EFFECT OF SADDLE SETTINGS AND TOE CLIPS ON EXERCISE BIKES IN REDUCING ENERGY EXPENDITURE

by

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B.E (Mechanical), University of Madras,

India, 1979

A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Industrial Engineering

KANSAS STATE UNIVERSITY

Manhattan, Kansas

1983

Approved by:

Major Professor

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ACKNOWLEDGEMENT

The author wishes to express sincere appreciation to Dr. Stephan A. Konz, his major professor, for his continuous guidance throughout this study.

Gratitude is extended to Dr. Corwin A. Bennett and Dr. Frederick H. Rohles, Jr. for serving on the committee. Sincere thanks are extended to Dr. Dallas E. Johnson for his help in statistical analysis.

Special thanks is offered to all the personnel at the Institute for Environmental Research for their help in conducting the experiment.

Last but certainly not the least, the author is very much indebted to his parents without whose encouragement and support this graduate program would not have materialized. It is to them that this work is dedicated.

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INTRODUCTION

Despite rapid technological development, if there is one machine which still depends upon man as a controlled power source, it is the bicycle. At a time when the appropriateness of technology is being questioned daily, the bicycle, which is perhaps the most "appropriate" and efficient machine ever invented , is making a rocky comeback in many countries. The increase in importance of bicycles has been exemplified by the increased world production of bicycles. From the year 1971 through 1979, about 96 million bicycles were bought by the American public (Sloane, 1980). The bicycle has come under close scrutiny by those who believe that it offers great potential for performing stationary work and for goods transportation. The bicycle posseses many advantages over other forms of transportation such as its small demand for energy and material resources, almost nil pollution effects, and positive contribution to health. In addition to its conventional uses, the bicycle driving mechanism also can be considered as a means for converting human energy directly into rotary motion, a form in which power generally is required to drive a machine.

The useable external power output of the body is limited to about 6 hp for short durations (about 1 s); 0.5 - 2.0 hp for 0.1 - 5.0 min; 0.4 - 0.5 hp for 5 - 150 min, and up to 0.2 hp for long durations of about a day (Wilkie, 1960). Harrison (1970) estimated that maximum power (2 hp for 6 s, 1 hp for 1 min, and 0.75 hp for 2 min) could be achieved using a rowing motion and that about 0.4 - 0.5 hp of power production could be maintained for a considerable period of time (of the order of an hour or so).

However, in addition to all the beneficial attributes, the bicycle has certain shortcomings. The riding position and the pedal crank power input are not ergonomically optimum (Whitt and Wilson, 1974). Only when the bicycle is

designed and adjusted to fit the operator can maximum comfort, efficiency, and performance be achieved. The same is true in the case of human powered generators (HPG). The criteria for the design of a bicycle and a HPG are different in the sense that wind resistance, balancing, etc. need not be considered in the design of a HPG.

SURVEY OF LITERATURE

Seat height

The seat (saddle) allows the operator to sit on the bicycle, relieving the leg muscles of their supporting function and resulting energy consumption. Hamley and Thomas (1967), in an experiment conducted at 105, 109, 113, and 117% of symphysis pubis height (height of inside leg from floor to the bone in the crotch, known as pubic symphasis palpation), found that a value of 109% of symphysis pubis height was the most efficient in terms of power output. A 4% saddle height alteration affected the power output by approximately 5%. (Refer to Figure 1 and Tables 1 and 2). Shennum and Devries (1976) conducted an experiment in which five subjects were tested at saddle heights of 100, 103, 106, 109, and 112% of inside leg length-- measured from the ishium (the bones which support the weight of the body while sitting) to the floor. They indicated that physiological cost could be minimized at a seat height of 104% of leg length. (Refer to Figure 1 and Tables 1 and 3). Nordeen-Snyder (1977), in a study to measure the efficiency at three bicycle saddle heights of 95, 100, and 105% of trochanteric leg length (the vertical distance from the standing surface to the most superior point of the greater trochanter of the femur) and to discern the kinematic patterns described by the hip, knee, ankle joints and the foot, indicated that the saddle height of 100% of trochanter leg length (corresponding to 107% of symphysis pubis height used by Hamley and Thomas) was the most efficient in terms of oxygen consumption. The mean oxygen consumption at 95, 100, and 105% saddle heights were found to be 105%, 100%, and 108%. (Refer to Figure 1 and Tables 1 and 4). The results indicated that the major adaptation to seat height occurs at the knee joint, with a 35% decrease in minimum knee angle from the low to high saddle heights. The amount of extention at the hip increased as the seat height was increased and so was the range of

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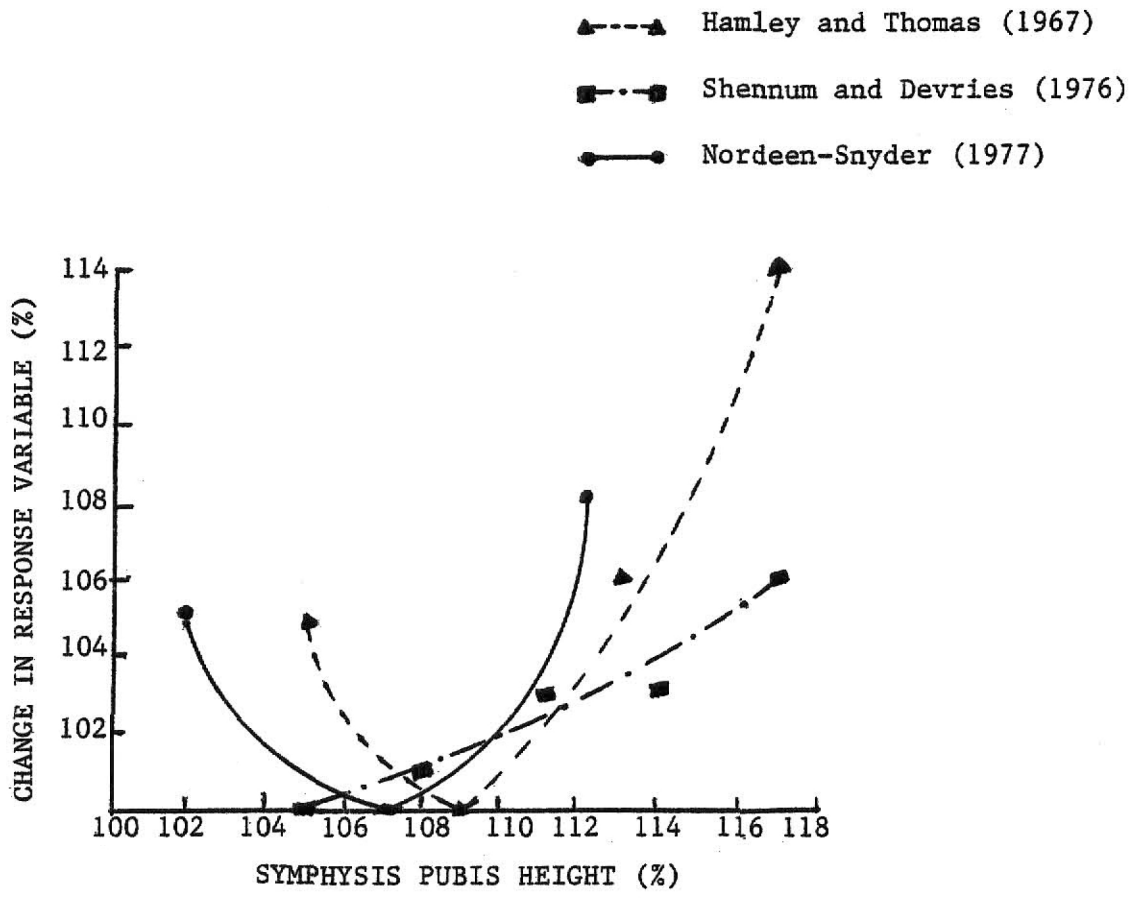


