CHAPTER 3

METHODS AND PROCEDURES

3.1 METHODS

In this chapter we will discuss the methods and procedures used for the testing of the subjects in the study.

3.1.1 Subjects

The number of subjects that participated in this study were 20 students all aged 20 to 24 years, a combination of males and females. The individuals were well matched with regard to their age, mass, length and activity level (Table 6). They were all recreational cyclists with no major known injuries. Each subject was tested both on the traditional pedal crank as well as the new designed pedal crank. This means that each subject formed part of the experimental group as well as the control group and the results of each person were measured against his own results.

The students (n = 20) each performed 4 tests:

i) economical movement test on the new designed pedal crank;
ii) VO_2- max on the new designed pedal crank;
iii) economical movement on the traditional pedal crank; and
iv) VO_2- max on the traditional pedal crank.

Table 6: Subject data of all the athletes taking part in the study

	Experimental and control X $^{+}$/- SD
Age	22,9 +/- 1,79
Length	173 +/- 7,93
Mass	70 +/- 13,27

There were certain criteria used to determine the subject's eligibility for the study:

a. history of Pulmonary disease: No persons with any kind of pulmonary disease were accepted for this study;

b. activity indexes: The subjects were not allowed to do any gymnasium or other high intensity activities 48 hours prior to the test;

c. medical history: No participants had any knee or hip injuries while taking part in the study; and

d. current health status: No participants were accepted who showed signs of flu within a period of two weeks prior to the tests.

3.1.2 Testing Environment

All the tests were done in the laboratory at the Institute for Sport Research at the University of Pretoria. The temperature was kept constant at 21 degrees Celsius and Barometric pressure at 662 mmHg. All tests were done out in the field where wind and temperature could influence the results. Thus, it can be stated that all tests were done in a controlled environment.

3.1.3 Equipment

In the study, the following equipment was utilized:

a. The Harpenden Anthropometer was used to measure the subject's standing length and a model D2391 Detecto standing scale was used to measure total body weight.

(a) (b)

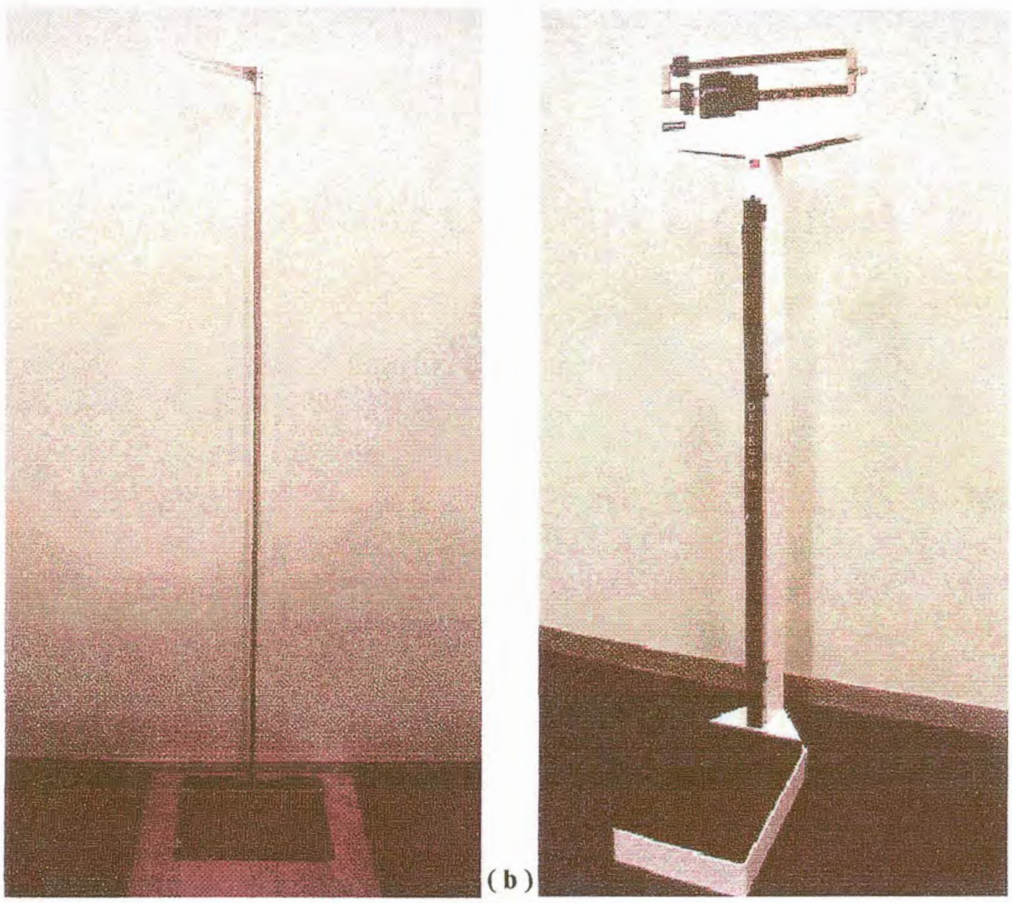


Figure 27: (a) The Harpenden Anthropometer; and (b) The Detecto Standing Scale

b. The Schiller Gas Analyzer was used to measure VO_2-max, the ventilatory threshold as well as economical movement.

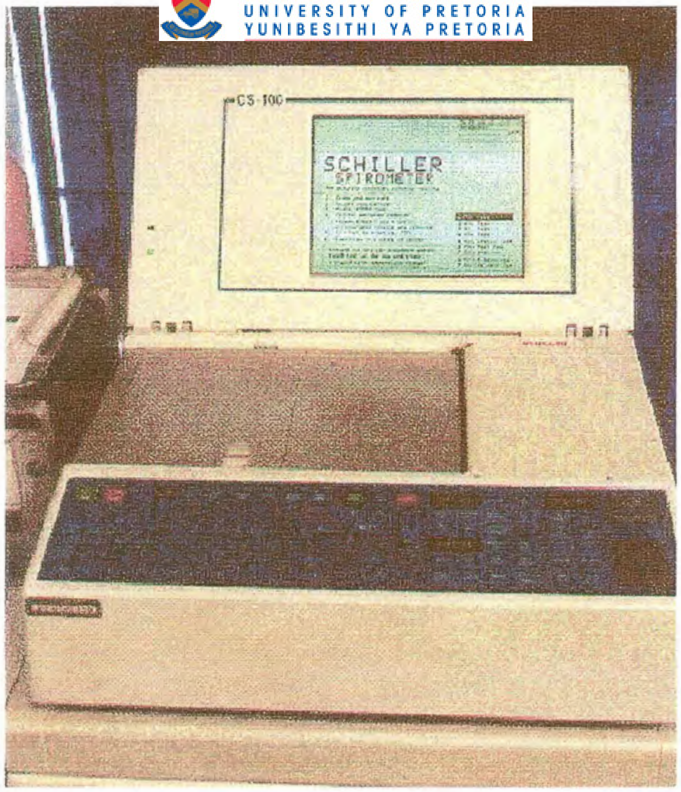


Figure 28: The Schiller Gas Analyzer

c. The Accutrend Lactate Meter was used to measure minimum and maximum lactate levels as well as the lactate threshold.

Figure 29: The Accutrend lactate meter

d. The Cybex Norm was used to measure knee flexion and extension strength after muscle fatigue during cycling on the two different pedal cranks.

Figure 30: The Cybex Norm

e. Cateye Cyclosimulator was used to mount the bicycle used for the tests.

Figure 31: Cateye Cyclosimulator (Model CS-1000)

f. The new designed pedals were used for the tests for the experimental group and a traditional pedal crank set was used for the tests of the control group.

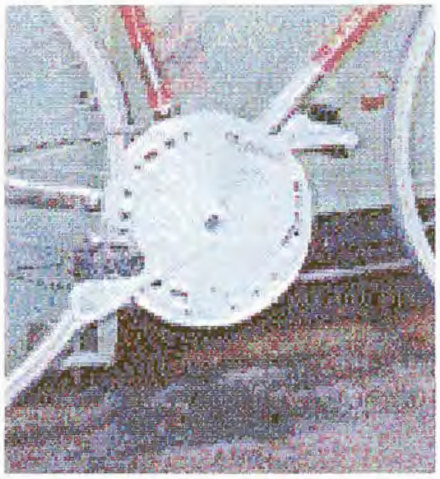


Figure 32: The new designed pedal crank set

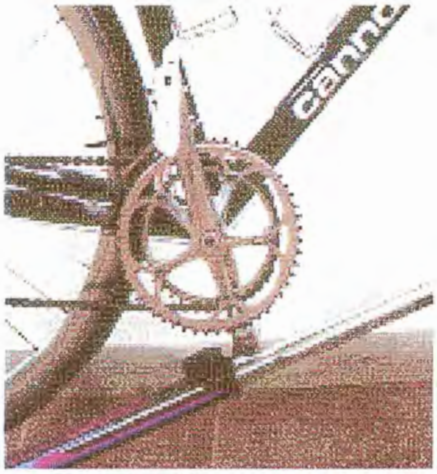


Figure 33: The traditional pedal crank set.

g. Cycling shoes which consist of light uppers with a thin but very stiff sole, generally with a metal plate built into the sole, were used to keep the feet attached to the clip-less pedals.

3.2 PROCEDURES

3.2.1 Physical Testing Procedures:

The tests commenced with a measurement of height and body mass, whereafter the physiological tests on the bicycle started. The 4 physiological tests can be defined as:

* Test 1: Economical movement on the new designed pedal crank followed by a muscle strength test on the Cybex Norm.
* Test 2: VO_2-max on the new designed pedal crank.
* Test 3: Economical movement on the traditional pedal crank followed by a muscle strength test on the Cybex Norm.
* Test 4: VO_2-max on the traditional pedal crank.

Procedures:

a. Height measurement:

The Harpenden anthropometer was used to measure normal standing height. The subject stood barefoot in a normal standing position with the feet together and back straight, as seen in figure 34.

Figure 34: Height measurement with the Harpenden Antropometer.

b. Body mass measurement:

The Detecto Standing scale was used to measure total body weight to the nearest 0,1 kilogram with the subject standing barefoot on the scale as seen in Figure 35.

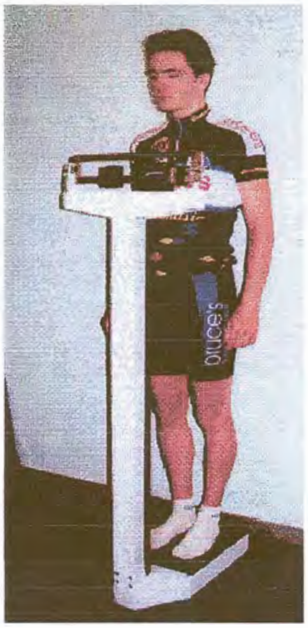


Figure 35: Body weight measurement on the Detecto Scale

c. Saddle height:

The saddle height of the bicycle was measured by the 109%- rule as discussed in Chapter 2.

d. Calibration of the Schiller Gas Analyzer:

Before each test, the gas analyzer was calibrated. This preparation included the environmental conditions, flow/volume calibration and gas calibration.

Figure 36: Calibration of the flow/ volume of the Schiller

e. Connecting the subject to the gas analyzer:

A polar heart monitor was used to monitor the heart rate during the test. Before mounting the bike, a correctly fitted gas mask was mounted to the subject's face to connect the subject to the gas analyzer. The subject was now ready to start the test.

f. Economical movement with the new designed pedal crank:

With the subject mounted on the bike and connected to the gas analyzer, the tests could start. The physical test started with a warm-up period of 1 minute at a speed of 20 to 25 km/h against an angle of 1 degree (50watts). After the warm-up period the testing started. The subject had to pedal for 6 minutes against a constant speed of 30 km/h and at an angle of 2 degrees (100watt). The gas analyzer recorded the physiological changes while completing the test.

Figure 37: Subject pedalling with the new designed pedal crank to determine economical movement.

Directly after completing the test, the isokinetic muscle strength of the quadriceps and hamstrings were measured on the Cybex Norm. The subject was given 3 trial repetitions before the actual test started. The test consisted of 5 maximal repetitions of knee flexion/extension against a pre-set speed of 60° per second. Peak torque and average work were measured and compared to the test done after pedalling on the traditional crank set.

