significant impact on overall performance. These arguments support the idea that cycling intensity during a triathlon is accessible and practical to manipulate in order to maximize performance. However, little is known about the effects of cycling intensity on the subsequent running time and on the overall triathlon performance. Therefore, the purpose of this study is to investigate the effect of three different cycling strategies on the total combined performance of cycling and running during a short-course triathlon. We hypothesize that significant differences exist in the combined cycling and run total accumulated times, during a short course triathlon, when the cycle portion is performed at a power output relating to maximum lactate steady state (MLSS) as compared to performance at power output below MLSS. The rationale for this hypothesis is based on evidence that demonstrates during aerobic events ranging from 60-90 minutes, exertion at a relatively high intensity is sustainable. Harnish et al.[7] reported that cyclists could maintain intensities associated with MLSS during a 40km TT. Zhou et al.[24] reported similar racing intensities, where athletes compete near their ventilatory threshold during a 1km swim, 30km cycle and 8km run. Based on this evidence, one may speculate that a short-course triathlon could be performed at an exercise intensity correlating to MLSS exercise intensity.

The results of this investigation should help triathletes and coaches plan a short-course triathlon racing strategy based on cycling intensity. In addition, this research will provide useful information regarding the implementation of a 40km time trial (TT) as a field test, to determine the ideal cycling pace for maximizing performance during a short course triathlon. Finally, new insights regarding the physiological and metabolic responses during a short course triathlon will contribute to understanding the complexity of triathlon racing.

CHAPTER 2

LITERATURE REVIEW

2.1 Controlled Studies of pace strategies

Ever since our ancestors were fleeing from their predators, the idea of appropriate pacing has been vital. Thousands of years ago, in order to survive the earth's adverse environment, our ancestor's day-to-day objective was to conserve energy. Although today's conditions have changed from ancient adverse environments of predators and long periods of starvation to crowded stadiums and competition fields, pacing represents a key factor in endurance athletic events. The attempt to conserve energy is essential to maximize performance.

Despite the obvious importance of pacing and pacing errors on athletic performance, there has been little systematic study of how various pacing strategies may influence the outcome of competitive results.[6] Most of the literature in this area has been focused on short duration events, and few studies have addressed the experimental manipulation of pacing strategies during long distance events. This is surprising considering the multitude of scientific research performed on other aspects: including the characteristics of athletes, physiological responses to training, dietary interventions, biomechanics, and even equipment manipulation. In modern Olympic games and World

Championships, the differences between gold medallists and non-medal winners are significantly small, usually less than 1 percent of the total time of the event. Therefore, information concerning the best method to expend limited energy resources is of considerable value.

Robinson et al.[20] performed the first systematic study examining the effects of pace variations on performance (1958). They had 3 well trained men run the same distance (individually different distances averaging about 1200m) with 3 different pace patterns: fast start (107% of even pace per minute 1); even start; and slow start (97% of even pace for minute 1). They found higher oxygen uptake (VO_2) requirements (including post exercise VO_2), higher post exercise blood lactate levels, and greater subjective effort with the fast start strategy. The authors concluded that the best way to run a middle distance event was to delay the heaviest effort until as late in the run as possible.

In running competitions, acceleration during the terminal stages of prolonged events is common. For example, the combined relative velocities (as percentage of peak velocity) of the men's and women's 1500m champions in the 1988 Olympic Games were 90%, 89.5%, 92% and 100% for the first three 400m laps and last 300m, respectively. In July of 1993, Y. Ondieki of Kenya became the first man to run 10km in less than 27 minutes. The paces during the first 3000m, from 3000m-5000m, from 5000m-9600m, and during the last 400m were 95%(6.23m/sec), 93.7 (6.14m/sec), 93.8 (6.15m/sec), and 100% (6.56m/sec), respectively. Although these were not controlled experimental competitions, these data suggest a behavior of long distance runners to raise their running pace in the later stages of a race.

There are two common pacing strategy models that have been tested by scientists for endurance events: constant and variable power output. Atkinson et al.[1] examined the effects of one self-selected and two imposed pacing strategies (constant and variable output) on cycling performance during a time trial, in which variable wind conditions were simulated. Seven male cyclists rode their own bikes on a Computrainer cycle ergomenter, which was programmed to simulate a 16.1 km time trial (TT) on a flat course with a 8.05 km/h head wind in the first half of the race and a 8.05 km/h tailwind in the subsequent half. Subjects rode an initial time trial (ITT) at a self-selected pace to the best of their ability. The mean power output from this trial was then used to calculate the pacing strategies in the subsequent two trials: constant (C) riders rode the TT at a mean power output; and variable (V) riders rode the first section at a power output 5% higher than their mean and subsequently reduced the power output in the last 8.05km to equal mean power output in the ITT. Mean finish times in the C and V TT were not significantly different, but they were significantly faster than the ITT even though overall mean power outputs were similar (234-235W). The present results confirm that the fastest times and lowest physiological and subjective responses to exercise were observed with the pacing strategy that varied power output with the simulated wind conditions. The sensitivity of heart rate and rate of perceived exertion (RPE) to detect small (+-5%) changes in power output within a race is low. Therefore, their usefulness for monitoring pacing strategies during races can be questioned.

Ramsay et al[19] performed a study examining two experimental pacing strategies. Trials consisted of 1 hour of cycling at either constant power (CP) performed at 95% of mean TT power, or at a variable intensity (VI) involving periods of work at either +-20%

(20VI) or +-40% (40IV) of CP. Upon completion of the cycle section, and following a 3 minute transition period, subjects performed a self-selected pace 10km run on a motorized treadmill. No differences were found within the 3 trials, although lactate levels were significantly elevated at the 40%IV trial compared to the 20%IV and CP trials at all given measured time points. The authors concluded that varying the intensity of exercise (up to 40% of mean power output of a maximal 40km TT) within 60 minutes of cycling has no effect on subsequent 10km run time.