FIGURE 1. Comparison of studies done on optimum seat height

TABLE 1

Comparison of studies on bicycle seat heights

Study by	Saddle height %	Load watts	Cadence rpm	Number of subjects	Time of trial min	Response variable
Thomas and Hamley (1967)	symphysis pubis height 105 109 113 117	80 for lighter loads	90	100	---	Time to complete a preset work 8.5 s 8.1 s 8.6 s 9.2 s
Shennum and Devries (1976)	height from ishium to floor 100 103 106 109 112	50 to 200 in increments of 25 every third minute	60	5	18	VO_2 VO_2 Ve heart rate
Nordeen-Snyder (1977)	trochanteric height 95 100 105	130	60	10	8-10 (till HR reached steady state) 10 min rest	VO_2

TABLE 2

Study on seat height by Hamley and Thomas (1967)

Seat height % of symphysis pubis height %	additional time/ change %	Response variable time seconds
105	105	8.5
109	100	8.1
113	106	8.6
117	114	9.2

TABLE 3

Study on seat height by Shennum and Devries (1976)

Height as % height of ishium to floor %	Equivalent symphysis pubis height %	change in VO_2 %	Response variable VO_2 L/min
100	105	100	1.753
103	108	101	1.767
106	111	103	1.802
109	114	103	1.804
112	117	106	1.868

TABLE 4

Study on seat height by Nordeen-Snyder (1977)

Seat height % of trochanteric height %	Equivalent symphysis pubis height %	change in VO_2 %	Response variable VO_2 L/min
95	101.7	105	1.69
100	107.1	100	1.61
105	112.1	108	1.74

motion at the ankle. The results of the above three studies were compared on a common scale in Figure 1.

Seat tilt and location

In adjusting the saddle, Baranet (1973) suggested that the saddle should be horizontal or with a slight upward tilt at the nose to prevent the body from sliding forward.

Astrand and Saltin (1961) conducted tests on ergometers which showed that pedaling in the near horizontal position (supine position) is only about 80% as effective, from the point of view of efficiency of muscle usage, as the normal upright position (sitting position). Hertzberg (1972) indicated that the line from the pedal crank axis to the center of the saddle should be inclined 20 to 30 degrees behind the vertical.

Time of trial

Katch (1973) found the optimal duration of bicycle endurance performance, using max VO_2 as the criterion, to be 12 minutes. Using 50 male college students, he found that five individuals were able to perform the full twelve minute test at 68 rpm without any decrement while the others showed varying amounts of decrement (the average being 25%). Glesser and Vogel (1971) observed no significant increase in endurance time between six work-rest schedules of 63 - 0, 4 - 1 and 12 - 3, and 9 - 1, 18 - 2 and 27 - 3 minutes. In their experiment, eight subjects rode the bicycle at 40 rpm at a work load of 75% of their maximal VO_2 over a period of six weeks. They were able to ride the bicycle for 63, 89, 117, 113, 109 and 130 minutes in the six runs. Stamford and Noble (1974), while studying the optimal speed of pedaling, compared continuous versus intermittent work responses. Of the six experimental testing sessions, three tests involved 15 minutes of continuous work at 40, 60, and 80 rpm. Three additional tests performed at the same pedaling rates were

segmented into alternating three min work bouts and three min rest periods (intermittent work). A significant increase of 6.6% of heart rate value was found during continuous work over intermittent work. (Refer to Figures 2 and 3).

Knee angle

Clarke, Elkins, Martin, and Wakin (1950) found that the greatest strength occurs within the range of knee angles from 105 to 124 degrees. Woodson and Conover (1960) indicated that, for maximum strength, the angle at the knee should be about 120 degrees. Linford and Rarick (1968) indicated that static leg strength (as measured by a leg dynamometer) is the greatest and remains about the same when the angle is between 135 and 164 degrees. However none of the above three studies were conducted on a bicycle ergometer and all were conducted under static conditions.

Loads

Astrand, Hallback, Hedman, and Saltin (1963) found that an untrained subject cannot perform at more than 50% of his maximal oxygen uptake for one hour of continuous work. Astrand and Rodahl (1970) indicated that loads of 1.43 kcal/min (100 watts) for female subjects and 2.15 kcal/min (150 watts) for male subjects were suitable for short duration (about 6 min) work tests. Gaimby, Nilsson, and Sanne (1966) found, in a 30 minute exercise at 600 - 900 kpm/min (97 - 146 watts), that the cardiac output increases in the first seven minutes and then stabilizes.

Cadence

Sloane (1970) and Henkel (1972) indicated that a cadence of 65 to 85 crank revolutions per minute was a pace that could be maintained comfortably over a long period of time. These were personal opinions rather than empirical studies. A lower cadence of 60 rpm was found by Astrand and Rodahl (1970) to be suitable for long pedaling periods. Stamford and Noble (1974), in their study using

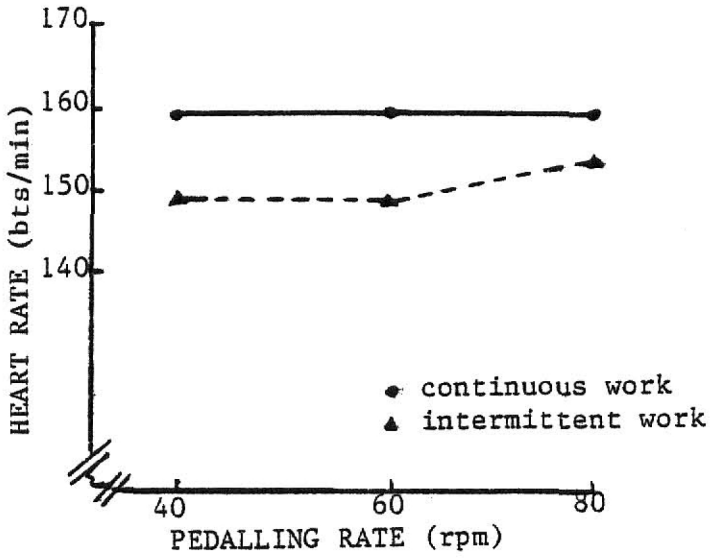


FIGURE 2. Heart rate for continuous versus intermittent work (as studied by Stamford and Noble, 1974)

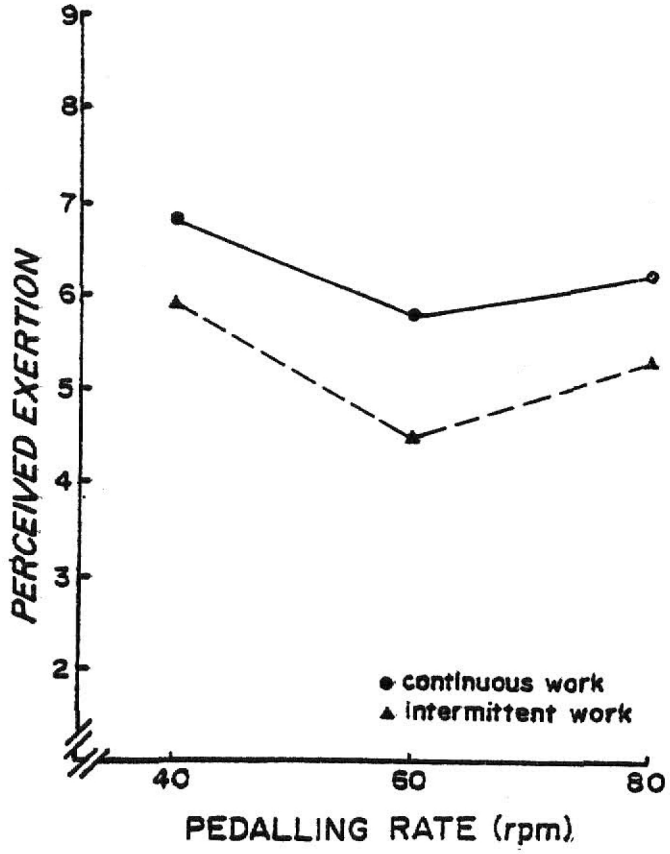


FIGURE 3. Perceived Exertion for continuous versus intermittent work (as studied by Stamford and Noble, 1974)

three speeds of 40, 60, and 80 rpm, observed that a speed of 60 rpm was the most efficient (VO_2 and heart rate) resulting in the least physiological cost. (See Figures 2 and 3). They indicated that 60 rpm was voted to be the least stressful rate of pedaling. Seabury, Adams, and Melvin (1977) conducted an experiment at speeds of 30 to 80 rpm in increments of 10 rpm, at various loads of 0, 82, 164, and 196 watts using three subjects. (Refer to Figure 4). The most efficient pedaling rate was found to increase with power output -- from 42 rpm at 41 watts to 62 rpm at 327 watts of load.