Figure 38: Isokinetic testing on the Cybex Norm

g. VO_2-max test with the new designed pedal crank:

The subject was mounted on the bike and connected to the gas analyzer. The physical test started with a warm-up period of 3 minutes against an angle of 2° and a speed of 25 km/h (75 watt). Level 1 then started with the subject pedalling at 30km/h against an angle of 2° for 3 minutes. Each level lasted for 3 minutes whereafter the blood lactate was taken and the speed then increased by 5km/h until the subject could not keep up with the speed anymore.

Figure 39: Blood lactate measurement during a VO_2-max test on the new designed pedal crank

h. Economical movement with the traditional pedal crank:

With the subject mounted on the bike and connected to the gas analyzer, the tests could start. The physical test started with a warm-up period of 1 minute at a speed of 20 to 25 km/h and against an angle of 1° (50watts). After the warm-up period the testing started. The subject had to pedal for 6 minutes against a constant speed of 30 km/h and at an angle of 2° (100watt). All the physiological changes were recorded by the gas analyzer during the test.

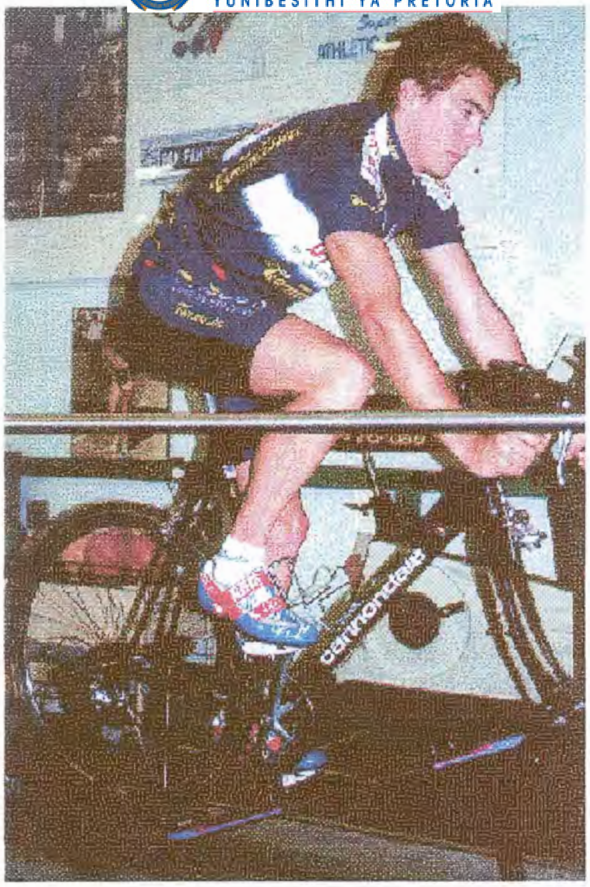


Figure 40: The subject pedalling with the traditional pedal crank to determine economical movement.

Once again, directly after completing the test, the isokinetic muscle strength of the quadriceps and hamstrings were measured on the Cybex Norm. The subject was given 3 trial repetitions before the actual test started. The test consists of 5 maximal repetitions of knee flexion/extension against a pre-set speed of 60° per second. Peak torque and average work were measured and compared to the test done after pedalling on the new designed crank set.

i. VO_2 -max test with the traditional pedal crank

The subject was mounted on the bike and connected to the gas analyzer. The physical test started with a warm-up period of 3 minutes, against an angle of 2° at a speed of 25 km/h (75 watt). Level 1 then started with the subject pedalling at

30km/h against an angle of 2° for 3 minutes. Each level lasted for 3 minutes whereafter blood lactate was taken and the speed then increased by 5km/h until the subject could not keep up with the speed anymore.

Figure 41: The subject pedalling with the traditional pedals to determine VO_2-max and the ventilatory threshold.

After completion of the 4 tests described in 3.2 (f), (g), (h) and (i), the physiological results were studied in order to determine the subjects' economical movements and ventilatory threshold. The following aspects measured were documented:

a. heart rate (beats per minute);
b. oxygen consumption during the steady state (VO_2);
c. respiratory coefficient (RQ);

d. respiratory rate (RR);

e. minute ventilation (VE);

f. tidal volume (VT);

g. metabolic equivalent (MET) ;

h. ventilatory threshold (Ve_{BTPS});

i. lactate (LA);

j. breathing equivalent (VE/VO_2); and

k. oxygen pulse (VO_2/ HT).

3.2.2 Preparation and procedures of the apparatus

3.2.2.1 Schiller Gas Analyzer Test Procedures:

a. Aim of tests:

* To measure changes in economical movement and ventilatory threshold;
* To determine correlation between the different variables during exercise;

b. Calibration of the Schiller gas analyzer:

Before each test, the gas analyzer was calibrated. This preparation included the environmental conditions, flow/volume calibration and gas calibration.

Firstly, the environmental conditions were monitored, which included:

- room temperature in ° C;
- absolute ambient pressure in mmHg;
- relative humidity in %; and
- dead space of the mask in ml (50ml).

Secondly, the flow/volume calibration followed:
The nominal pump-volume is 2 litres.

Thirdly, the gas calibration followed:
A tube is led from the gas bottle to the CS-100 connector "CAL.GAS" on the unit.
As calibration gas the following composition is required:

- 6% CO_2 (Tolerance: 0,3%)
- 15% O_2 (Tolerance: 0,5%)
- Rest N_2

c. Positioning of the subject:

A polar heart monitor was used to monitor the heart rate during the test. Before mounting the bike, a correctly fitted gas mask was mounted to the subject's face to connect the subject to the gas analyzer. The subject was now ready to start the test.

3.2.2.2 Isokinetic Test Procedures:

a. Aim of the testings:

* To determine the effect of the two different pedal crank sets on muscle power and total work after cycling;

b. Calibration of the Cybex Norm:

* Calibration is a process for adjusting or "fine tuning" the accuracy of the gradations of a measurement system. The NORM system is capable of measuring from 0 to 500 ft-lbs. (678Nm.) of torque and of attaining a speed of up to 500 deg/sec. The weight calibration procedure makes use of the principle that "the quantity of weight on an input arm set to a specific, pre-determined length will generate a known amount of torque when it falls." During weight calibration, a quantity of 100 lbs. is dropped.

c. Positioning of the subject:

* The importance of positioning and stabilizing of the subject on the dynamometer, is to isolate the target muscle group and to eliminate contribution from accessory muscles as much as possible (MacDougall et al., 1991; Perrin, 1993). In order to eliminate contribution of the upper extremities during the assessment of the lower extremities, the subject should be stabilized with straps at the waist and the chest and the arms should be across the chest (Perrin, 1993).

* To isolate the performance of single muscle groups, the isokinetic testing usually occurs through the cardinal planes of the body (fig. 43). These movements include rotation through the transverse plane, abduction and adduction through the frontal plane and flexion and extension through the sagital plane (Roy & Irvin, 1983; Perrin, 1993).

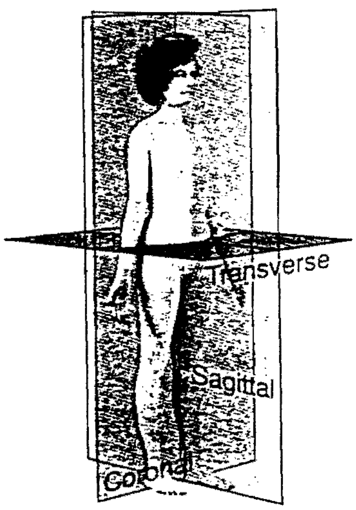


Figure 42: Cardinal planes of the body (Perrin, 1993)

* In order to facilitate movement through the planes showed in figure 43, the axis of rotation of the joint that is being assessed should be aligned as close as possible with the axis of rotation of the dynamometer (MacDougall et al., 1991; Perrin, 1993).

d. Validity and Reliability:

* The mechanical reliability of several isokinetic dynamometers has been reported in the scientific literature (Farrel & Richards, 1986; Bemben et al., 1988; Taylor et al., 1991; Patterson & Spivey, 1992).

* Intertesting and intratesting reliability will be enhanced by adhering to established protocols, particularly with respect to the patient setup and verbal encouragement (MacDougal et al., 1991; Perrin, 1993).

* The most complex aspect is subject reliability. This includes willingness to provide maximum effort and also to tolerate discomfort of maximal muscle contraction (Taylor et al., 1991; Perrin, 1993).

3.3 RESEARCH DESIGN

The research done in this study, was contract research (Mouton & Marais, 1992) where the designer of the new pedal crank set wanted a physiological comparison between the traditional and the new designed pedal crank set.

The crank designer needed physical proof of the effect of the new designed pedal crank on the physiological aspects of cycling which lead to the application of epidemiological research strategies. The specific aspects tested included:

a. economical movement;

b. ventilatory threshold;
c. oxygen consumption;
d. lactate;
e. heart rate values; and
f. muscle fatigue in maximum strength.

According to Mouton & Marais (1992) the following two aspects are necessary to achieve internal validity:

a. the connections of the central concepts have to be clear, unambiguous and articulated; and

b. the denotations of the central concepts in the problem setting have to be accurate indicators of the connections used.

In cognizance of the aforementioned, the study was an experimental epidemiological study where the same group of subjects was used as the experimental and the control group (Thomas & Nelson, 1990).

The aim and purpose of this design for a research study was to determine the difference of two types of cycling pedal crank sets on physiological variables during cycling. The question had to be answered, whether the new designed crank set had a positive effect on the physiological aspects, which influence performance on a bicycle.

3.4 STATISTICAL ANALYSIS

In any research study, it is very important that the number of subjects, their characteristics as well as their representative nature of the sample are taken into consideration. In this universal study, a group of subjects was measured and the results are representative of the average population (Mouton & Marais, 1992).

The aim of the analyses is to determine the relationship between various physiological variables during cycling. The exact nature of these relationships will become clear in the next section, which focuses on the results.

Non-parametric techniques were used to analyse the data. These distribution-free tests do not rely on parameter estimation or distribution assumptions and it accommodates data that is not normally distributed (Howell, 1992). The following statistical analyses were used to analyse the data of the study.

a. **Cross tabulations of variables:**

This procedure cross tabulates the values of one variable against another variable (Thomas & Nelson, 1990).

b. **Spearman rank order correlation:**

This method of correlating two variables is used when the data is not normally distributed. Both the direction and the strength of a relationship between variables can be determined (Thomas & Nelson, 1990).

c. **Wilcoxon's matched pairs signed-rank test:**

This test is a distribution-free analogue of the t-test for related samples. It also tests the null- hypothesis that two related samples were drawn either from identical populations or symmetric populations with the same mean (Thomas & Nelson, 1990). The null hypothesis assumes that there is no significant difference between the means of two values (Mouton & Marais, 1992).

As required by Thomas & Nelson (1990), the 95% level of confidence ($p<0,05$) has been used as the minimum to determine significant differences among various sets of data.

CHAPTER 4

RESULTS AND DISCUSSION

Test 1	=	Economical movement on the new designed pedal crank set.
Test 2	=	VO_2-max test on the new designed pedal crank set
Test 3	=	Economical movement on the traditional pedal crank set
Test 4	=	VO_2-max on the traditional pedal crank set

4.1 RESULTS OF ECONOMICAL MOVEMENT IN TEST 1 AND TEST 3

4.1.1 VO_2 differences in tests 1 and 3 (economical movement):

As seen in Table 7 and Figures 43 and 44, there was a significant difference for VO_2 scores on test 1 and 3 ($p<0{,}02$). In 12 of the cases the VO_2 scores in test 3 were higher than the VO_2 scores in test 1. Thus, the VO_2 scores were significantly higher when using the traditional pedals than the new designed pedals. According to McArdle et al. (1991) the oxygen consumption (VO_2) during sub- maximal exercise is an indication of economical movement. For example, at a given sub-maximal speed of cycling, the subject with the greater economy of movement will consume less oxygen while performing the task and will have a lower VO_2 (McArdle et al., 1991; Noakes, 1992). This was also supported by research done by Ericson & Nisell (1988), Coyle et al. (1992) and Hawley (1995). By using the **new designed** pedal crank set, the cyclist will have a more economical way of movement, oxygen consumption will be lower and therefore more oxygen will be available for energy production of the muscles.