2.2 Physiological and technical aspects of triathlon

Triathlon competitions are performed over markedly different distances and under a variety of technical constraints. In standard distance triathlons (1.5km swim, 40km cycle, and 10km run) a World Cup series and a World Championship race exists for elite competitors. In contrast, age-group (categories progress in 5 year increments) tri-athletes may compete at a World Championship level, but not against elite competitors. The elite triathlon population is relatively small compared with the age-group population; the ratio is approximately 1 elite triathlete for every 15 age-group tri-athletes. An alternative distance, 750m swim, 20km cycle, and 5km run has become the most popular type of triathlon race in the World. The difference between elite and age-group races is that during the cycle stage elite competitors may 'draft' or cycle in a sheltered position, age-group athletes complete the cycle stage as an individual time trial. Within triathlons there are multiple aspects that create different physiological demands from the individual sports of swimming, cycling and running. As well, the physiological demands of the cycle stage in elite races may differ compared with the age-group competitors. Although non-drafting conditions are more frequent than drafting conditions. Considering these factors performance may be influenced during the cycle stage and subsequent run.

Several investigators[17, 21, 22, 24] have indicated that the main requisites for successful triathlon performance are high maximal oxygen uptake (VO_2MAX), lactate threshold, and maximal sustainable percentage of VO_2MAX, as well as a low energy cost of exercise for each discipline. Elske et al.[4] reported that cycling peak power output is highly correlated with the cycle portion of an Olympic distance triathlon, and race times for top triathletes competing Olympic distance triathlons can be accurately predicted from the results of maximal and submaximal laboratory measures. The following equation has been suggested to predict actual race time from laboratory data: race time (s) = -129 (peak treadmill velocity in km/h) + 122 (lactate at 4 W x kg BM) + 9456. The relationship between these variables measured separately in each discipline is not as prominent as seen in the respective single sports vs. triathlon performance. Prior exercise affects the strength of correlation between physiological variables specific to one discipline and performance under conditions characteristic of triathlon competition[16]. Linking the three disciplines of triathlon in an optimal manner is a determinant for success.

As explained previously, the VO_2 MAX has been used as an important parameter to predict triathlon performance. When VO_2 MAX tests are performed on non-triathlon populations in endurance disciplines of: swimming, cycling and running, the values obtained are typically significantly higher during running vs. cycling, and cycling vs. swimming. This trend is also observed when comparing ventilatory thresholds and maximum heart rates. In contrast, when triathletes are tested for VO_2 MAX and ventilatory threshold, the values obtained for cycling and running are not significantly different, but values obtained for swimming are typically lower[10, 22].

Margaritis[15] stated, "the physiological conditions in which the first transition is made can limit performance in the two following events"; this is also the case for the second transition. Within non-drafting races, the first transition is regarded as having a negligible effect on overall performance. However, there are few studies performed on the swim to cycle transition during simulated races [2, 14]. According to Hue [9], the second transition, cycle to run, is traditionally considered more important in overall short-course performance.

The duration of a short-course triathlon typically ranges from 55 to 75 minutes, depending on the characteristics of the event. Zhou[24] indicated that trained tri-athletes could maintain an exercise intensity close to their ventilatory threshold level during a 1km swim, 30km cycle, and 8km run triathlon race. In addition, Sleivert[22] reported ventilatory threshold values of trained tri-athletes close to 80-85% of their VO_2MAX. Harnish et al.[7] tested the hypothesis of linking a 1 hour maximum test (a 40km TT) to estimate the maximum lactate steady state (MLSS), and concluded the average power output elicited during this test is associated with MLSS, and therefore suggests that the highest intensity at which blood lactate concentration remains stable could be maintained for events of 1 hour in duration. Based on this evidence, it appears that the intensity that could be maintained during short-course triathlon is close to that of the MLSS. However, there are no studies to our knowledge that have tested this hypothesis.

CHAPTER 3

METHODOLOGY

3.1 Subjects

The Institutional Review Board for Human Subjects of The Ohio State University has approved all the proceedings and methods that will be used in the present study.

The investigators met with each potential subject and they were informed of the risks and benefits associated with the study. The subjects signed a consent document that explained the proceedings, risks and benefits of the present research, and completed a Physical Activity Readiness Questionnaire (PAR-Q), and a Comprehensive Fitness Testing Questionnaire (CFTQ) as part of the criteria to participate in this study. Pregnant Women were not allowed to participate, and they were asked about this condition in the medical questionnaire.

Eight competitive triathletes met the following criteria in order to participate in this research:

- Training experience in triathlon of at least 3 years
- 10 hours or more of weekly training including the 3 disciplines
- A peak oxygen consumption (VO_2) higher than 50ml/kg/min^{-1} for males, or 41ml/kg/min^{-1} for females

- 25-40 years of age
- Free of cardiopulmonary abnormalities

3.2 Descriptive measurements

For descriptive purposes, height, weight, and body fat were measured. Body fat was estimated using skin fold measurements, according to the methods of Jackson and Pollack [11]. The skinfolds used for body fat estimation were: major pectoral , abdominal, quadriceps for males. Triceps, supra-iliac, and quadriceps were used for females

Subjects performed five tests described below, in succession over a period of 4 weeks. Firstly, an incremental peak VO_2 test on a motorized treadmill and a maximal exercise intensity 750-meter swim test completed the same day, including a resting interval of 20 minutes. Secondly, three days subsequent to the previous tests, a 40km cycling TT. Finally, three different indoor triathlons were performed in the following three weeks, one week apart, in a randomized order.