Toe clips

Tate and Shierman (1977) found that when toe clips are used, the tibialis anterior is working for a longer period of time than when toe clips are not used. The findings imply that the additional duration of the effort by the tibialis anterior when toe clips are used relieves the other muscles usually associated with cycling fatigue. Since toe clips prevent the foot from slipping from the pedals, they allow for the application of the force through the entire 360 degrees of pedal rotation. (See Figure 5). A useful feature of foot usage with pedals and cranks is that among the numerous muscle actions involved is that of ankle. Ankle movement can assist the pedaling action either through the classic "ankling" method or, when toe clips are fitted, through a "kicking forward" action at top dead center. Ankling brings into play the muscles of the ankle and permits full use of the leg muscles pulling up on one pedal while pushing down on the other. Instead of drawing propulsion power only from the leg muscles used in pushing down on pedals, ankling distributes muscle activity among three sets of muscles (gastrocnemius- commonly known as calf muscle and found on the back of the lower leg; rectus femoris- on the front of the thigh; biceps femoris- on the back of the thigh), thereby increasing power and endurance. This action, called ankling, results in saving of effort of about 15%

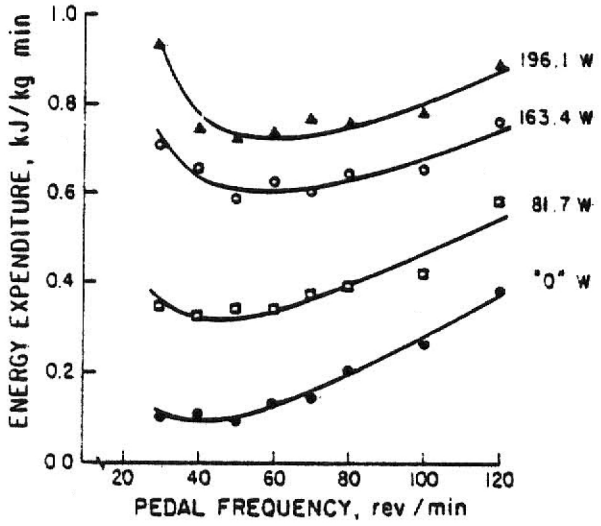


FIGURE 4. Energy expenditure versus pedaling rate (as studied by Seabury, Adams, and Melvin, 1977)

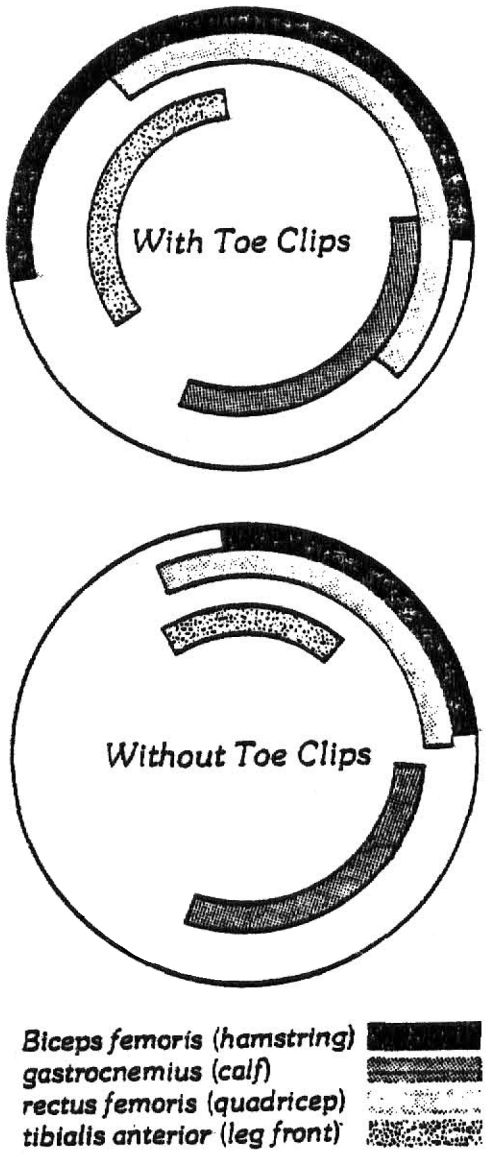


FIGURE 5. Application of muscle force during pedal rotation (as studied by Tate and Shierman, 1977)

as measured by the pedal thrust on a pen chart (Whitt, 1971).

Toe clips come in three sizes; small, medium and large. According to Call (1980), the toe of the operator's shoes should not touch the inside edge of the clips; if it does, chafing can occur. If the clips are too long, the top edge will hit the tongue of the shoes and chafe the top of the foot. In general, men who wear American shoe sizes from 6 to 8 should use the small size toe clips; those who wear shoe sizes from $8^{1}/2$ to 10 should use the medium size toe clips; and over shoe size 10 should use the large size toe clips. (Refer to Table 5).

TABLE 5

Selection of toe clip size based on shoe size

American shoe size	Toe clip size
6 - 8	small
$8^{1/2}$ - 10	medium
above 10	large

PROBLEM

As there has been little research done regarding the location (fore-aft adjustment) and tilt of the seat, it was felt necessary to determine the effect of various saddle settings considering the horizontal displacement and tilt. Also, earlier studies regarding use of toe clips for pedaling the bicycle could not clearly indicate the amount of energy (physiological cost) saved by using toe clips.

Specifically, the hypotheses were :

1. The use of toe clips while pedaling results in a reduction in the energy expenditure (heart rate).
2. There is a saddle position (horizontal and tilt) which causes the least energy (heart rate) to be expended by the operator.
3. Toe clips and saddle position affect perceived exertion.
4. Toe clips and saddle position affect comfort.

METHOD

Task

Subjects were seated on the bike (designed by the Federal Emergency Management Agency, FEMA) in an environmentally controlled room where the temperature was maintained at 77 degrees Fahrenheit and a relative humidity of 50%. They then pedaled the bike for 10 minutes at a constant pedaling rate of 60 rpm and at a constant work load of 100 watts. The experiment was repeated at various saddle positions (12 combinations of seat location, tilt, and use of toe clips) with a 20 minute rest/recovery period in between every test. During the rest period, the subjects sat on a chair.

Subjects

Ten males (age range 18 - 27, mean 20.5 years) were paid $20 each for participating in the experiment. The selection of subjects was made through advertisement. Only those subjects having a leg length less than 37 inches and height less than 6'5" were chosen (due to the equipment design limitation). Leg length was assumed to be 48% of stature height (Contini, 1972, as cited by Konz in Work Design, 1979). At the time of selection, an instruction/experiment orientation sheet (see Table 6) was given to the subjects and their age and bicycling experience details were recorded. The general physical characteristics of the subjects are given in Table 7.

Independent Variable

Three levels of seat location, two levels of seat tilt, and two levels of use of toe clips were used as independent variables for the experiment. The factors and the levels are given in Table 8. The pictorial representation of the independent variables is shown in Figure 6.

TABLE 6

Experiment Orientation Sheet

The experiment you are participating is to determine the optimum saddle setting in an exercise bike (designed by the Federal Emergency Management Agency for use in survival shelters for ventilation) and to find the effect of toe clips in reducing physiological cost while pedaling at a constant speed at a moderate load requiring some physical exertion.