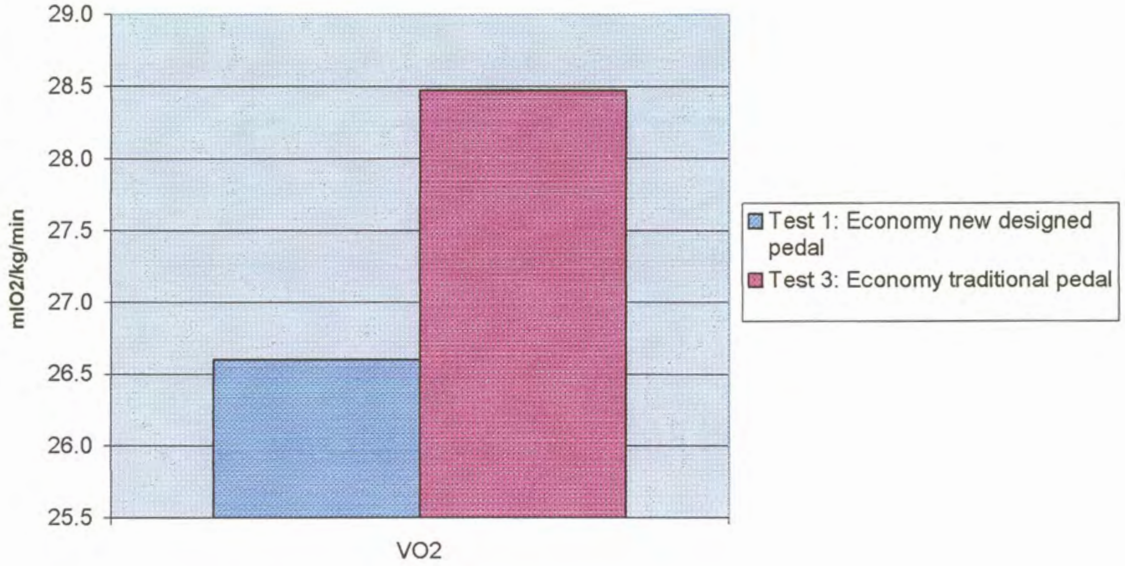


Figure 43: Difference in average VO_2 in tests 1 and 3 for the whole group (economy of movement)

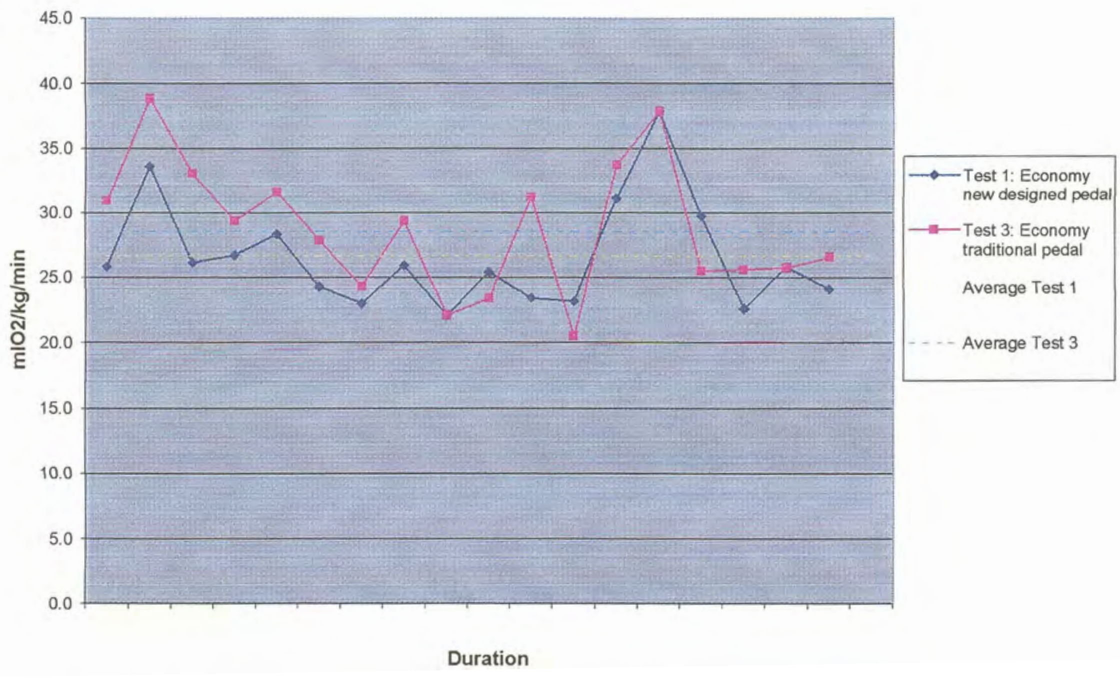


Figure 44: Individual difference in VO_2 in test 1 and 3.

Table 7: Descriptive statistics: Wilcoxon rank order test for VO_2 scores in test 1 and 3 during economical movement.

	N	Mean	Std. Dev.	Minimum	Maximum
VO_2 1	18	26.61	4.15	22.10	37.80
VO_2 3	19	28.47	5.07	20.50	38.80

A statistical significantly correlation ($p < 0,05$) was found between heart rate and VO_2-max results in test 1 (fig. 45). According to Berg (1984), heart rate is the most consistent factor involved with the increase in VO_2 during exercise. The relation between heart rate and oxygen consumption can be seen during various exercise intensities. The slope of these lines is a reflection of the individual's aerobic fitness. The lower the heart rate at high intensities, the lower the oxygen consumption will be (Schulman & Gerstenblith, 1989). This means that the higher the heart rate of the person, the higher the VO_2. A strong positive correlation ($p < 0.05$) was found between the heart rate and VO_2 for test 3 (fig. 46). It is clear that lower scores of heart rate correlate with lower scores of VO_2 and higher scores of heart rate correlate with higher scores of VO_2 (Berg, 1984; Schulman & Gerstenblith, 1989; McArdle et al., 1991). The heart rate: VO_2 correlation of test 3, using the **traditional** pedal crank set, were stronger than that of test 1 with the new designed pedal crank set. According to this relationship, the athlete can determine his sub-maximal VO_2 and also predict his VO_2-max by simply monitoring his heart rate during exercise.

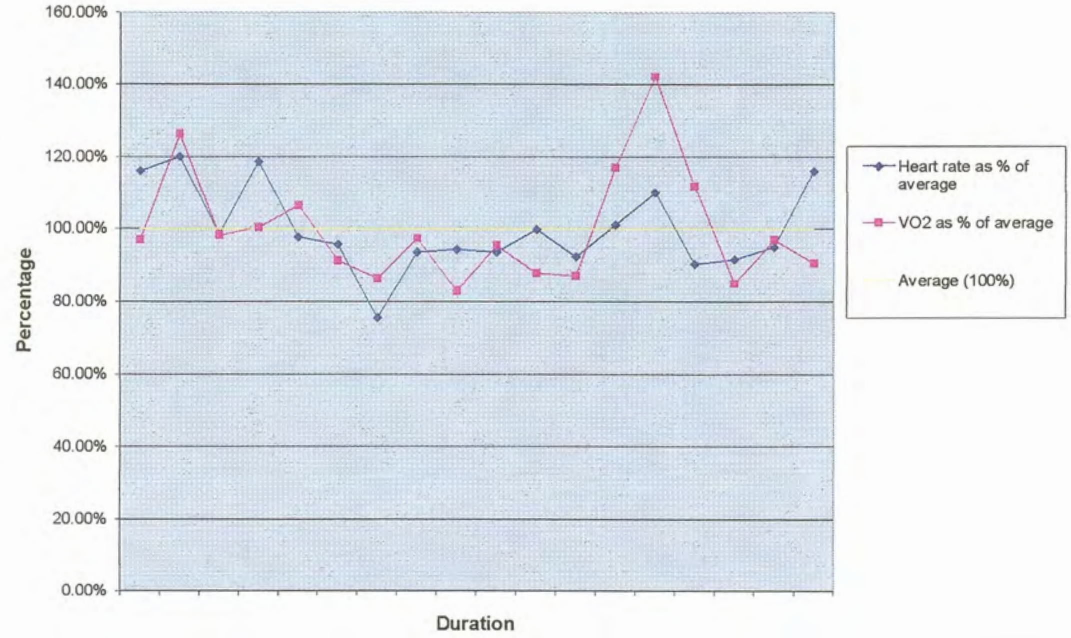


Figure 45: The relationship between heart rate and VO_2 scores for test 1 (economy of movement on the new designed pedal crank).

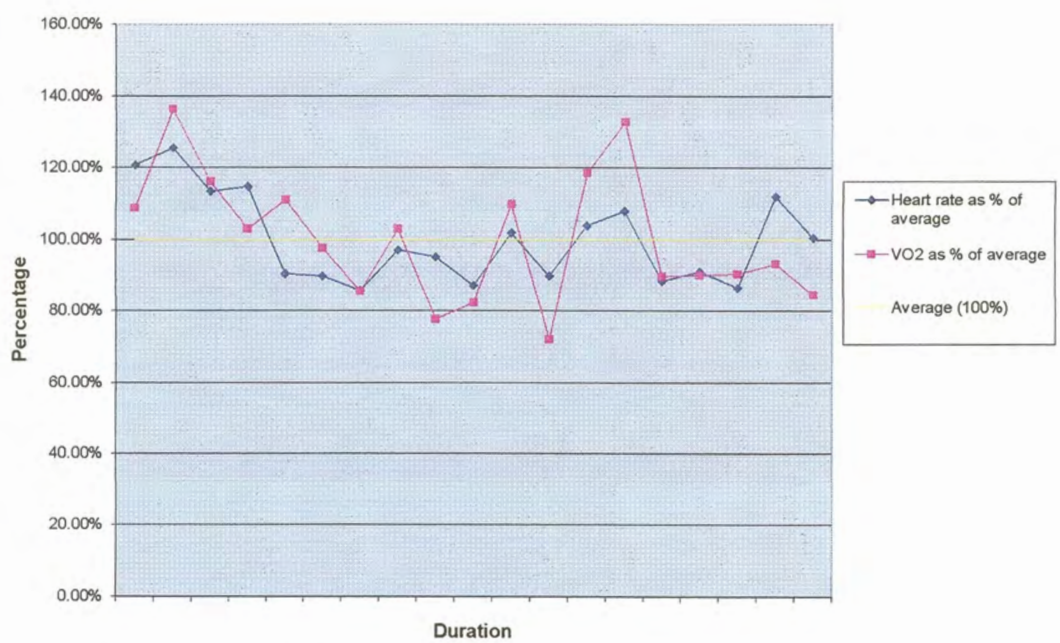


Figure 46: The relationship between heart rate and VO_2 scores for test 3 (economy of movement on the traditional pedal crank).

4.1.2 Heart rate and RQ differences in tests 1 and 3 (economical movement:

As seen in Figure 47, no statisticallly significant differences were found between the heart rate scores in test 1 and 3 ($p = 0.74$) or the RQ scores in test 1 and 3 ($p = 0.27$). The kind of pedal crank used does not seem to have an effect on the heart rate or RQ scores during sub- maximal cycling at a constant speed and resistance.