Subjects were asked to maintain a constant training schedule during the four weeks of the study, and they also were asked to keep a constant training volume and intensity during this four-week period. Subjects were to avoid any kind of high intensity exercise (defined as one that in which a conversation with a partner cannot be maintained) 24 hours before each testing procedure. To ensure this, the subjects recorded training information utilizing a training log provided and reviewed by the investigators. The training log (Appendix A) was designed to assess the volume and intensity of weekly training sessions, using time and distance as parameters to measure volume of training, and heart rate or perceived exertion as parameters to measure exercise intensity.

3.3 Experimental procedures

3.3.1 Peak $V0_2$ test

The incremental test (Appendix A) was performed on a motor driven treadmill. Before testing, the subjects performed a warm up for 3 minutes at 6 miles/hour and 0% grade. The subjects then performed a graded exercise testing protocol designed by Costill [3], where each stage has a duration of 2 minutes, velocity remains constant at 9 miles/hour, and the incline increases 2% every stage after the second stage. The two criteria used to establish that a peak VO_2 was obtained included a respiratory exchange ratio (RER) greater than 1.1 and a peak heart rate (HR) near the predicted maximum HR according to the Karvonen formula of 220-age. VO_2 and HR were measured using a metabolic cart (Med Graphics Inc, Campaign, Illinois) and a heart rate monitor (Polar Instruments Inc., Oulu, Finland), respectively. Peak VO_2 was determined by averaging the highest volume of oxygen consumed for 60 seconds recorded during the test.

3.3.2 Swim test

Each tri-athlete performed a maximum exercise intensity 750m swim test, 20 minutes after termination of the VO_2 peak test. The test was performed in a 50m indoor pool. At the end of the test, the total finish time was recorded

3.3.3 Time trial (TT):

A maximum exercise intensity 40km TT (Appendix A) was performed by each subject using their own racing bicycles. An electronic resistance device was attached to the rear wheel to provide measurable, changeable resistance (Computrainer^{tm} Racer Mate

8000, Seattle WA). The accuracy of this resistance device has been previously confirmed (Cane, 1996). Average time, speed, heart rate (HR), and workloads were recorded during this test. Blood samples were also collected in 25 υl capillary tubes every 10km and immediately analyzed for lactate concentration using a portable lactate analyzer (Yellow Springs Inc., 1500 Sport Lactate Analyzer, Yellow Springs, OH). The analyzer was calibrated prior to each test according to manufacture recommendations. Oxygen consumption was collected breath by breath for 3-minute intervals at kilometer 16 and 32, and the values were averaged.

3.3.4 Triathlon Trials

All subjects performed three triathlons (PO-100, PO-95, PO-90) during the following 3 weeks. An example of a data sheet for the experimental trials can be found in Appendix A. Subjects were randomly assigned to three groups, and each group performed the three levels of the independent variable. Group A performed the triathlon trials in the following order: First, trial PO-100, one week after, trial PO-95, and two weeks after, trial PO-90. Group B order was: First, trial PO-95, then trial PO-90, and finally trial PO-100. Group C order was: First, trial PO-90, then trial PO-100, and finally trial PO-95. To manipulate the exercise intensity during the cycling portion, three different cycling strategies were designed using as a reference the average power output obtained during the 40km TT. The three cycling strategies to be explained in detail will follow. Exercise intensity during the swimming portion of each triathlon was held constant at a pace 5% slower than the initial 750m swim test. For example, if the time obtained during the 750m tests was 600 seconds, the swimming portion of the three triathlons was performed in 630 seconds. The intensity maintained during the running portion of each triathlon was maximal effort. The following is a description of the three-triathlon trials that each subject performed:

First trial (PO100): Subjects performed a triathlon including the swim course previously described. To ensure that subjects maintained proper pace, athletes were provided with a pre-programmed pace watch. Following the swim portion, the tri-athletes had a 2-minute transition period to run from the pool to the laboratory, wearing their cycling shoes an accommodation for the cycling portion. The subjects then rode their own bikes (attached to a Computrainer) for 18.8km, at the average workload recorded during the 40km time trial. Upon completion, the tri-athletes had a 1-minute transition to the run event. The subjects ran 5km at their maximum exercise intensity on a treadmill with a 1% grade of incline, in order to simulate outdoor conditions [12]. During both the cycle and run portions of the triathlon, subjects received feedback regarding their pace, and were encouraged to maintain the target workload for cycling and to maximize effort during the running segment. Total and split times for cycling and running were recorded. During the bike segment, VO_2 was collected in three-minute intervals at 1km, 6km, and 11km. During the running segment, VO_2 was collected at 1km, and 3km. Blood samples for lactate analysis were drawn during the cycling portion, prior to each VO_2 collection and at 17km.

Trial PO95 and trial PO90: The protocols for these two trials are identical to trial PO-100, with one exception: during PO-95, the cycling portion was performed at a pace 5% slower than the subjects 40km TT pace, and for Trial PO-90, subjects pedaled at a pace 10% slower than their 40km TT pace.

Subjects were asked to avoid high intensity exercise (as previously defined) 24 hours before each testing trial. Subjects were asked to eat consistently (at the same time of the day and a similar meals) and to keep a record on a sheet (appendix A) provided to them 3 hours before each protocol. Subjects were allowed to drink water *ad libitum* only during the cycling portion of the triathlon. Fluid intake was measured and kept consistent among the three cycling strategies. Food intake and carbohydrated drinks were restricted during the three experimental trials.