Upon arrival, your inside leg length will be measured and you will be required to wear a heart rate monitor around you chest. You will be wearing your own clothes. Since all the subjects must be dressed in a similar fashion to minimize experimental error, you are requested to wear a T-shirt, trousers, socks, and athletic shoes during the experiment.

You will then be seated on the bike and the handlebar position will be adjusted to your convenience to keep your body in a straight position (approximately at an angle of 90^{o} with the horizontal). You will then be pedaling at a constant speed of 60 rpm as paced by a metronome. Each experimental session would be for 3 hours, during which you will be exposed to six different treatments. For each treatment, you will pedal for 10 minutes and rest for 20 minutes; you will be required to read your heart rate every 30 s; you will also be asked to indicate your opinion of how hard you are working. After about 72 hours, the experiment will be duplicated. The only difference will be the use or non use of toe clips while pedaling. You are required to wear the same type of clothing.

The following instructions should be followed:

1. Do not engage in energetic bodily activities during the day of the test.
2. Do not eat for at least one hour prior to the test.
3. Do not smoke for at least 30 minutes prior to the test.

If you have any questions, please ask Prabhakar (Durland Hall Room 231).

TABLE 6 (continued)

While your participation in the experiment will be recorded, your name will not be disclosed and anonymity will be maintained.

_____ _____

Name Date

Age : _____ Bicycling Experience : _____

Height : _____ Weight : _____

TABLE 7

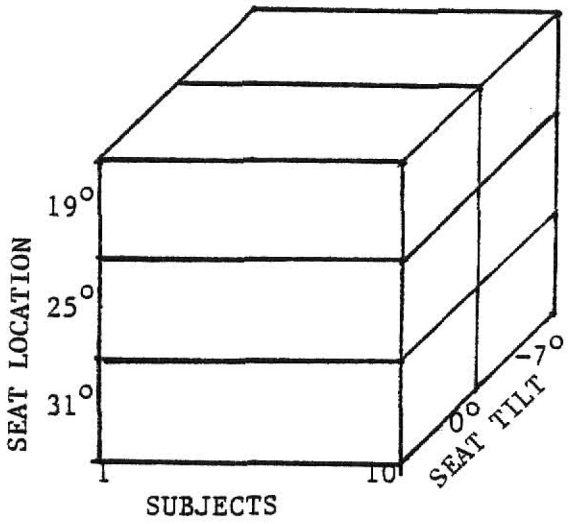
Subject Data

Subject #	Age yrs.	Bicycling Experience yrs.	Height ft-in.	Weight lbs.	symphysis pubis height inches
1	19	12	5-9	150	32.0
2	18	11	5-11	175	32.25
3	21	0	5-8	145	29.5
4	19	1	5-10	164	31.0
5	27	8	5-10	162	31.5
6	18	1	5-11	145	33.5
7	20	2	5-6	125	30.0
8	23	4	6-0	165	32.5
9	20	0	6-0	150	33.75
10	20	2	5-7	150	29.75

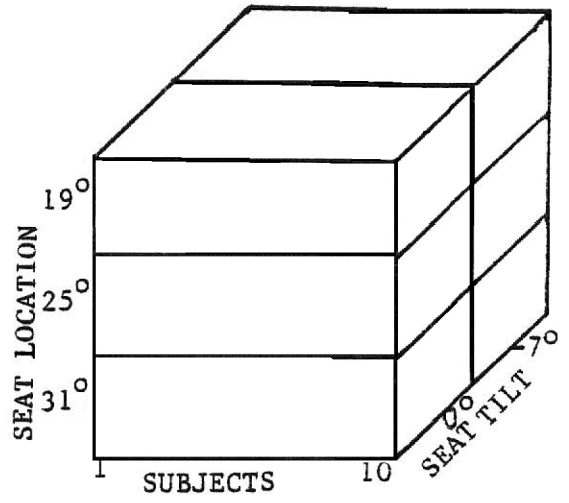
TABLE 8

Levels of Independent Variable

Factor	Levels
Location of seat (fore-aft adjustment)	19°, 25°, 31° with vertical
Seat tilt	0°, -7° with horizontal
Toe clips	with, without



with toe clips



without toe clips

FIGURE 6. Levels of independent variable

Criteria

Heart rate, Borg's Perceived Exertion Rating scale, and subjects opinion of the condition were used as criteria.

Heart rate. Heart rate sensors were attached to the subject's chest and then monitored by a heart rate monitor. The heart rate in beats/min was recorded every 30 seconds during the exercise period of 10 minutes and rest/recovery period of 20 minutes. The maximum heart rate permitted was around 150 beats/min. The data form is shown in Table 9.

Rating of perceived exertion. Once evry five minutes during the exercise and rest periods, the subjects rated their perceived exertion according to the RPE scale developed by Borg (1962). (See Figure 7).

Semantic-differential rating. The subjects were asked for their opinion or preference of the various conditions at the end of each test. The SD scale using various factors is shown in Table 10.

Equipment and measurement Techniques

Exercise Bike. An exercise bike (designed by FEMA for use in survival shelters to provide ventilation) was used in this study. (See Figure 8). The frame of the Bike Ventilation Kit is a one piece frame of 0.083 inch wall electric welded rectangular tubing 1.25 X 3.0 inches. The material used is steel. The rear support stand and the handlebar are separate and must be attached. The design feature of the bike included an adjustable seat support tube to provide an easy way to extend the seat-support tube to the desired height. A metallic plate with six holes was fabricated and fitted on to the seat support tube. This enabled the seat to be fitted at various angles with the vertical. (See Figure 9). This provision, along with the seat height adjustability, enabled the seat to be set both at a desired angle and at 107% of symphysis pubis height of the subject.

TABLE 9

Data Form

Subject # _____ Date _____ Time _____

Toe clips : with without Treatment # 1 2 3 4 5 6

Exercise

Minute	Heart rate	Borg Vote
0		
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

Rest

Minute	Heart rate	Borg Vote
0		
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		
16		
17		
18		
19		
20		

Vote		WORK LEVEL Subjective Description
6	---	
7	---	Very, very light
8	---	
9	---	Very light
10	---	
11	---	Fairly light
12	---	
13	---	Somewhat hard
14	---	
15	---	Hard
16	---	
17	---	Very hard
18	---	
19	---	Very, very hard
20	---	

FIGURE 7. Borg's Perceived Exertion (BPE) Rating Scale

TABLE 10

Semantic Differential Rating Sheet

Subject # _____ Date _____ Time _____

Toe clips : with without Treatment # 1 2 3 4 5 6

like	____:____:____:____:____:____:____	dislike
bad exercise	____:____:____:____:____:____:____	good exercise
uncomfortable	____:____:____:____:____:____:____	comfortable
easy	____:____:____:____:____:____:____	hard
useful	____:____:____:____:____:____:____	useless
inconvenient	____:____:____:____:____:____:____	convenient
interesting	____:____:____:____:____:____:____	disinteresting
dissatisfied	____:____:____:____:____:____:____	satisfied