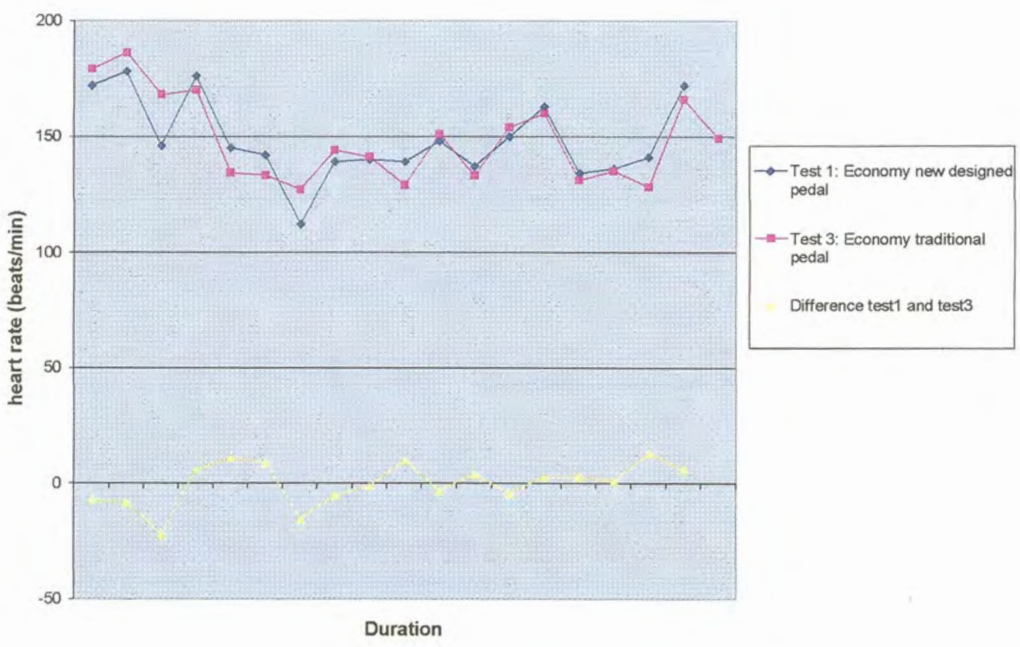


Figure 47: No relationship was found between heart rate scores in tests 1 and 3

Table 8: Descriptive statistics: Wilcoxon rank order test for heart rate and RQ in test 1 and 3 during economical movement.

	N	Mean	Std. Dev	Minimum	Maximum
HR1	18	148.33	17.40	112.00	178.00
HR3	19	148.32	18.52	127.00	186.00
RQ1	18	1.04	0.07	0.90	1.20
RQ3	19	1.05	0.09	0.94	1.24

A significantly strong positive correlation ($p < 0.05$) was found between the heart rate and RQ scores in test 1 (fig. 48) as well as in test 3 (fig. 49). This means that there is a strong tendency that the higher the heart rate scores the higher the RQ scores. According to Astrand & Rodahl (1986) the RQ is useful during rest and sub-maximal aerobic exercise, because it serves as a convenient guide to the nutrient mixture being catabolized for energy. When the intensity of exercise increases, the body needs more energy to operate and the heart has to contract more frequently. This causes increase in the exercise heart rate equivalent to the RQ. (Schulman & Gerstenblith, 1989). The correlation between heart rate and RQ scores was higher in test 1 when making use of the **new designed** pedal crank set than with the traditional pedal crank set in test 3. This relationship indicates that the body needs more nutrients when exercising at a high intensity than a low intensity.

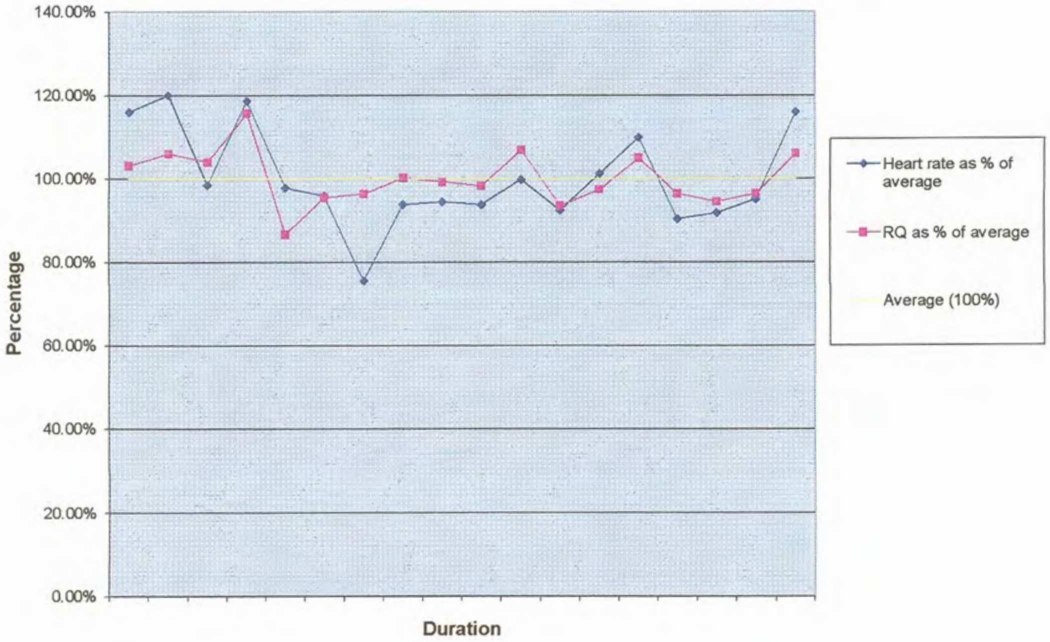


Figure 48: The relationship between heart rate and RQ scores for test 1: Economy of motion on the new designed pedal crank.

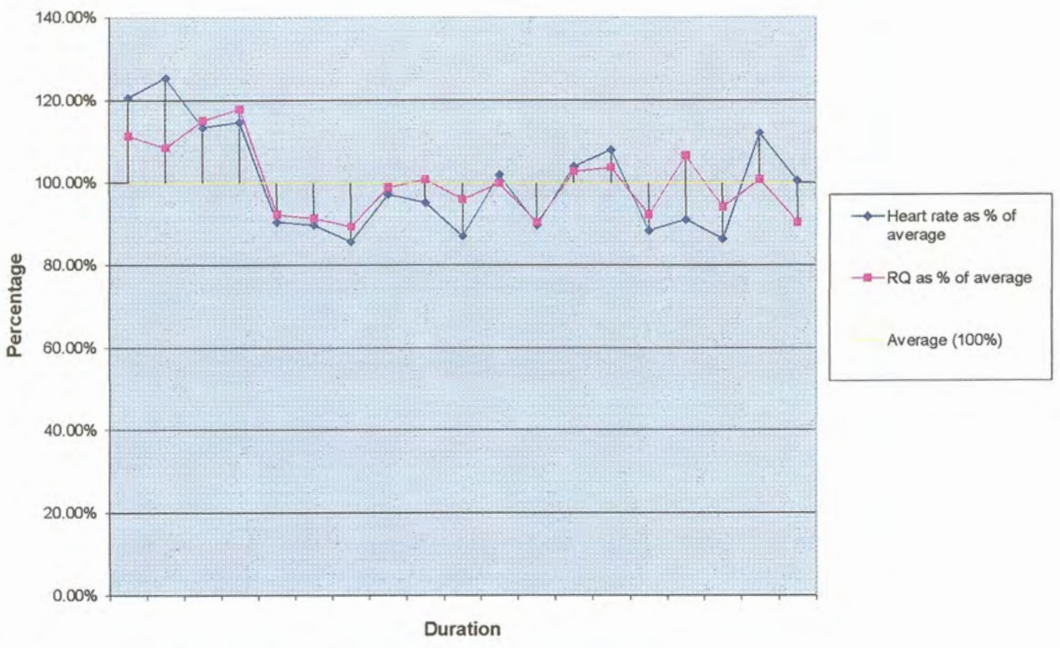


Figure 49: The relationship between heart rate and RQ scores for test 3: Economy of motion on the traditional pedal crank.

higher ventilatory threshold is beneficial for any aerobic exercises such as cycling. Loftin & Warren (1994) identified the ventilatory threshold as one of the major factors influencing running and cycling performance. Thus, if the athlete reaches his ventilatory threshold at a higher heart rate, it means that he would be able to cycle in the aerobic zone for a longer time period before entering the anaerobic zone. Total muscle fatigue will then take longer to occur.

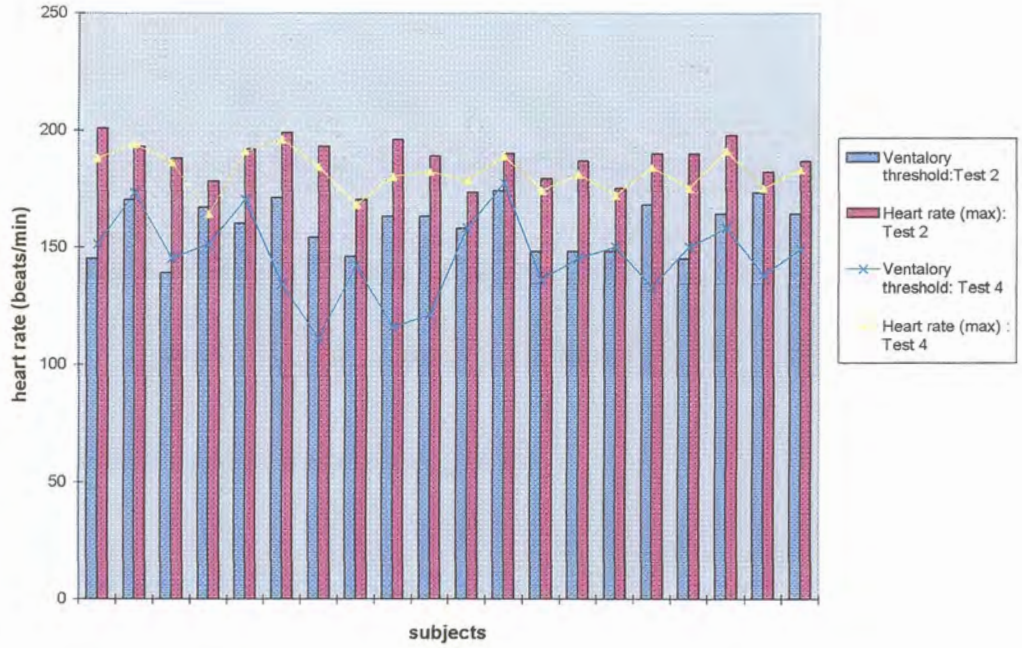
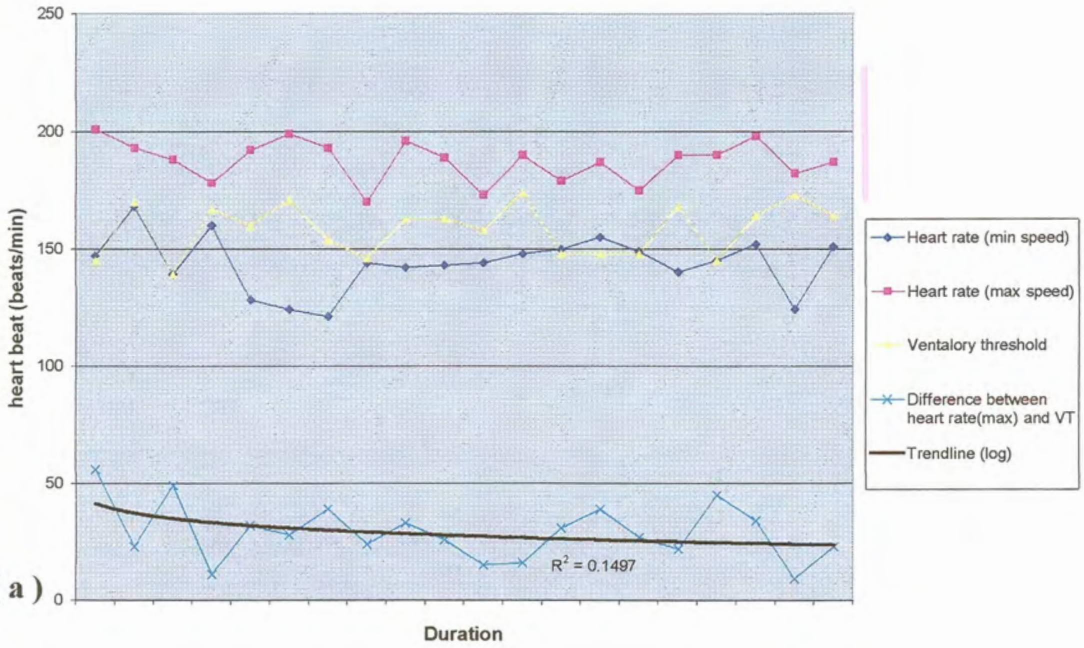


Figure 50: Maximum heart rate and heart rate at ventilatory threshold during a VO_2-max test on the new designed (test 2) and the traditional (test 4) pedal crank set.