3.4 Statistical methods

The means and standard error of the mean (SEM) from all the data are presented as descriptive statistics. The analysis of variance (ANOVA) with repeated measures was used to assess the differences between the three experimental trials and for all the dependent variables measured during this study: completion time, VO_2, HR and blood lactate. If significant differences were discovered between the experimental trials, a paired t-test was then used to determine which group or groups differ from the other(s).

CHAPTER 4

RESULTS

4.1 Descriptive data

Eight triathletes completed all experimental trials as described in the methodological section. As previously stated, the purposed of this study was to investigate the effect of three different cycling strategies on the total combined performance of cycling and running during a short-course triathlon. It has been hypothesized that significant differences exist in the combined cycling and run total accumulated times, during a short course triathlon, when the cycle portion is performed at a power output relating to maximum lactate steady state (MLSS) as compared to performance at power output below MLSS. Three levels of the independent variable (cycling intensity) were implemented in order to test the hypothesis: P0-100 was defined as the cycling intensity equal to the average power output of the 40km TT, PO-95 was performed at a pace 5% slower than the subjects 40km TT pace, and for Trial PO-90, subjects pedaled at a pace 10% slower than their 40km TT pace. The dependent variables measured during this study were: cycling plus running combined time, heart rate (HR), oxygen consumption (VO_2), and blood lactate concentration (La).

The summary of physical and physiological variables of subjects is shown in Table 1 and time trial completion times and physiological variables are shown in Table 2. Individual values for each subject are shown in Appendix B.

	AGE (years)	Body Fat (%)	Weight (Kg)	Height (cm)	VO_2MAX ($ml*kg^{-1}*min^{-1}$)	HR MAX (bpm)	750m swim time (min:sec)
Mean	32.6	11.0	153.3	174.6	67.9	185.7	12:57
SEM	±1.4	±1.8	±6.1	±3.0	±2.5	±1.94	±0:28

Table 4.1: Summary of physical and physiological characteristic of subjects.

	Total time (min:sec)	Average Power output (Watts)	Average Lactate (mM/dl)	Average VO_2 ($ml*kg^{-1}*min^{-1}$)	Average Heart Rate (bpm)
Mean	65:33	223	5.06	50.3	160.5
SEM	± 2:38	± 15.7.	± 0.5	±1.9	± 3.4

Table 4.2: 40km Time Trial finish times and physiological variables of subjects.

4.2 Experimental data

Values are shown as means ± SEM. Repeated measures ANOVA were calculated to compared the three experimental trials. Paired T tests were then used to determine which groups were significantly different. The time to complete the combined cycle and run portions of the experimental trials was significantly ($p< 0.05$) lower for PO-100 (56:08 ± 1:40 min:sec) when compared to both PO-95 (56:56 ± 1:49 min:sec) and PO-90 (58:00 ± 2:0 min:sec). In addition, subjects required significantly more time to complete PO-90 than PO-95 (Fig.4.1).

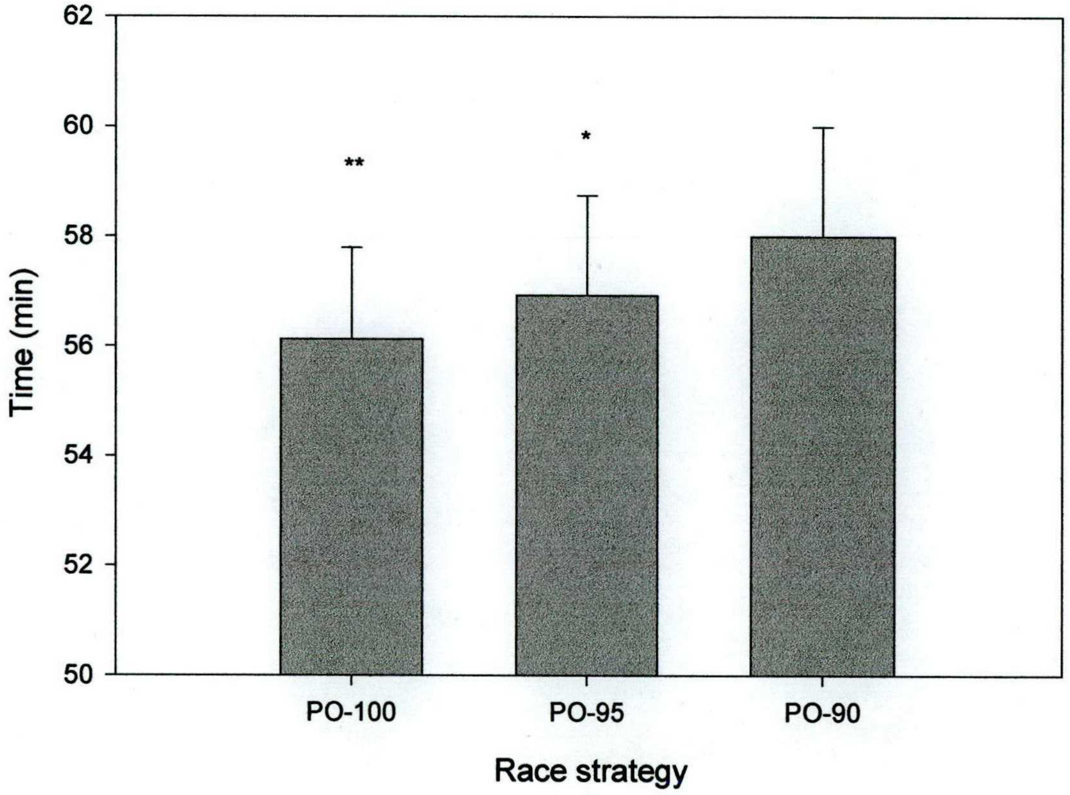

Fig. 4.1: Mean completion times ±SEM of the three different racing strategies.