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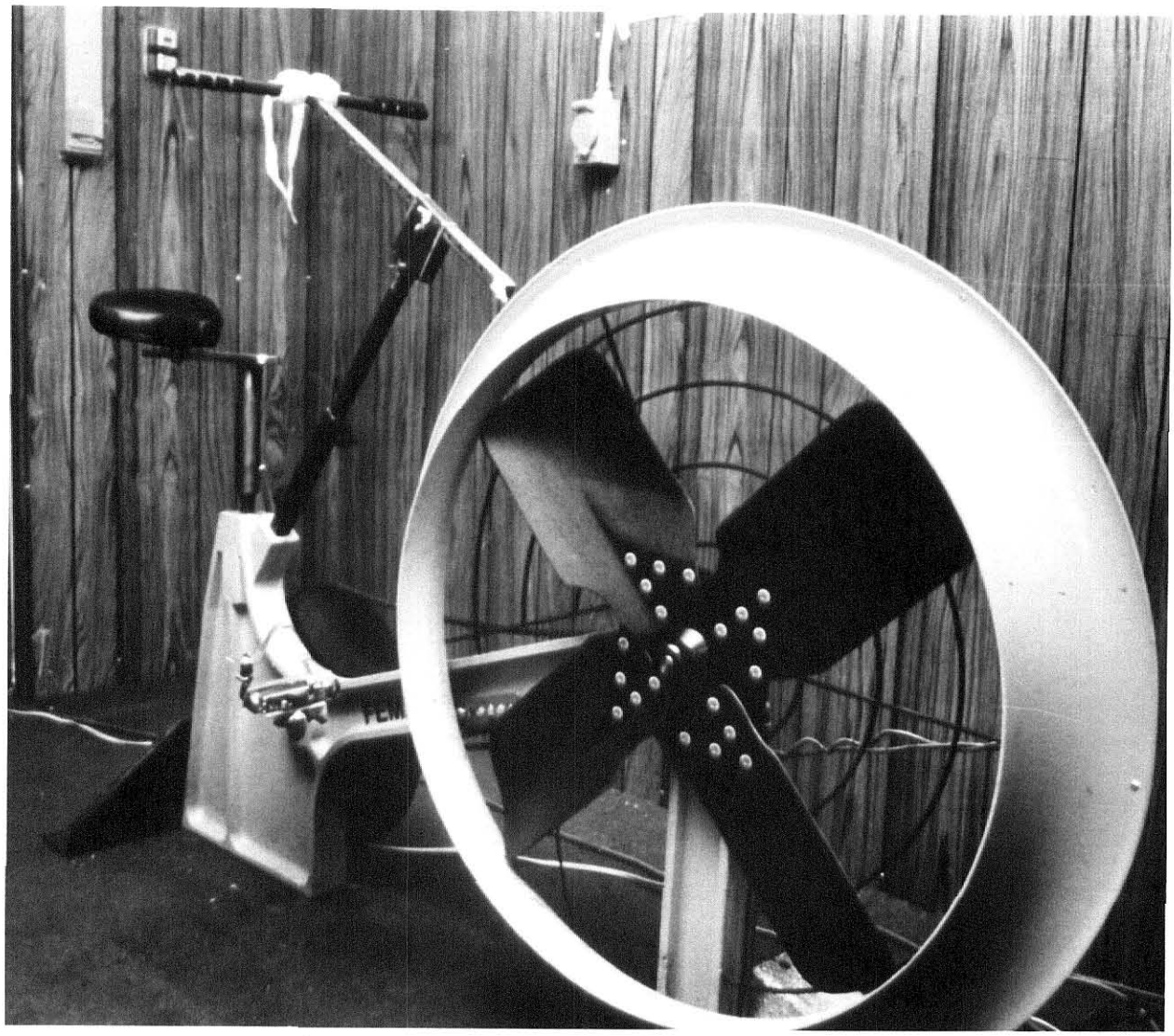

FIGURE 8. Photograph of the exercise bike designed by FEMA

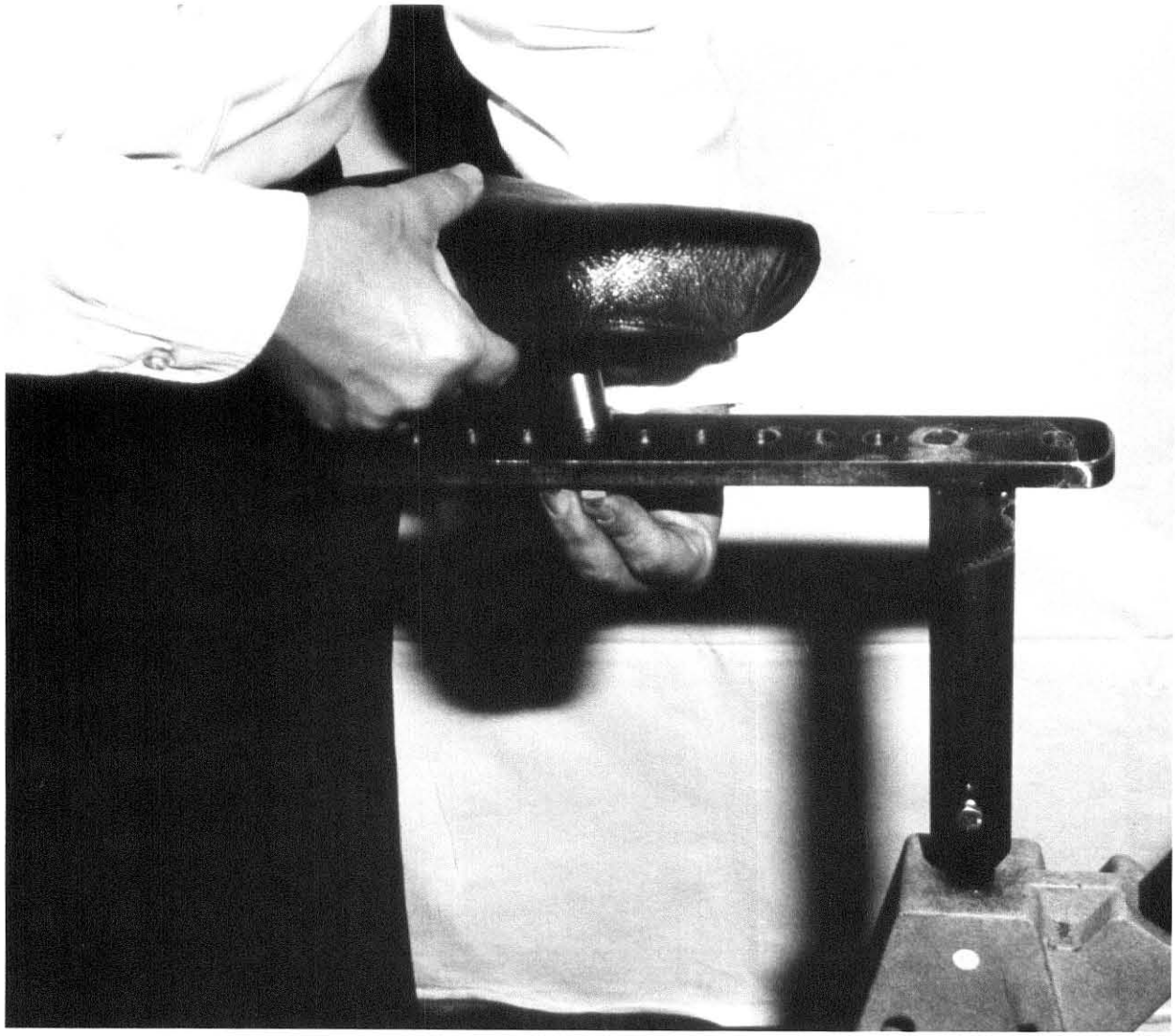

FIGURE 9. Photograph of seat location adjustment

Heart rate Monitor. A heart rate monitor (model Exersentry manufactured by Respironics, Inc.) (see Figure 10) was attached to the subject's chest to record the heart rate. Since the Exersentry is small and light weight (about the size of a deck of playing cards), it could be worn conveniently under standard clothing and presented no obstacles to movement and exercise.

Metronome. A metronome was used to enable the subject to pedal at the required speed. It is a small unit provided with a beeper and light. The metronome was set to make exactly 60 beats/min and by following this metronome timing (could be seen and could be heard), the subject was able to pedal at a speed of 60 rpm.

A time study board with stop watches was used to record the heart rate at regular intervals of time.

Procedure

Subjects wore their own clothing (T-shirt, trousers, socks, and athletic shoes; about 0.6 clo). Upon the subject's arrival, several anthropometric measures were recorded. These included the subject's inside leg length from "symphysis pubis" to the floor (refer to Figure 11) while standing erect with the back against the wall, height, and weight. Instructions regarding the experiment then was given to the subject (see Table 11).