Table 10: Descriptive statistics: Pretest and post test analysis of ventilatory threshold for tests 2 and 4

	N	Mean	Std. Dev.	Minimum	Maximum
VT2	20	158.40	10.90	139.00	174.00
VT4	20	145.40	17.60	111.00	177.00

(a)



(b)

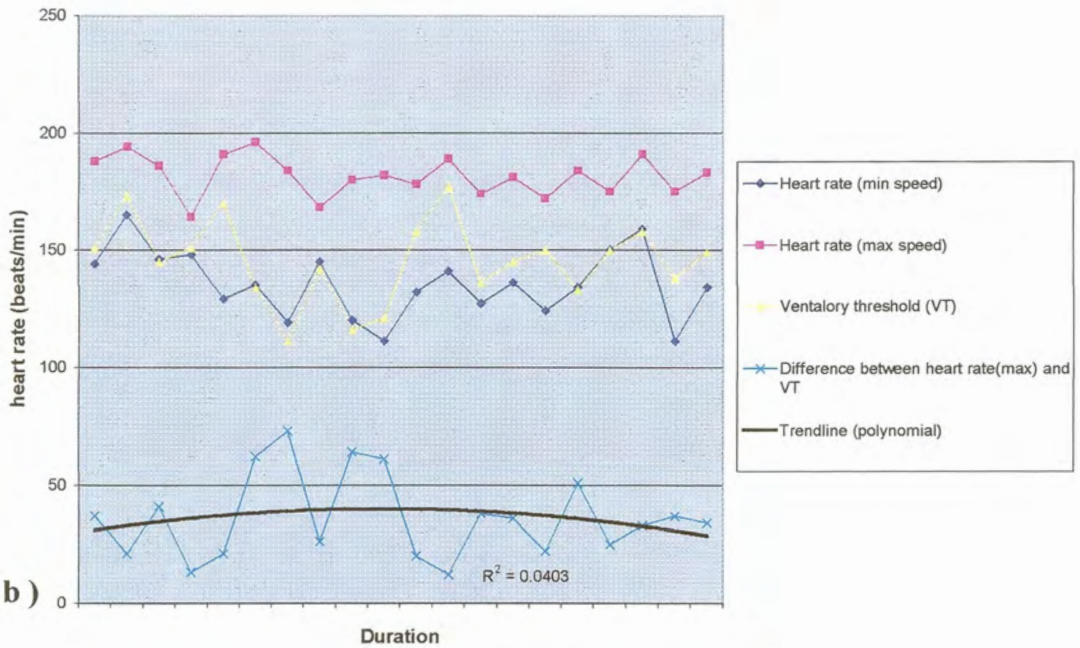


Figure 51: The relationship between heart rate and ventilatory threshold in (a) Test 2 and (b) Test 4

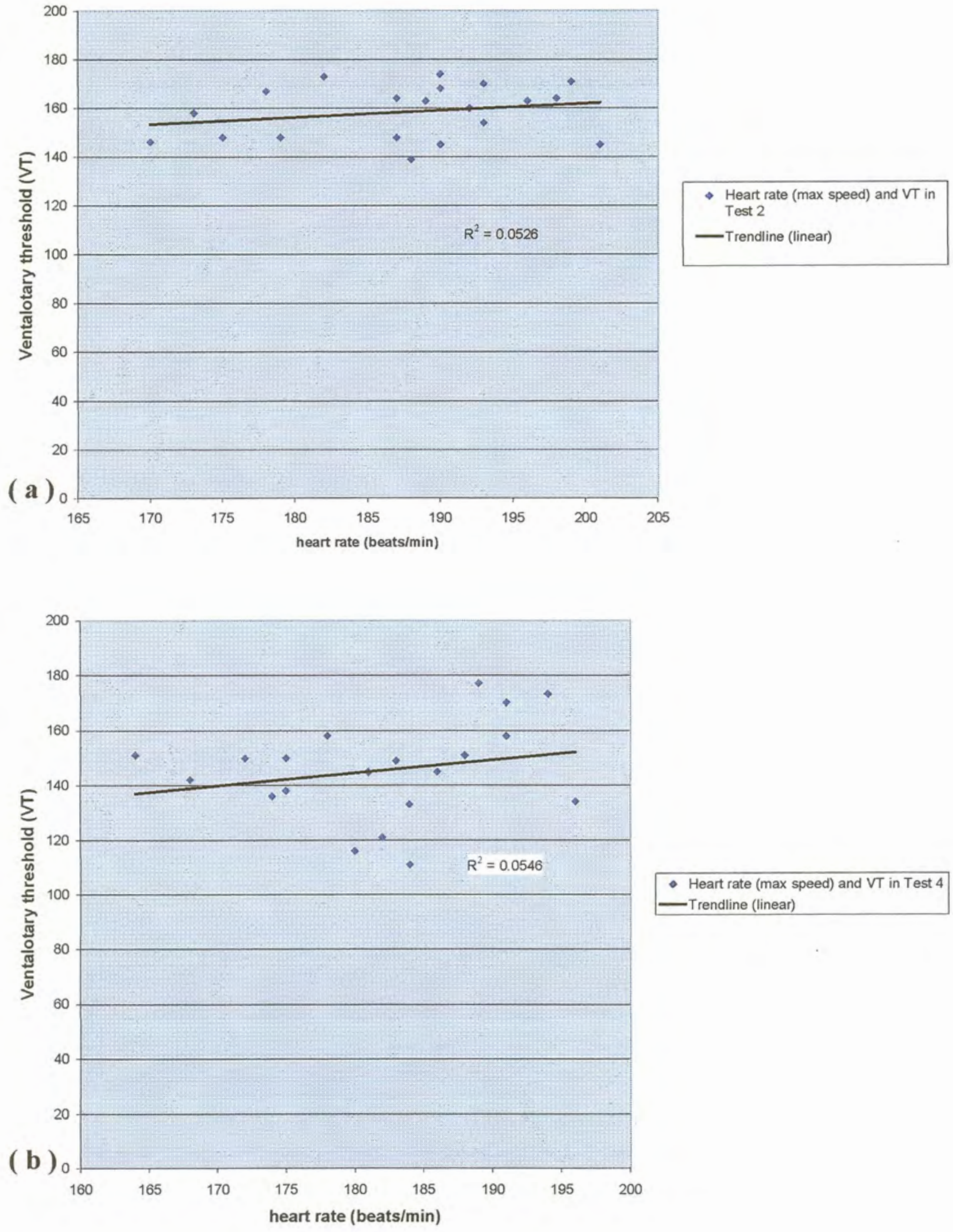


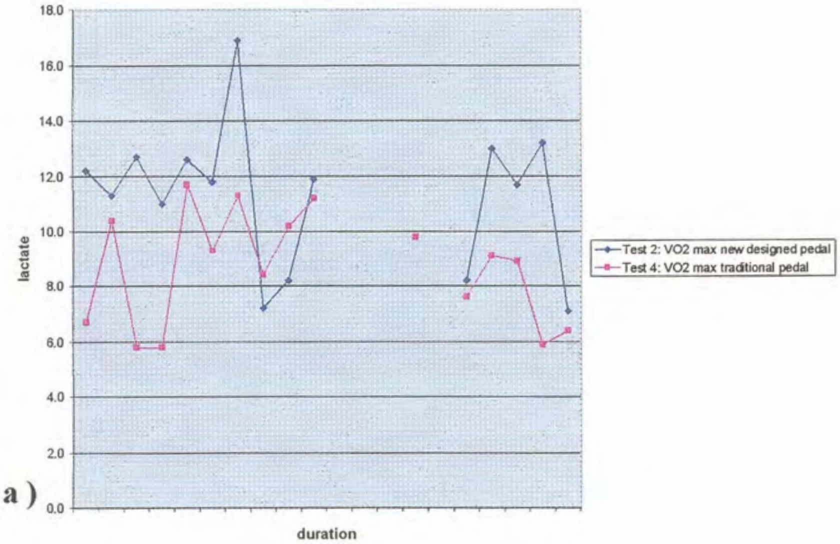
Figure 52: A linear trendline illustration of the relationship between heart rate and ventilatory threshold in (a) Test 2 and (b) Test 4.

4.2.2 Lactate differences in a VO_2-max test (test 2 and 4)

A significant difference was found between the lactate scores at maximum speed in test 2 and 4 ($p < 0.01$). In the majority of cases the lactate scores in test 4 were lower than the lactate scores in test 2. Lactate scores were thus significantly higher at maximum speed when making use of the new designed pedal crank (fig. 53 and 54). Research done by Maffulli et al. (1994) shows that performance relates more to sub-maximal effort measures, such as the onset of blood lactate accumulation and the anaerobic threshold, than to VO_2-max.Thus, it is very important to look at the response of blood lactate during exercise. Lactate accumulation starts to increase after reaching the anaerobic threshold at a blood lactate concentration of 4 $mmol.l^{-1}$ (Kinderman et al., 1979; Kinderman, 1985; Heck, 1991). The ability to generate a high lactic acid level at high intensity exercise can be increased with specific "anaerobic training". The blood lactate level of well- trained athletes have shown to be 20% to 30% higher than those of untrained athletes under similar circumstances (McArdle et al., 1991). In this study, all subjects had similar fitness levels. The findings obtained during the VO_2-max test involving maximal lactate levels, show that the new developed pedal crank enabled the athletes to reach higher maximal lactate levels than on the traditional pedal crank set. The new designed pedal crank set is thus beneficial to cyclists, because of the ability to reach higher maximal lactate levels (McArdle et al., 1991; Dassonville et al., 1998). These results basically indicate that athletes would be able to cycle in the anaerobic zone for a longer period before fatigue occurs when making use of the new designed pedal crank set.

No significant difference was found between lactate values at minimum speed ($p = 0.36$) between tests 2 and 4. The kind of pedal crank does not seem to have an influence on lactate at minimum speed. In all the cases the subjects were pedalling below their anaerobic threshold while pedalling at minimum speed. During light and moderate exercise intensities, the energy demands of both groups are adequately met by the reactions that use oxygen. ATP is therefore made available predominantly through the energy generated by the oxidation of hydrogen (McArdle et al., 1991). According to Wasserman & Mellroy (1964) and Schneider et al. (1989) an increase in blood lactate accumulation occurs only after the anaerobic threshold is reached. This explains why there are no measurable differences in lactate concentrations while pedalling at minimum speed during the first stages of a VO_2-max test.

(a)



(b)

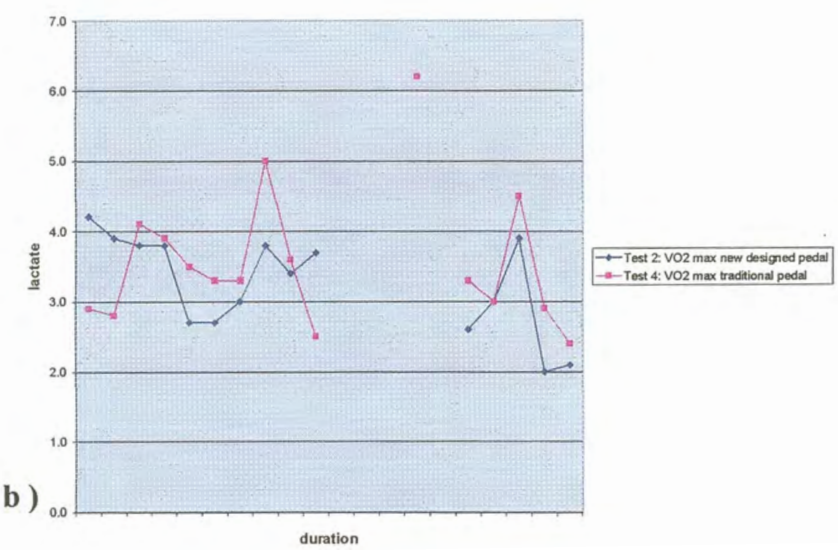


Figure 53: Differences in lactate levels during VO_2-max tests at (a) maximum and (b) minimum speed on the two different pedal crank sets.