** Denotes that PO 100 is significantly different than PO 95 and PO90 ($p< 0.05$)
* Denotes that PO 95 is significantly different than PO 90 ($p< 0.05$)

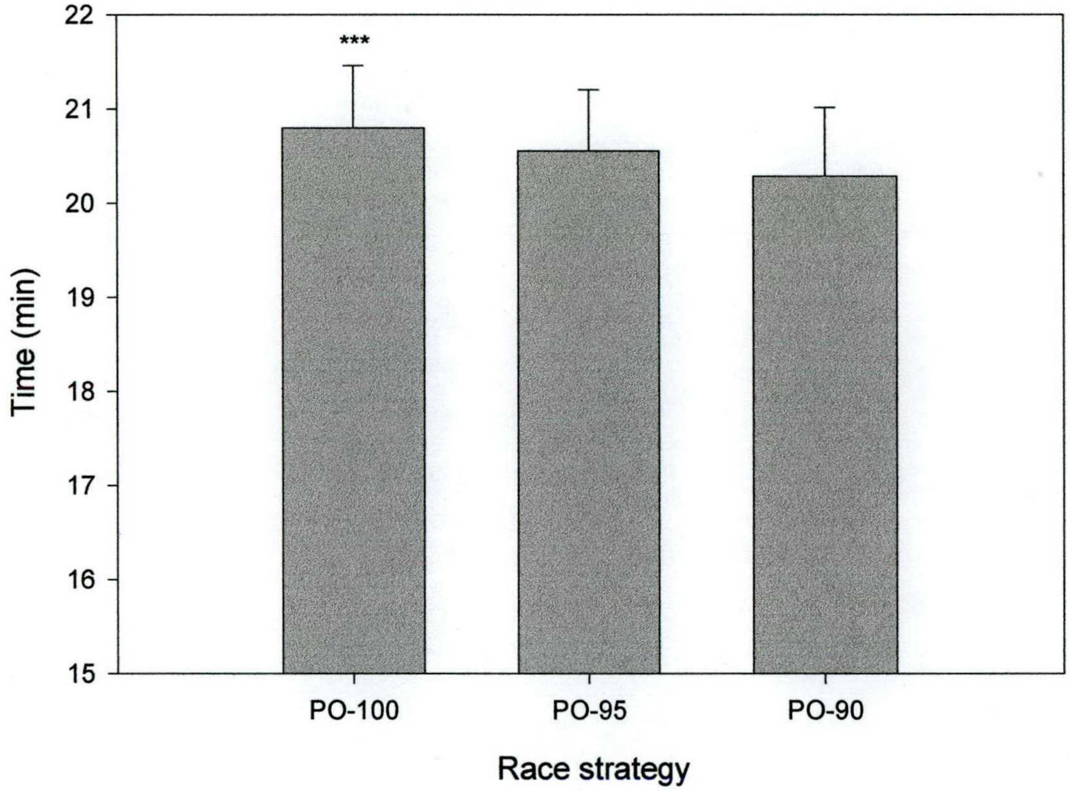

Fig. 4.2: Mean completion time ±SEM of the running portion of each racing strategy.

*** Denotes that PO 100 is significantly different than PO-90 ($p < 0.05$).

The time to complete the bike portion was significantly ($p < 0.05$) lower for PO-100 when compared to both PO-95 and PO-90. In addition, subjects required significantly more time to complete PO-90 than PO-95. Table 4.3 shows a summary of the physiological parameters measured during each racing strategy. VO_2 values during the bike portion were not significantly different between PO-100 and PO-95 ($p < 0.05$). However, when VO_2 values were compared between PO-100 and PO- 90 and between PO-95 and PO-90, significant differences were found ($p < 0.05$ respectively). The same trend was observed for blood lactate concentration and heart rate responses. Lactate concentrations for PO-95 were significantly higher than PO-90 values, and PO-100 blood lactates were significantly higher than PO-90 values ($p < 0.05$). In addition, La were higher at the beginning of each cycling segment and later during this stage tended to drop (Fig.4.3). Heart rate values for PO-95 were significantly higher than PO-90 values ($p < 0.05$), and PO-100 heart rates were significantly higher than PO-90 values ($p < 0.05$). No significant differences were observed between PO-100 and PO-95 for either variable (lactate and heart rate).

There were three dependent variables measured during the running portion of each racing strategy: completion time, VO_2, and heart rate. Completion times were significantly different during PO-100 (20:48 ± 0:40 min:sec) when compared to PO-90 (20:17 ± 0:44 min:sec) but not significantly different when compared to PO-95 (20:33 ± 0:39 min:sec). VO_2 and heart rates values were significantly higher during PO-90 when compared to PO-100 (Table. 4.3). In addition, VO_2 and heart rate values for PO-95 were significantly higher than PO-100 (Table 4.3).

Discipline	Physiological parameter	PO-100	PO-95	PO-90
Cycling	VO_2 ($ml*kg^{-1}*min^{-1}$)	49.8 ± 2.1**	47.9 ± 2.3**	44.8 ± 2.0
	% OF PEAK VO_2	73 ± 3.1**	70.5 ** ± 3.4	66 ± 3.0
	LACTATE (MM/DL)	5.5 ± 0.5**	4.8 ± 0.4**	4.0 ± 0.4
	Heart Rate (bpm)	162 ± 3.7 **	154 ± 3.5 **	149 ± 4.3
	% Of Max Heart Rate	87 ± 5.4**	83 ± 5.1 **	80 ± 6.3
	Time (min:sec)	35:18 ± 1:10***	36:22 ± 1:20 **	37:43 ± 1:30
Running	VO_2 ($ml*kg^{-1}*min^{-1}$)	60.6 ± 2.1 ***	62 ± 2.1	62.7 ± 2.4
	% OF PEAK VO_2	89 ± 3.1 ***	91 ± 3.1	92 ± 3.5
	Heart Rate (bpm)	171 ± 2.7 ***	173.5 ± 2.4	174.4 ± 2.5
	% Of Max Heart Rate	92 ± 4.0 ***	93 ± 3.5	94 ± 3.7
	Time (min:sec)	20:48 ± 0:40 **	20:33 ± 0:39	20:17 ± 0:44
Cycling and running combined	Time (min:sec)	56:08 *** ± 1:40	56:56 ** ± 1:49	58:00 ± 2:0

Table 4.3: Means ± SEM of completion time and physiological variables measured during the three racing strategies.