The subjects were instructed not to engage in energetic bodily activities during the day of the test, not to eat for at least one hour before the test, and not to smoke for at least 30 min prior to the test. The purpose of these instructions was to reduce the influence these factors would have on the subject's heart rates.

The various treatment combinations were randomized (see Tables 12 and 13) and the saddle was positioned such that the distance from the seat to the pedal was 107% of symphysis pubis height of the subject. For tests with toe clips,

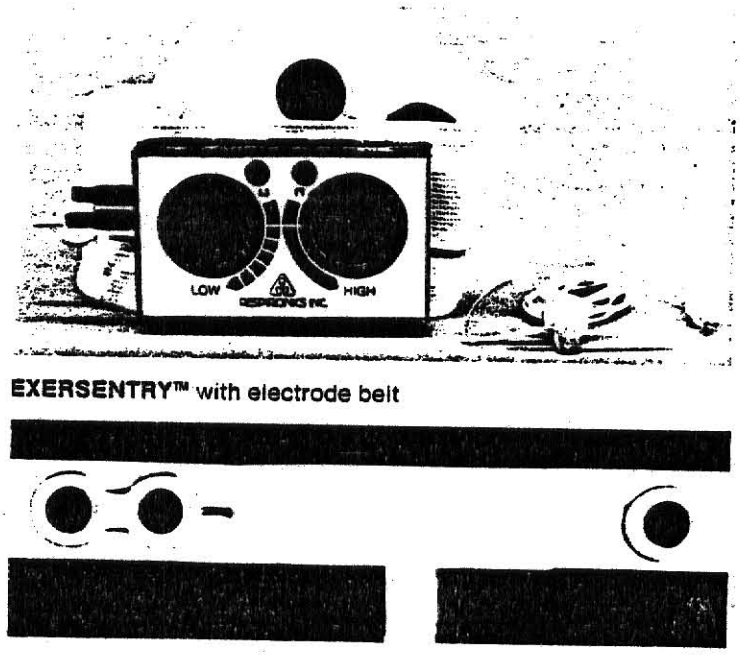

FIGURE 10. Heart rate monitor

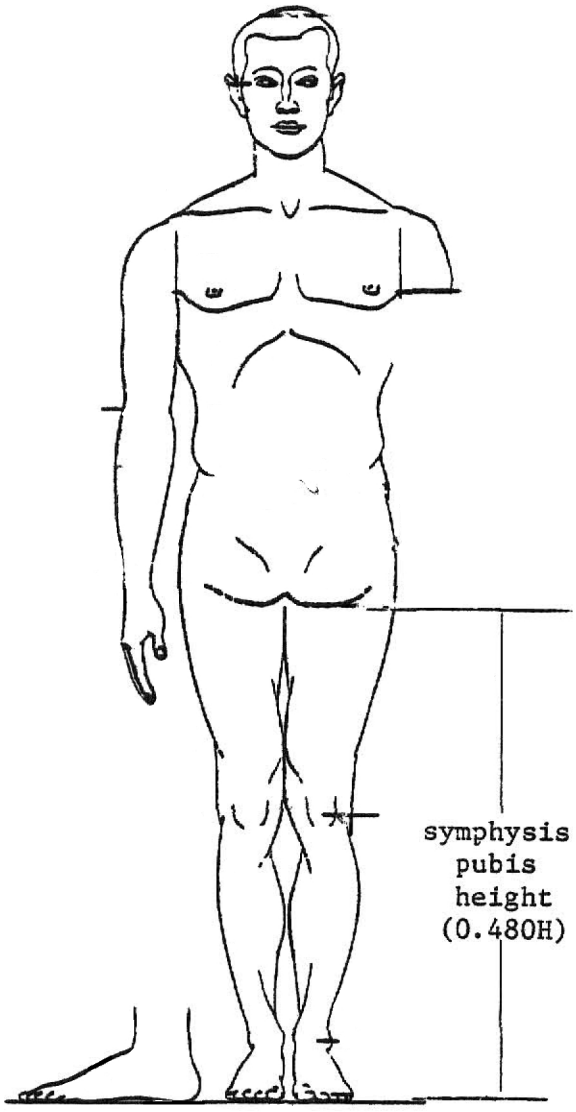

FIGURE 11. Symphysis pubis height

TABLE 11

Instructions to Subjects

This is an experiment to determine the optimum saddle (seat) position on an exercise bike while pedaling at a constant rate against a moderate load, and to find the effect of using toe clips while pedaling. Your heart rate will be measured to find the physiological cost. A heart rate monitor will be tied around your chest for this purpose. After recording the initial reading at minute "0", you will start pedaling. Accelerate to and maintain 60 rpm keeping in pace with the light and sound from the metronome. Read out your heart rate every 30 seconds and continue pedaling for 10 minutes. At the end of minute 10, you will be seated on a chair. You will rest for 20 minutes; but continue to record your heart rate every 30 seconds.

You will also be asked, once every 5 minutes during your pedaling and rest periods, to indicate on a scale as to how hard you are working/feeling. At the end of minute "30" (after 20 minutes of rest), you will be asked to rate your preference of the condition of pedaling on a rating scale.

This procedure will be repeated for six conditions for three hours. The monetory compensation for your participation will be given to you only after your second session.

TABLE 12

Randomization of the order of toe clip condition

Subject #	-	Order
1	-	1 , 2
2	-	2 , 1
3	-	1 , 2
4	-	1 , 2
5	-	2 , 1
6	-	2 , 1
7	-	1 , 2
8	-	2 , 1
9	-	2 , 1
10	-	1 , 2

1 -- With toe clips

2 -- Without toe clips

TABLE 13

Randomization of location - tilt combination

Subject #	Toe clip	No toe clip
1	4,1,3,2,5,6	5,6,4,1,3,2
2	2,4,6,1,3,5	3,4,1,2,5,6
3	4,2,6,3,1,5	2,3,1,6,4,5
4	4,1,2,6,3,5	6,3,5,1,2,4
5	3,1,6,2,5,4	6,3,2,5,4,1
6	2,4,3,1,5,6	1,6,3,2,4,5
7	2,3,6,4,5,1	6,5,2,4,3,1
8	5,3,4,6,2,1	2,3,5,4,6,1
9	1,6,5,2,4,3	6,4,2,1,3,5
10	5,3,6,4,2,1	5,3,2,6,4,1

Treatment #	Seat location	Seat tilt
1	19°	0°
2	25°	0°
3	31°	0°
4	19°	-7°
5	25°	-7°
6	31°	-7°

toe clips were attached to the subject's shoes and tightened. The heart rate sensor then was attached to the chest of the subject. The subject then was seated on the bike and the handlebar position adjusted so that the subject's torso remained in a vertical position (see Figure 12). The subject then was instructed to pedal the bike at a speed of 60 rpm as could be seen and heard from the metronome set at 60 beats/min. The subject's heart rate was monitored and recorded every 30 s during the 10 min of pedaling period and BPE rating was taken every fifth minute. The subject was seated on a chair after 10 min of continuous pedaling and his heart rate recorded during the rest/recovery period of 20 min. During this rest period, the subject's preference of the bike condition was taken on the SD scale. The next saddle setting was made while the subject was resting and the experiment continued.

Experimental Design

The study consisted of 20 experimental sessions (spread over 18 days); each session was of about 180 min duration. Each subject was in 2 sessions and in each of the 12 conditions; six tests with toe clips were done on one day and six tests without toe clips were done on another day. Each day had six trials of 30 min each for a subject. The experimental treatments within the toe clip - no toe clip block were presented to each subject in a different random order. (Refer to Table 13).

The experiment thus was of the "split-plot" design type where the factor toe clips was considered as the whole plot treatment and the six combinations of saddle settings were considered as the sub plot treatments.