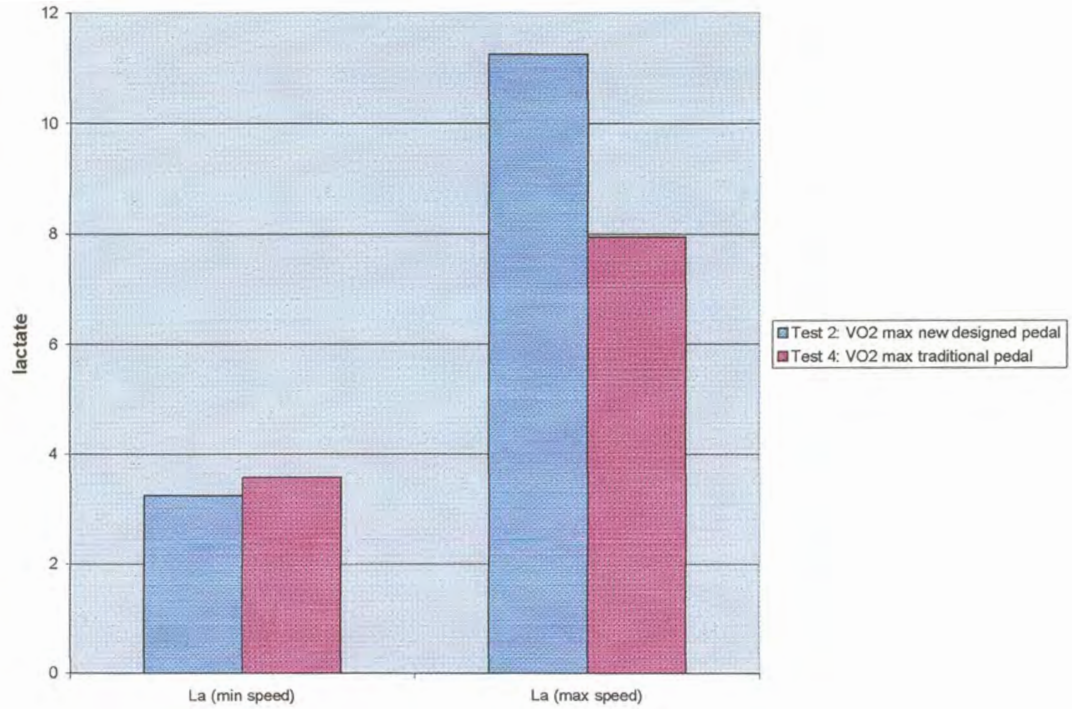


Figure 54: Average lactate levels in test 2 vs. test 4

Table 11: Descriptive data: Wilcoxon rank order tests for lactate at maximum and minimum speed for test 2 and 4

	N	Mean	Std Dev	Minimum	Maximum
La2-max	15	11.27	2.63	7.10	16.90
La4-max	16	8.66	2.07	5.60	11.70
La2-min	15	3.24	0.70	2.00	4.20
La4-min	16	3.58	0.99	2.40	6.20

There is a strong statistical positive correlation ($p<0.01$) between heart rate and lactate levels at minimum speed. This means that the higher the heart rate is at the beginning of the test the higher the lactate levels will be (fig. 55 and fig. 56). Lactate is one of the products of glycolysis and is both *produced* and *used* by the muscles. The rate of production increases as the exercise rate increases and as more carbohydrate is used as fuel for exercise (Noakes, 1992). Thus, the harder the person exercises, the higher the heart rate rises and the more lactate will be produced. More oxygen is used at a higher heart rate and also more waste products are formed. If the cyclist's heart rate is lower at the beginning, the oxygen consumption will be better and he will have a more economical way of movement.

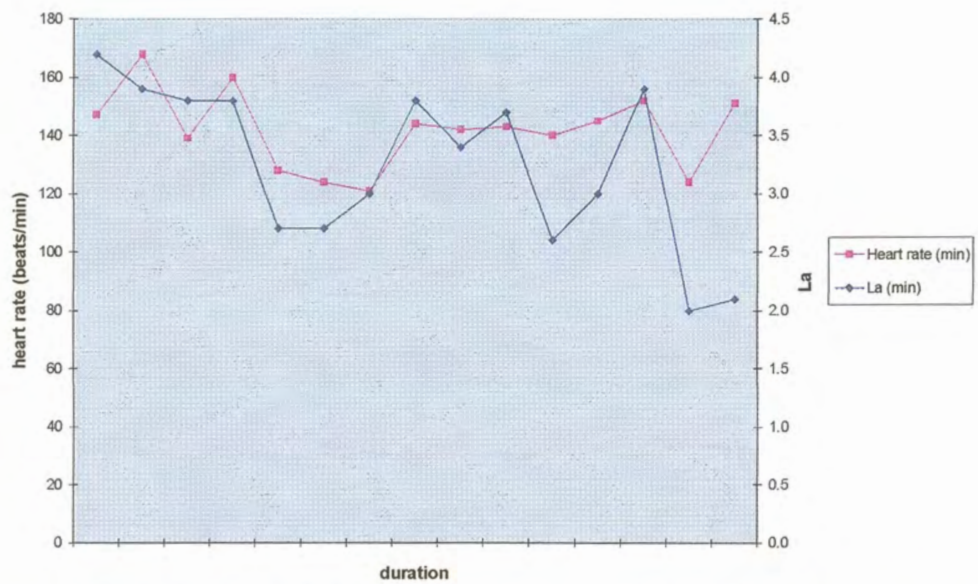


Figure 55: The correlation between heart rate and lactate levels at minimum speed during Test 2 (new designed pedal crank)

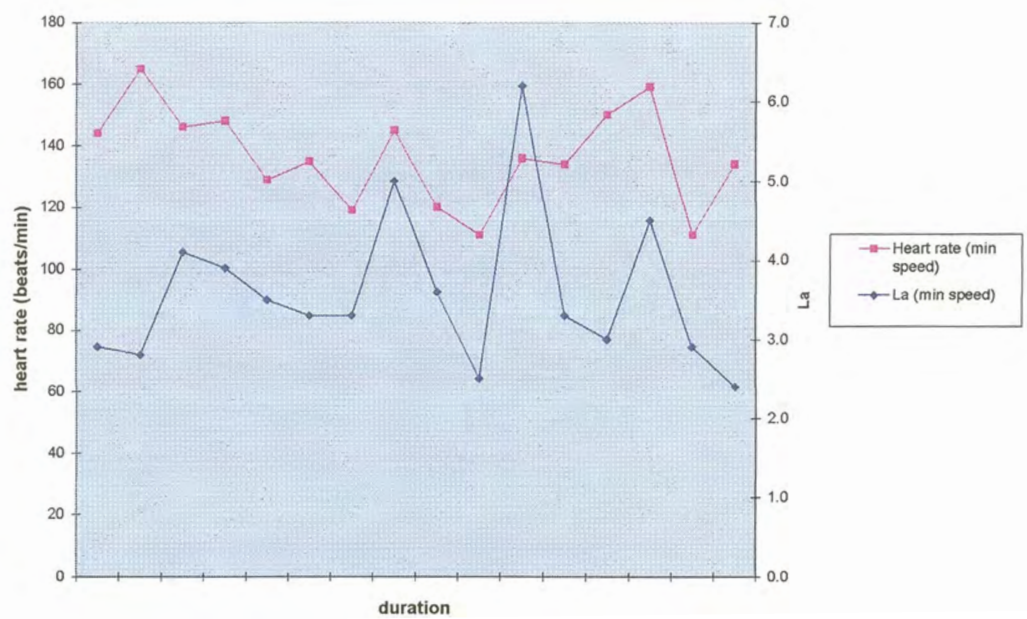


Figure 56: The correlation between heart rate and lactate levels at minimum speed during Test 4 (traditional pedal crank)

4.2.3 Heart rate scores at minimum and maximum speed during a VO_2-max test

There was a statistically significant difference between the heart rate scores at the minimum speed ($p < 0.01$) and maximum speed ($p < 0.001$) on test 2 and 4. In the majority of cases the heart rate scores on the traditional pedal crank set (test 4) were lower than on the new designed pedal crank set (test 2). Thus, the heart rate scores were significantly higher at both minimum and maximum speed when making use of the new designed pedal crank rather than with the traditional pedal crank set (Figure 57). Schulman & Gerstenblith (1989) define heart rate as the frequency of contraction of the heart. Two factors that reduce the maximum heart rate, are endurance training and heart disease. Highly- trained athletes have maximum heart rates which are lower than expected for their ages (Noakes, 1992). None of the subjects suffered from any form of heart disease, and they all had more or less the same activity level. Physiologically, according to Davis (1985) and Noakes (1992), it is not beneficial for the athlete to have increased heart rates at low, moderate or high training intensities. However, Mandroukas (1990) and Heil et al. (1997) found that a change in any biomechanics of cycling requires a learning period for the athlete. In this study the athlete did not get sufficient time to get used to the new pedal crank set, which may have had an effect on the heart rate response during the first few minutes of cycling.

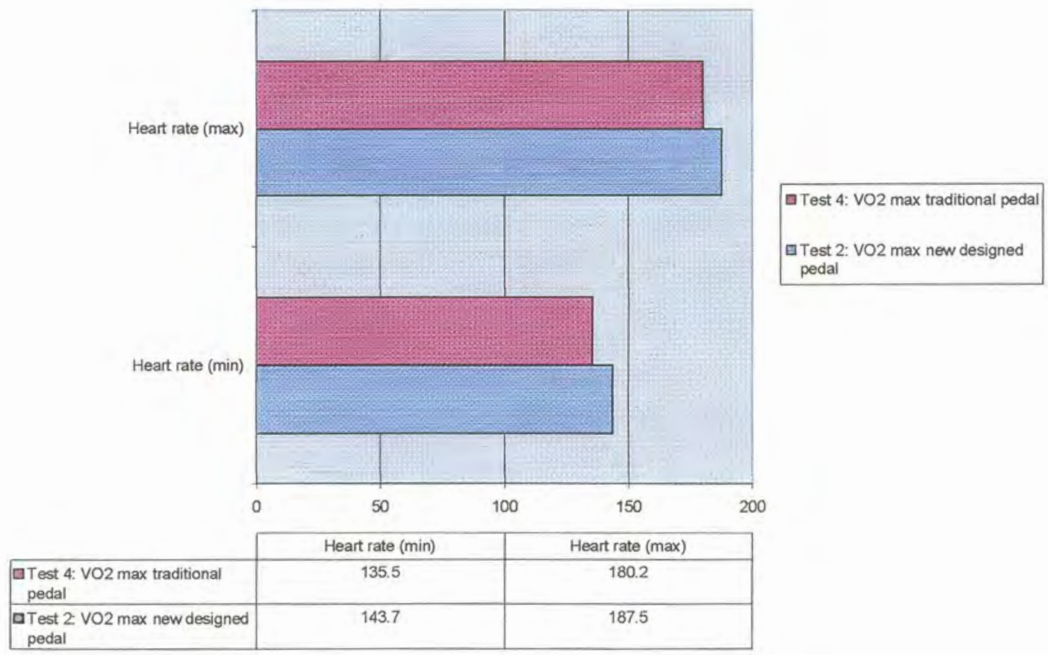


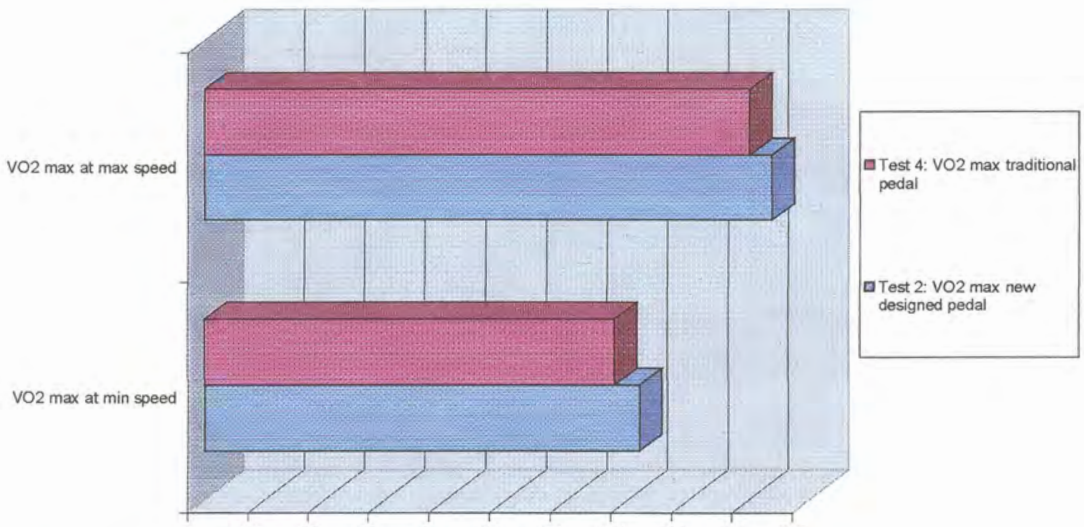
Figure 57: Average heart rate scores obtained at minimum and maximum speed during VO_2-max tests on the two different pedal crank sets.