*** Significantly different from PO-95 and PO-90

** Significantly different from PO-90

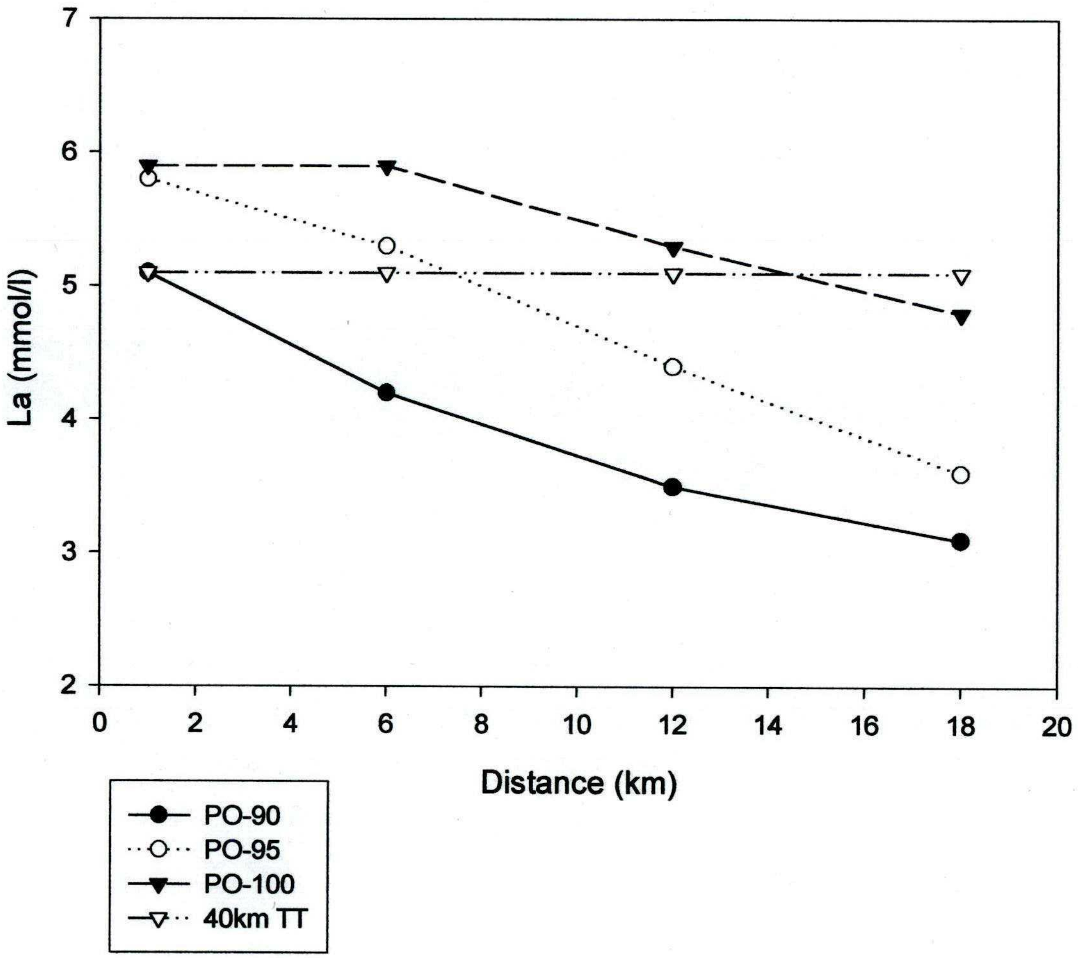

Fig. 4.3: Lactate values during the cycling portion of the three experimental trials.

CHAPTER 5

DISCUSSION

To our knowledge, this is the first study to test different race strategies during a short-course triathlon. The main finding in this study confirmed our initial hypothesis that the best performance in a short-course triathlon (measured as the time spent to complete the combined cycle-run portions) is elicited when the triathletes perform the bike portion at an exercise intensity equal to their 40km TT average power output.

In the present study, a 750m swimming segment was implemented as part of the experimental trials. The objective was to simulate racing conditions like those experienced during a short course triathlon. The post swimming lactate values found during the experimental trials were significantly higher ($p < 0.05$) than those averaged during the cycling portions. These changes are congruent with those found by Farber[12] during an Ironman distance triathlon, where higher blood lactate values were observed relative to the proceeding cycle and running stages. These similarities between swimming race conditions lead us to believe that the intensity at which the swim portion was performed during our study was similar to race conditions. The swim portion was performed at the same intensity in each of the experimental trials.