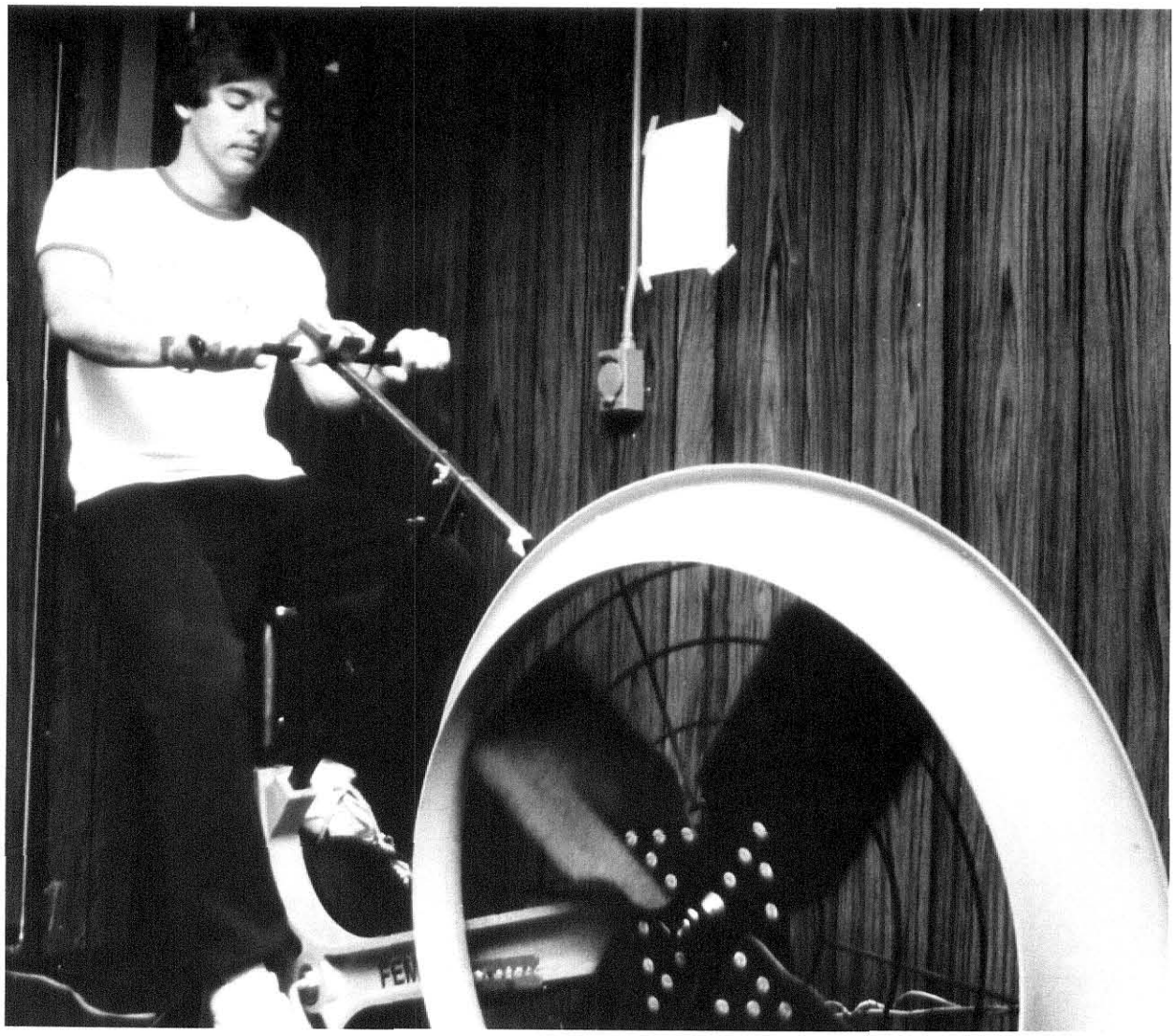

FIGURE 12. Photograph of a subject pedaling the exercise bike

RESULTS

There were three criteria: heart rate, Borg's Perceived Exertion (BPE) rating, and the semantic-differential questionnaire.

Heart rate Analysis

The ANOVA summary of heart rate during the exercise (10 min), recovery (20 min), and the combined periods (30 min) is given in Table 14.

Toe clip effect. Using ANOVA, there were no significant differences in heart rates between the toe clip conditions during the exercise, recovery, or combined period. (See Table 14).

However, a paired comparison sign test also was done for the toe clip conditions. The toe clip condition was significant ($\alpha < 0.05$) during the exercise, recovery, and combined periods. (See Appendices A, B, and C). Use of toe clips reduced the heart rate by 3.5% during exercise, by 2.8% during recovery, and by 3.1% during the combined periods. (See Table 15).

Location effect. The ANOVA gave significant differences in heart rates between the seat location at 25° (mean 106.4 beats/min) and at 19° (mean 107.8 beats/min) during the exercise period (resulting in a difference of 1.3%). However, no significant differences were observed during the recovery and combined periods.

The sign test showed no significant differences in the mean heart rates between the seat locations during any of the three periods.

Tilt effect. There were no significant differences in heart rates between the two tilt conditions (0° and -7°) during any of the three periods using either the ANOVA or the sign test.

Borg's Perceived Exertion (BPE) Scale Analysis

The ANOVA summary of BPE during the exercise, recovery, and the combined

TABLE 14

ANOVA summary of heart rate during the three periods

Source	d.f	F-ratio		
		Exercise	Recovery	Combined
toe clip	1	3.9	1.3	2.2
subject	9	5.3 **	10.2 *	8.4 **
toe clip X subject	9	14.0	9.3	13.9
location	2	3.0 *	0.9	1.6
tilt	1	2.2	1.2	2.0

* $p < 0.05$

** $p < 0.01$

TABLE 15

Mean heart rates for the toe clip condition from the Duncan's Multiple Range Test

Condition	Mean heart rate in beats/min					
	Exercise	Group	Recovery	Group	Combined	Group
toe clip	105.4	A	67.7	A	80.7	A
no toe clip	109.1	A	69.6	B	83.2	B

* Means with the same letter do not differ significantly from one another at $p < 0.05$.

periods is shown in Table 16.

Toe clip effect. Using ANOVA, there were no significant differences in BPE between the toe clip conditions during any of the three periods. (See Table 16).

However, from the sign test, the mean BPE between toe clip conditions (11.9 without toe clips and 11.7 with toe clips) differed significantly (0.05) during the exercise period resulting in a difference of 1.7%. (See Appendix A).

Location effect. The ANOVA gave significant differences in BPE between the seat locations during all the three periods. (See Tables 16 and 17). There were significant differences in BPE only between 25^{o} and 19^{o} during all the three periods. Location at 25^{o} was perceived to be less stressful than location at 19^{o} by 6.1% during the exercise period, by 6.3% during the recovery period, and by 5.4% during the combined period.

The sign test (see Appendices D, E, and F) showed significant differences between 25^{o} and 19^{o} during both the exercise and recovery periods (25^{o} was perceived to be less stressful). There was a significant difference between 25^{o} and 31^{o} but only during the recovery period; 25^{o} was perceived to be 3.8% less stressful than 31^{o}.

Tilt effect. Using ANOVA, there was a significant difference between the two tilt conditions only during the exercise period (see Tables 16 and 18). The no tilt condition (mean 11.6) was perceived to be 3.4% less stressful than the -7^{o} tilt condition (mean 12.0).

From the sign test (see Appendices G, H, and I), there were significant differences in BPE means during all the three periods. The no tilt condition was perceived to be less stressful than -7^{o} tilt condition by 3.4% during the exercise period, by 1.2% during the recovery period, and by 1.1% during the combined periods. (See Table 18).

TABLE 16

ANOVA summary of BPE rating during the three periods

Source	d.f	F-ratio		
		Exercise	Recovery	Combined
toe clip	1	0.5	0.9	1.3
subject	9	13.4 **	7.1 **	12.7 **
toe clip*subject	9	2.4 *	11.4 *	5.7 *
location	2	3.9 *	4.4 *	5.9 *
tilt	1	5.5 *	0.04	1.9 *

* $p < 0.05$

** $p < 0.01$

TABLE 17

Duncan's Multiple Range Test for BPE rating for location *

Location	Exercise		Recovery		Combined	
degrees	Mean BPE	Group	Mean BPE	Group	Mean BPE	Group
25	11.5	A	8.0	A	9.2	A
31	11.8	A	8.3	A	9.5	A
19	12.2	B	8.5	B	9.7	B

* Means with the same letter do not differ significantly from one another at $p < 0.05$.