Table 12: Descriptive data: Wilcoxon rank order tests for heart rate (HR) at maximum speed during VO_2-max tests (test 2 and 4).

	N	Mean	Std. Dev	Minimum	Maximum
$HR_{min}2$	20	143.70	12.10	121.00	168.00
$HR_{min}4$	20	135.50	14.63	111.00	165.00
$HR_{max}2$	20	187.50	8.78	170.00	201.00
$HR_{max}4$	20	181.75	8.63	164.00	196.00

4.2.4 VO_2 scores during VO_2-max tests

No significant differences were found on VO_2 scores at minimum ($p = 0.60$) or maximum ($p=0.57$) speed in tests 2 and 4. The kind of pedal crank does not seem to have an effect on the oxygen consumption when doing a VO_2-max test (fig. 58). Hawley (1995) defined VO_2 as the rate at which oxygen can be consumed during exercise and is a reflection of the individual's maximum rate of energy utilization. According to Schneider et al. (1989) VO_2-max has a moderate to poor correlation with the performance of tri-athletes, for there are several aspects influencing VO_2-max, including temperature and genetics. According to Noakes (1992) and Loftin & Warren (1994) the ventilatory threshold and economical movement are more important determinants of cycling and running performance than VO_2- max.



	VO2 max at min speed	VO2 max at max speed
Test 4: VO2 max traditional pedal	135.5	180.2
Test 2: VO2 max new designed pedal	143.7	187.5

Figure 58: Average VO_2 scores obtained at minimum and maximum speed during VO_2-max tests on the two different pedal crank sets.

Table 13: Descriptive data: Wilcxon rankorder tests for oxygen consumption at minimum and maximum speed during VO_2-max tests (test 2 and 4).

	N	Mean	Std. Dev.	Minimum	Maximum
$VO_{2\text{-}min}2$	20	24,06	5.39	15.60	32.80
$VO_{2\text{-}min}4$	20	23.39	3.52	17.50	31.70
$VO_{2\text{-}max}2$	20	43.98	7.74	33.30	59.60
$VO_{2\text{-}max}4$	20	41.97	7.31	32.60	60.20

A strong positive correlation ($p<0.01$) was found between heart rate and VO_2 at maximum speed during a VO_2-max test. The results indicate that the lower scores in heart rate correlate with the lower VO_2-scores and the higher heart rate scores correlate with higher VO_2-scores (fig. 59, 60 and 61). The rate of oxygen consumption rises rapidly during the first few minutes of exercise and then reaches a plateau. At this stage, oxygen consumption reactions supply the energy required for exercise (McArdle, 1991; Swensen et al., 1998). Thus, the harder the muscles are working, the more oxygen is consumed. According to Berg (1984) and Schulman & Gerstenblith (1989), heart rate is also influenced by the activity level of the athlete and can be used to predict VO_2-max. Davis (1985) and McArdle et al. (1991) supported these findings that there is a linear relationship between heart rate and VO_2-max during sub-maximal and maximal exercise. The athlete can use his heart rate to predict his estimated VO_2-max during cycling. Because of the linear relationship between heart rate and VO_2-max, the athlete will be able to reach a higher VO_2-max if he can push his heart rate to its maximum.

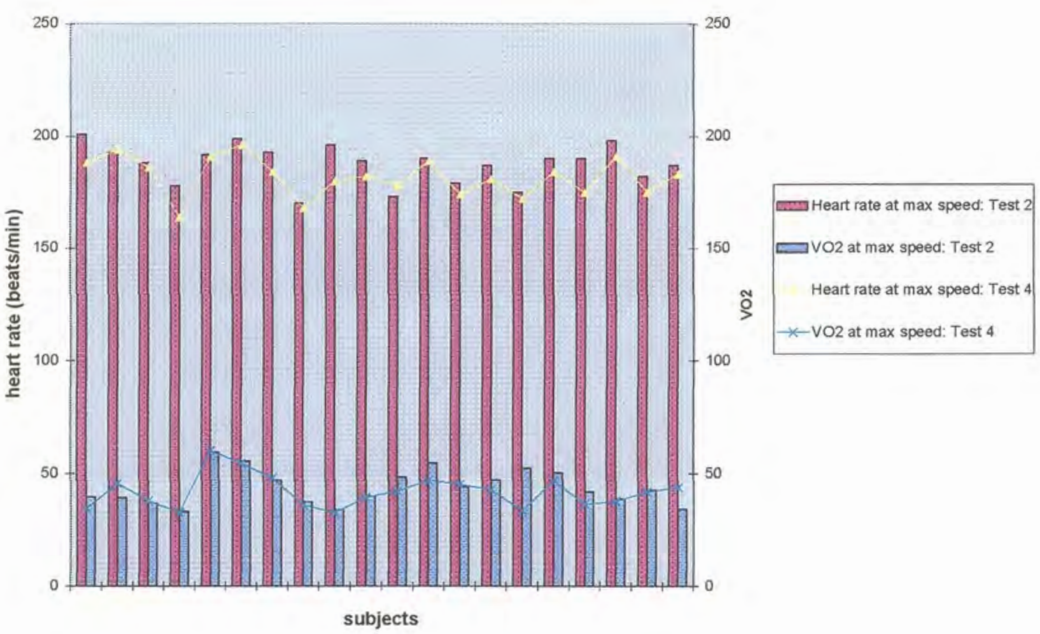


Figure 59: The correlation between heart rate and VO_2 at maximum speed during Test 2 and Test 4.

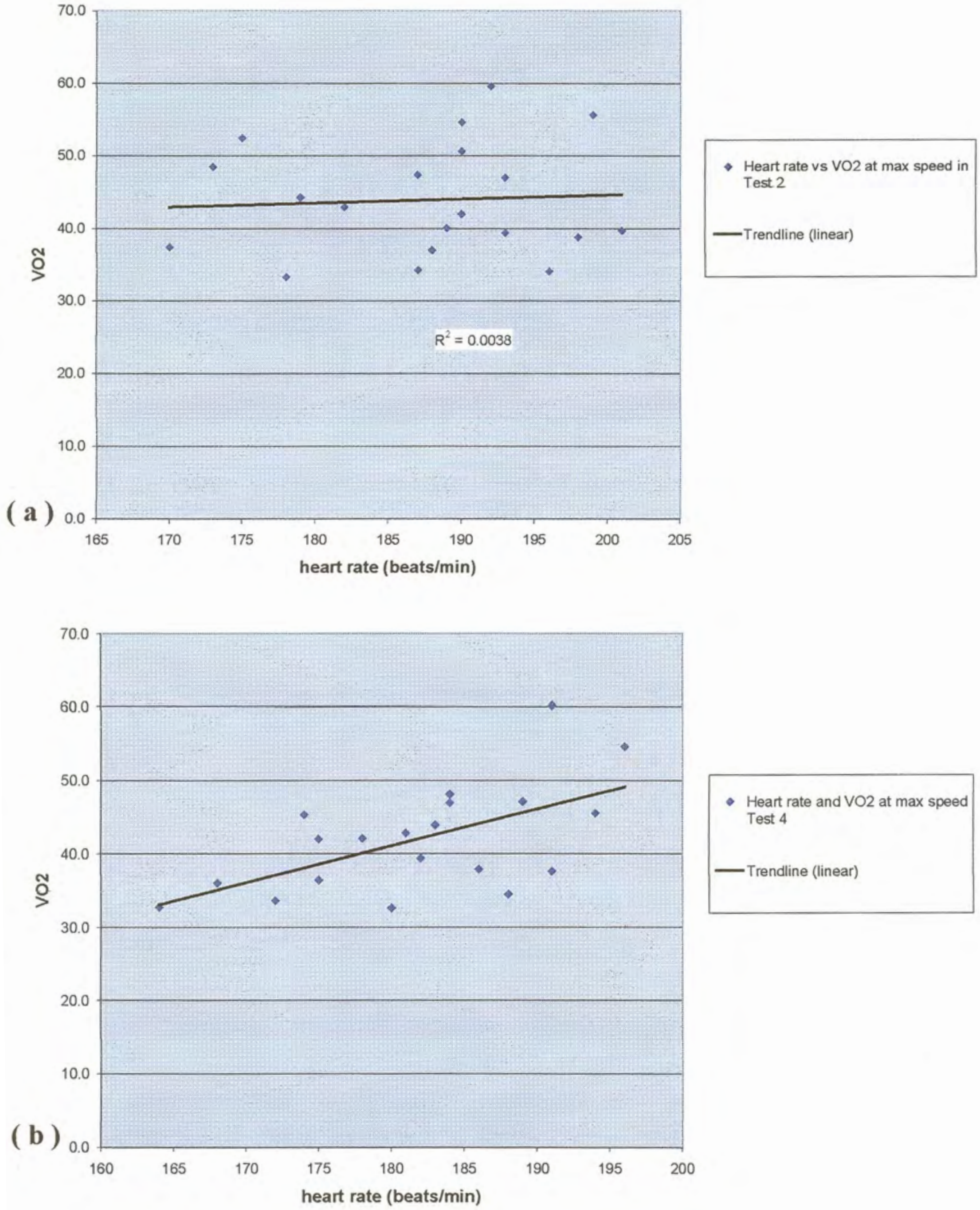


Figure 60: A linear trendline illustration of the correlation between heart rate and VO_2 at maximum speed during (a) Test 2 and (b) Test 4