Three experimental trials were tested in this study: PO-100, PO-95, and PO-90. It was found that the fastest time to complete the cycle and run portions of a short-course triathlon was elicited during trial PO-100 (56:08 ± 1:40 min:sec), and as the cycle exercise intensity was lower (trials PO-95 and PO-90), the time to complete the cycle and run portions was significantly ($p < 0.05$) slower (56:56 ± 1:49 and 58:00 ± 2:0 min:sec respectively). A steady power output (variation less than ± 2 watts) was maintained during the cycling portion of each of experimental trials. In contrast to our results, it has been shown by others[7] that varying the intensity of exercise, within 60 minutes of cycling, has no effect on subsequent 10km running

In the present study, blood lactate levels were significantly higher at PO-100 ($p < 0.05$) compared to PO-90 (5.5 ± 1.5 vs. 4.0 ± 1.1 mM/dl). The same situation occurred with VO_2 and HR values (49.8 ± 6.0 vs. 44.8 ±5.8 $ml*kg^{-1}*min^{-1}$ and 162 ± 10.5 vs. 149 ± 12.1 bpm respectively). However, regardless of the high metabolic and cardiorespiratory demands of the PO-100 trial, the subjects were able to run fast enough to complete the cycle- run portion in the lowest time. Thus, it appears that in order to maximize athletic performance during a short distance triathlon, the cycling intensity should be equal to that of a 40km TT average power output.

Although during this study we only tested 3 race strategies, an exercise intensity lower than PO-90 (10% slower pace than the 40km TT average power output) would not be likely to elicited a faster performance, as clearly suggested by the trend where the worst performances where attained during the lowest cycle power outputs. The question of whether a race strategy more aggressive than PO-100 would result in better overall triathlon performance is valid, however, we believe that this situation is unlikely to occur because the La levels measured at the first km of the cycling portion of PO-100 were similar than those observed during the 40km TT, which is the highest exercise intensity at which La remains stable [13], suggesting that a race strategy 5% higher than PO-100 will result in a high rate of lactate production, and consequently will negatively affect performance. This argument is also supported by unpublished data collected from our laboratory, where trained cyclists were asked to ride their bikes for 30 minutes at an intensity 5% above the maximum intensity at which their lactate levels remain constant, and many were unable to finish this task. In addition to this, triathletes are required to swim before the cycling portion of a triathlon, and it has been reported [14] that 800m of submaximal swimming before 75 minutes of cycling at 75% of maximal VO_2 resulted in a significant reduction in power output (191W vs. 159W) when compared with a control 75-minute cycle without prior swimming. Therefore, it is unlikely that an intensity 5% over the athlete's 40km TT average power output could be maintained for a long period of time, due to the relatively high physiological demands of swimming before of the cycle portion during a triathlon.

In this study we found that a workload equal to that of a 40km TT, elicited 73% of peak VO_2. It would appear than this level of work may establish a threshold for metabolic and neurological fatigue during the cycle stage which did influence subsequent running performance. In contrast, triathletes were able to maintain an intensity equal to 89% of their VO_2 during the running portion of the PO-100 trial. These differences in exercise intensity are partially explained by the fact that the peak VO_2 was calculated on a treadmill. It has been reported that trained triathletes obtained lower values (5%) in a peak VO_2 test, when it was performed using a cycle-ergometer protocol.[15]. Therefore, the relative intensity for the cycling portion could be underestimated. In addition, these differences could indicate that triathletes are better trained to maintained high exercise initensities during running than during the cycling. More research is needed to investigate the potential factors that cause a higher relative cardiorespiratory response during the running portion of a triathlon in contrast with the cycling segment.

It is concluded that an ideal cycling strategy exists in order to maximize performance during a short-course triathlon. This ideal cycling strategy pace is equal to the average power output obtained during a 40km TT. In addition, it is recommended to keep a constant pace rather than a variable pace in the early stages of the cycling segment, in order to avoid further increments in the blood lactate levels (already high immediately after the swim), which may negatively impact overall triathlon performance.

APPENDIX A: Data sheets

Triathlon Training Log

Name:
From______________ to ____________

	Monday	**Tuesday**	**Wednesday**	**Thursday**	**Friday**	**Saturday**	**Sunday**
Volume							
Description							

Zones	% Intensity of Maximal Heart Rate (%MHR)	Heart Rate
Zone 1	60- 69%	
Zone 2	70- 79%	
Zone 3	80-85%	
Zone 4	85-89%	
Zone 5	90-100%	

Formula:

% MHR = Max Heart Rate – Resting Heart Rate x (% intensity/100) + Resting Heart Rate.
Example: Chris McCormack (Triathlon World Champion 1997)

195-30 x (.85) + 30 = 170 bpm

VO_2max Data Sheet
Costill Protocol

Name:	Date:
ID:	Time:
Height	Age:
Body Fat: Pectoral or triceps: _____ Abdominal or suprailiac: _____ Thigh: _____ Total: _____ Body fat%: _____	Weight: _________

Stage	Duration (min)	Grade	Speed miles/h	HR	VO2
1	3	0%	6		
2	2	0%	9		
3	2	2%	9		
4	2	4%	9		
5	2	6%	9		
6	2	8%	9		
7	2	10%	9		
8	2	12%	9		
9	2	14%	9		

Total test time: _____________ Peak Heart rate _______

Peak RER _____________

Vo2max _____________ 750m Swimming time __________

____

40km Time Trial Data Sheet

Name: ______________________ Date ____________

ID: ____________ Time ____________

Distance (km)	Time (min)	Lactate (mM)	Worload (Watts)	HR (BPM)	RPE
0					
10					
20					
30					
40					
TOTAl Average					

Total test time: _____________ Average Heart Rate: _______
Average Speed: _____________
Average wattage: _____________
____

Experimental procedures data sheet

Name: ______________________________

Date: ______________________________

Id: ______________________________

Swimming Time:

Swimming pace:

Cycling Data

Mile	Lactate	Heart Rate	VO2 (3minutes)	Time
1				
4				
8				
12				

Cycling time in 12 miles:

Running data

km	Heart Rate	VO2 (minutes)	Time
1			
3			
5			

Running time in 5km: ______________

Fluid intake: ______________

Food intake recall sheet

Date	Type of experimental trial	Time of ingestion	Description of food intake

APPENDIX B

INDIVIDUAL DESCRIPTIVE AND EXPERIMENTAL DATA

Subject	Age (years)	% Body Fat	Weight (Pounds)	Height (cm)	VO_2 (ml/kg/min	VO_2 (l/min	Max HR	750m time (sec)
1	40	7.3	145	169	69	4.55	180	11:36
2	31	12.7	156	172	69	4.89	185	11:40
3	34	10.5	160.5	183	75	5.47	180	11:25
4	27	4.7	167	188	81	6148	194	13:55
5	31	20	120	162	62	3381	186	12:17
6	32	6.2	145.5	170	65.4	4325	192	13:55
7	30	10.9	154	173	62	4362	186	14:13
8	35	15.9	178.5	180	59.7	4840	183	14:39
Mean	**32.5**	**11.0**	**153.3**	**174.6**	**67.9**	**2883.9**	**185.7**	**12:57**
SD	**3.9**	**5.1**	**17.4**	**8.5**	**7.2**	**2503.0**	**5.5**	**1:20**

40km TT Individual data

Subject	Distance (km)	Power output (Watts)	Completion Time (h:min:sec)	Blood Lactates (mM/dl)	Hear Rate (bpm)	VO_2 (ml/kg/min^{-1})
	10			4.8	152	50.1
1	20			4.3	153	
	30			2.1	148	51.2
	40	213	1:16:36	3.1	147	
	10			5.0	165	49.5
2	20			4.6	169	
	30			4.4	169	49
	40	219	1:11:36	4.2	171	
	10			4.6	149	56.4

3	20			4.5	153	
	30			4.4	153	57.4
	40	276	1:04:20	3.7	151	
	10			6.5	144	51
4	20			4	151	
	30			4.6	160	59
	40	289	1:04:55	3.4	161	
Subject	**Distance (km)**	**Power output (Watts)**	**Completion Time (h:min:sec)**	**Blood Lactates (mM/dl)**	**Hear Rate (bpm)**	**VO_2 (ml/kg/min^{-1})**
	10			9.7	176	54.7
5	20			6.35	174	
	30			3.95	173	52
	40	186	1:15:27	5.62	176	
	10			6.7	170	48.7
6	20			5.9	168	
	30			4.2	170	52.6
	40	188	1:15:37	4.1	173	
	10			7.7	153	39
7	20			2.3	152	
	30			4.3	153	38.3
	40	167	1:29:23	3.5	150	
	10			11	162	49
8	20			10	164	
	30			6.7	154	46.6
	40	251	1:15:52	4.4	160	

Combined cycling and running completion times (min:sec)				Cycling Lactates (mM/dl)		
Subject	PO-100	PO-95	PO-90	PO-100	PO-95	PO-90
1	56:15:00	57:00:00	57:45:00	4.02	4.15	3.45
2	53:27:00	54:20:00	55:07:00	4.82	3.05	2.40
3	49:56:00	50:04:00	50:37:00	8.50	5.97	4.29
4	50:47:00	51:03:00	51:43:00	4.30	4.50	3.80
5	57:53:00	59:04:00	59:39:00	5.30	4.31	3.08
6	59:50:00	59:22:00	61:01:00	6.95	6.33	6.15
7	64:07:00	66:18:00	68:25:00	4.82	4.85	4.20
8	56:43:00	58:23:00	59:43:00	5.24	5.25	4.30

Cycling VO_2 (ml* kg^{-1} * min^{-1})				Cycling heart rates (bpm)		
Subject	PO-100	PO-95	PO-90	PO-100	PO-95	PO-90
3	58.0	53.6	49.7	149	139	140
2	46.4	45.4	42.4	153	152	142
8	47.4	42.5	39.5	172	166	160
1	48.0	49.0	49.0	161	156	149
4	56.8	55.4	48.8	155	149	137
5	53.2	55.5	52.1	179	150	147
6	48.6	45.1	40.9	167	170	166
7	39.5	37.2	35.9	154	149	129

Cycling completion times (min:sec)				Running VO₂ $(ml* kg^{-1} * min^{-1})$		
Subject	**PO-100**	**PO-95**	**PO-90**	**PO-100**	**PO-95**	**PO-90**
3	30:59:00	31:32:00	32:23:00	67.5	68.7	68.2
2	34:34:00	34:59:00	36:36:00	53.4	54.4	52.9
8	34:02:00	36:17:00	37:30:00	57.5	61.0	61.5
1	34:27:00	35:24:00	36:09:00	68.5	69.7	69.4
4	32:50:00	33:40:00	34:51:00	58.8	58.8	57.6
5	36:35:00	37:26:00	38:40:00	66.3	68.8	72.6
6	36:57:00	37:17:00	38:39:00	56.6	58.2	60.7
7	42:05:00	44:28:00	46:59:00	56.0	57.4	58.8

Running completion times (min:sec)				Running Heart Rates (bpm)		
Subject	**PO-100**	**PO-95**	**PO-90**	**PO-100**	**PO-95**	**PO-90**
3	18:47	19:21	18:31	185	189	186
2	22:43	22:06	22:13	164	172	169.5
8	21:48	21:36	21:36	167	168	164
1	18:57	18:32	18:14	163	167	171
4	22:53	22:01	22:32	171	169	176
5	17:57	17:23	16:52	171	173	179
6	21:18	21:38	20:59	176	176	180
7	22:07	21:50	21:26	171	174	170

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