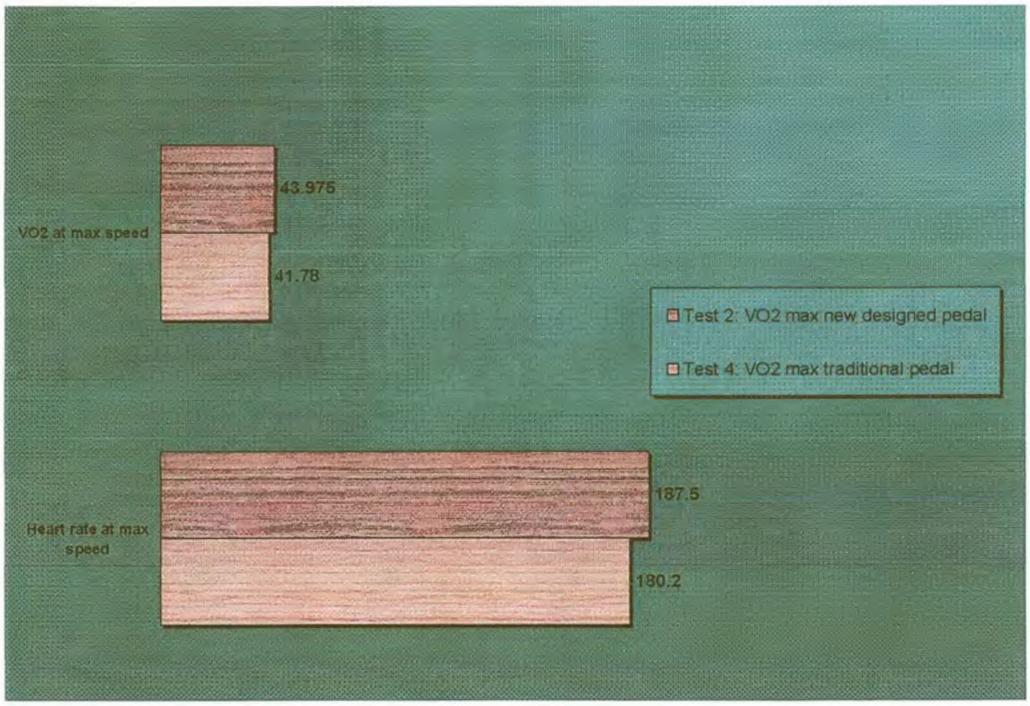
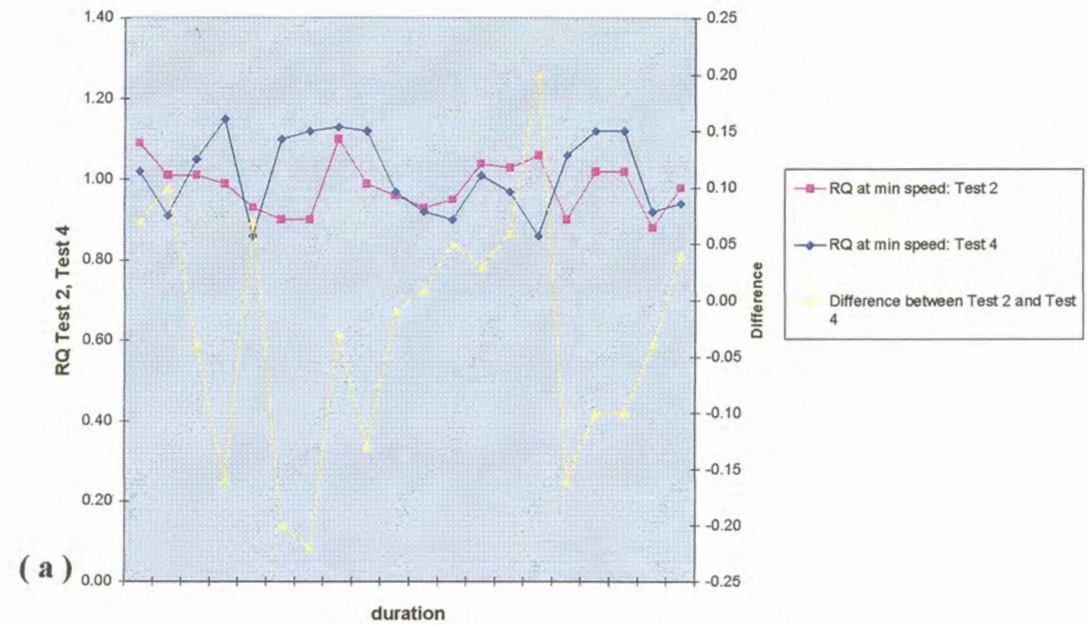


Figure 61: Average heart rate and VO_2 values at maximum speed in test 2 and test 4.

4.2.5 RQ scores during VO_2-max tests

No significant differences were found on RQ scores at minimum ($p=0.36$) or maximum ($p=0.30$) speed in tests 2 and 4. The kind of pedal crank does not seem to have an effect on RQ scores at minimum or maximum speed during a VO_2-max test (fig. 62). The RQ is dependent on the *substrate* metabolized during exercise (Pannier et al., 1980; McArdle et al., 1991). According to Astrand & Rodahl (1986) and van der Plas (1989), the RQ serves as a useful guide to the nutrient mixture being catabolized for energy and also to estimate the body's heat production. Their values are dependent on the substrate in the athlete that is being used to produce energy and will vary from person to person (Pannier et al., 1980; McArdle et al., 1991).



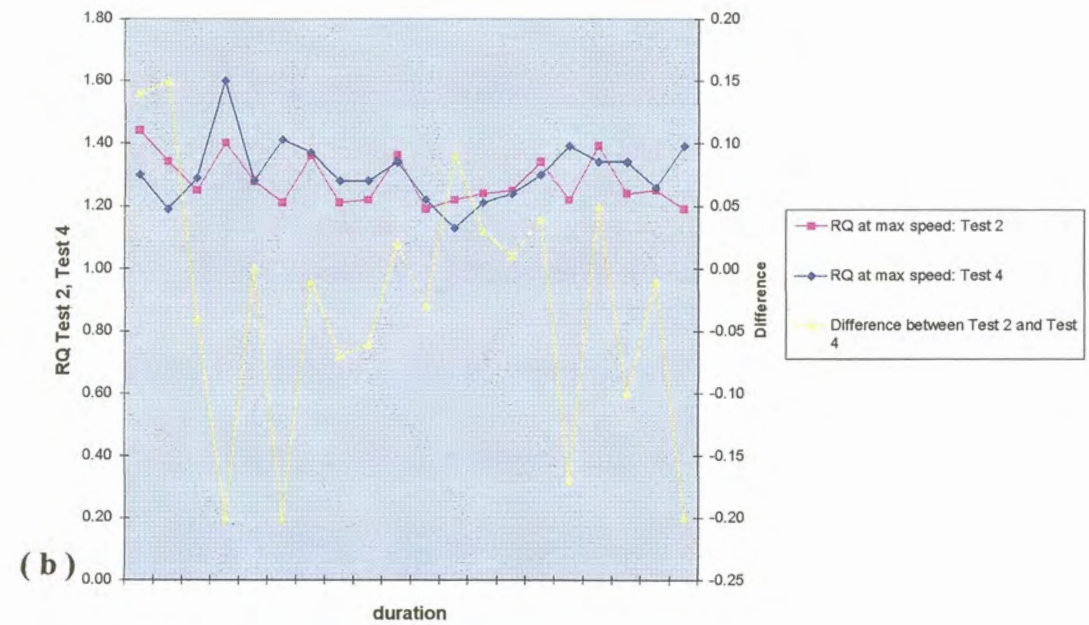


Figure 62: Differences in RQ scores obtained at (a) minimum speed and (b) maximum speed during VO_2-max tests during Test 2 and Test 4.

Table 14: Descriptive data: Wilcoxon rank order tests for respiratory coefficient (RQ) at minimum and maximum speed during VO_2-max tests (test 2 and 4).

	N	Mean	Std. Dev.	Minimum	Maximum
$RQ_{min}2$	20	0.98	0.06	0.88	1.10
$RQ_{min}4$	20	1.01	0.10	0.86	1.15
$RQ_{max}2$	20	1.28	0.08	1.19	1.44
$RQ_{max}4$	20	1.31	0.10	1.13	1.60

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

The compulsion to test one's abilities against those of others is inherent in human nature (Rushall & Potgieter, 1987; Beneke et al., 1989). One of the first things people wanted to do while cycling, was to go faster than anyone else. This obsession with speed and competition can be seen in most cyclists (Burke, 1986; Beneke et al., 1989). Science has identified various factors that can influence cycling performance, including maximal oxygen consumption, lactate or ventilatory threshold, economy of movement, body composition, muscle fibre type and years of cycling experience (Kyle & Burke, 1984; Krebs et al., 1986; Brandon & Boileau, 1987; Coyle et al., 1988; Brandon & Boileau, 1992). This has led to significant debate among engineers and physiologists concerning the biomechanics of the pedal crank set. The well- known cycle pedal mechanism, as everybody knows it, has been unquestionably accepted and unsuccessfully challenged for many decades. Any improvement, however marginal it may be, will in all probability affect the cycling community worldwide. By creating a **new crank drive**, it should allow optimal adaptation to the biological system of the human body (Burke, 1986). Empirical measurements have shown that cyclists apply the largest forces in the area of 135 degrees past 'top dead centre' (TDC). This is due to muscle-physiological reasons. In cycling with the new designed pedal crank, the goal is to produce maximal torque in the biologically favourable working regions of the muscle system (Burke, 1986; Ericson & Nisell, 1988; Power Pedal I, 1993). Going through the literature leads one to ask whether or not, and to what extent, a different pedal crank mechanism could benefit the cyclist.

The subjects that participated in this study were 20 biokinetics students, males and females, all aged 20 to 24 years. Each subject was tested both on the traditional pedal crank as well as the new designed pedal crank. This means that each subject formed part of the experimental group as well as the control group and the results of each person were measured against his own results. The test commenced with a measurement of the subject's height and body mass. Thereafter, specific tests were carried out as discussed under Procedures in Chapter 3 (3.2).

To recapitulate, the study undertaken was delimited to an experimental epidemiological study. The purpose of this study was to determine a way in which the athlete could optimize his oxygen consumption. The primary aim of the study was to determine whether a variation in the crank lever arm length would influence economical movement and the ventilatory threshold of the cyclists. Secondly, the study focused on the biomechanical working of the leg action while pedalling and the influence of different crank lever arms on muscle fatigue. In the light of the results discussed in Chapter 4, the conclusions and recommendations are presented accordingly:

Results of the tests done to determine **economical movement**, showed that there was a significant difference for **VO_2** scores ($p<0,02$) with the VO_2 scores being higher on the traditional pedals than the new designed pedals. A significantly strong positive correlation ($p < 0.05$) was found between the **heart rate and RQ** scores, with a strong tendency that the higher the heart rate scores the higher the RQ score. The correlation between heart rate and RQ scores was higher when making use of the new designed pedal crank set than with the traditional pedal crank set in test 3. These results also indicate that there is no statistically significant difference ($p < 0.05$) between the **hamstrings and quadriceps** peak power output after the various tests.

Results of the tests done to determine **VO_2-max,** showed that a statistical significant correlation ($p < 0,05$) was found between **heart rate and VO_2-max.** The higher the heart rate, the higher the VO_2 on both pedal cranks. There was a strong positive correlation ($p < 0.05$) between the **heart rate and VO_2**, which shows that lower scores of heart rate correlate with lower scores of VO_2 and higher scores of heart rate correlate with higher scores of VO_2. A statistically significant difference ($p = 0.02$) was found between the **heart rate at the ventilatory threshold** during a VO_2-max test on the two crank sets. The heart rate at the ventilatory threshold was significantly higher when making use of the new designed pedal crank set. A significant difference was found between the **lactate scores at maximum speed** ($p = 0.01$), with the lactate scores being significantly higher at maximum speed when making use of the new designed pedal crank. There is a strong statistically positive correlation ($p=0.02$) **between heart rate and lactate levels at minimum speed**. This means that the higher the heart rate is at the beginning of the test the higher the lactate levels will be. There was a statistically significant difference between the **heart rate** scores at the **minimum speed** ($p = 0.01$) and **maximum speed** ($p = 0.01$). The heart rate scores were significantly higher at both minimum and maximum speed when making use of the new designed pedal crank. A strong positive correlation ($p=0.01$) was found between **heart rate and VO_2** at maximum speed during a VO_2-max test. The results indicate that the lower scores in heart rate correlate with the lower VO_2-scores and the higher heart rate scores correlate with higher VO_2-scores.

No significant difference was found between **lactate values at minimum speed** ($p>0.5$), **VO_2** scores at minimum ($p = 0.60$) or maximum ($p=0.57$) speed, and **RQ** scores at minimum ($p=0.36$) or maximum ($p=0.30$) speed in tests 2 and 4. The kind of pedal crank does not seem to have an effect on any of these physiological variables.

Due to the results of the parameters obtained from the physiological tests, the two hypotheses of this study can thus be accepted. It is important to notice that the two important indicators of improved physiological functioning during cycling, showed a positive improvement. The ventilatory threshold occurred at a higher heart rate with the new designed pedal crank, which is a positive physiological indicator (Conley & Krahenburt, 1980; Coyle et al., 1991; Hoffmann et al., 1993; Loftin & Warren, 1994). Also, the results indicated that the oxygen consumption (VO_2)

stayed lower during the test for economical movement, which indicates a more economical use of oxygen when using the new designed pedal crank (Ericson & Nisell, 1988; Coyle et al., 1992; Hawley, 1995).

The hypotheses of this study have been successfully completed according to the results obtained during the tests and the supporting literature. There are, however, certain aspects in the physiology and biomechanics of cycling that need further research (Heil et al., 1997). The following recommendations are thus made to expand on the improvements and scientific knowledge of cycling:

- although the subjects had a warm-up period on the day of the test, the belief is held that the subjects should be able to exercise on the new pedal crank for a few days prior to the test in order to adjust to the different biomechanical working;
- a larger group of subjects must be used for the tests;
- the same tests should be done in the field in order to see the effect of cycling a route outside a controlled environment;
- a comparative study can be done to compare recreational, competitive and professional cyclists; and
- more research must be done on the effect of different saddle heights and the positioning of the subject when changing the biomechanics of the pedal crank.