TABLE 18

Mean BPE ratings for the tilt conditions from the Duncan's Multiple Range Test

Condition	Mean BPE ratings					
	Exercise	Group	Recovery	Group	Combined	Group
no tilt	11.6	A	8.2	A	9.4	A
tilt	12.0	B	8.3	A	9.5	A

* Means with the same letter do not differ significantly from one another at $p < 0.05$.

Correlation Analysis

The correlation coefficient between heart rate and BPE rating was 0.36 ($p < 0.001$) during the exercise period, 0.41 ($p < 0.001$) during the recovery period, and 0.39 ($p < 0.001$) during the combined period.

The ratios of heart rate to BPE rating are shown in Table 19. The ratio was 9.6 during the exercise period and 8.3 during the recovery period; 10.0 is the "nominal" value. Note that during recovery, the correlation is higher than during exercise although the 8.3 is farther from 10.0 than is the 9.6. That is, although it ranks the effort better, it has a higher absolute error in predicting heart rate.

Principal Component (Factor) Analysis of subjective ratings

The subjective ratings obtained on the eight semantic-differential scores were factor analyzed; this resulted in identification of three principal components. The correlation matrix among the eight semantic scores and the factor pattern are shown in Tables 20 and 21. The factors and the factor loadings are shown in Table 22. The ANOVA summary of the three principal components is shown in Table 23.

Toe clip effect. There were no significant differences in subjective preference between the toe clip conditions.

Location effect. Location at 25^{o} was preferred over 19^{o} by 23% for Factor 1, by 18% for Factor 2, and by 19% for Factor 3. (See Table 24). There were no significant differences between the locations at 25^{o} and 31^{o}.

Tilt effect. The no tilt condition was significantly preferred over -7^{o} tilt condition by 20% for Factor 1, by 13% for Factor 2, and by 15% for Factor 3. (See Table 25).

From the Table 22, the three factors that emerged could be interpreted

TABLE 19

Ratios of actual heart rate to BPE rating

Condition	Mean	Standard deviation	Minimum	Maximum
Exercise	9.6	1.785	6.9	15.1
Recovery	8.3	1.713	4.2	14.8

TABLE 20

Correlation matrix for the eight semantic scales

DF=89	S1	S2	S3	S4	S5	S6	S7	S8
S1	1.0	0.68	0.86	0.57	0.65	0.68	0.55	0.76
S2	0.68	1.0	0.65	0.56	0.61	0.67	0.67	0.62
S3	0.86	0.65	1.0	0.56	0.68	0.75	0.60	0.77
S4	0.57	0.56	0.56	1.0	0.61	0.53	0.52	0.55
S5	0.65	0.61	0.68	0.61	1.0	0.72	0.60	0.63
S6	0.68	0.67	0.75	0.53	0.72	1.0	0.58	0.73
S7	0.55	0.67	0.60	0.52	0.60	0.58	1.0	0.57
S8	0.76	0.62	0.77	0.55	0.63	0.73	0.57	1.0

S1 - like -- dislike

S2 - bad exercise -- good exercise

S3 - uncomfortable -- comfortable

S4 - easy -- hard

S5 - useful -- useless

S6 - inconvenient -- convenient

S7 - interesting-- dis interesting

S8 - dissatisfied-- satisfied

TABLE 21

Factor Pattern

Scales	Factor 1	Factor 2	Factor 3
S1	0.54	-0.17	0.34
S2	0.16	0.48	0.42
S3	0.64	0.07	0.11
S4	-0.01	0.63	0.25
S5	0.13	0.07	-0.37
S6	0.32	0.26	-0.61
S7	0.02	0.52	0.26
S8	0.38	-0.08	-0.22

S1 - like -- dislike

S2 - bad exercise -- good exercise

S3 - uncomfortable -- comfortable

S4 - easy -- hard

S5 - useful -- useless

S6 - inconvenient -- convenient

S7 - interesting -- disinteresting

S8 - dissatisfied -- satisfied

TABLE 22

Factors and Factor loadings

Factor 1 --- Comfort	Loading
like - - - - - - - - dislike	0.54
comfortable - - - - - - - - uncomfortable	0.64
dissatisfied - - - - - - - - satisfied	0.38
Factor 2 --- Difficulty	
bad exercise - - - - - - - - good exercise	0.48
easy - - - - - - - - hard	0.63
interesting - - - - - - - - disinteresting	0.52
Factor 3 --- Usefulness	
useful - - - - - - - - useless	0.37
convenient - - - - - - - - inconvenient	0.61

TABLE 23

ANOVA summary of the three factors

Source	d.f	Factor 1	Factor 2	Factor 3
toe clip	1	1.5	0.4	0.6
subject	9	4.0 *	3.3 *	3.5 *
toe clip X subject	9	0.6	1.2	1.0
location	2	5.7 *	6.3 *	5.9 *
toe clip X location	2	2.6 *	2.8 *	2.6
tilt	1	12.9 *	9.2 *	11.7 *
toe clip X tilt	1	6.0 *	4.7 *	4.9 *

* $p < 0.05$

TABLE 24

Mean Factor scores for location from Duncan's Multiple Range Test ($\alpha < 0.05$)

Location	Factor 1			Factor 2			Factor 3		
	Mean scores	Mean Prate **	Group *	Mean scores	Mean Prate **	Group *	Mean scores	Mean Prate **	Group *
25°	10.2	60	A	10.8	63	A	12.4	63	A
31°	9.5	55	A	10.4	60	A	11.6	58	A
19°	8.3	46	B	9.2	51	B	10.4	50	B

* Means with the same letter do not differ significantly from one another at p 0.05.

** Mean Percentage rating on the semantic scale (0 - 100%).

TABLE 25

Mean Factor scores for seat tilt from Duncan's Multiple Range Test ($\alpha < 0.05$)

Condition	Factor 1			Factor 2			Factor 3		
	Mean scores	Mean Prate **	Group *	Mean scores	Mean Prate **	Group *	Mean scores	Mean Prate **	Group *
0° tilt	10.2	60	A	10.8	62	A	12.3	62	A
-7° tilt	8.5	47	B	9.6	54	B	10.7	52	B

* Means with the same letter do not differ significantly from one another at p 0.05.

** Mean Percentage rating on the semantic scale (0 - 100%).

as a comfort factor (consisting of the scales like----dislike, comfortable----uncomfortable, and dissatisfied----satisfied); a difficulty factor (consisting of the scales bad exercise----good exercise, easy----hard, and interesting----disinteresting); and a usefulness factor (consisting of the scales useful----useless, and convenient----inconvenient).

DISCUSSION

Three criteria were used as estimates of the same variable (the energy expended by each subject for each condition). Two of these were psychological measures (rating of perceived exertion on a Borg scale, and preference rating on a semantic-differential scale). The other measure, heart rate, was a physiological measurement.

The effects of the various conditions were analyzed during exercise and recovery periods separately and also during the combined period.

Toe clip effect

Use of toe clips while pedaling reduced the heart rate by about 3% during both the exercise and rest periods; it was perceived to be 1.7% less stressful during work (using Borg's Perceived Exertion rating).

The possible reason may be that, while using toe clips, the acceleration and deceleration of legs are achieved efficiently, since the strongest muscles are not used almost exclusively. The rising leg also has to be lifted and is not raised by only the downward thrust of the other leg. The results of BPE may be that the subjects were able to perceive effort better while the toe clips were used (during work) and not otherwise (during rest).

An indepth analysis of data indicated more energy expended while using toe clips in 2 out of the 10 subjects. They were the only two subjects without any bicycling experience. It may be that the subjects should practice pedaling using toe clips in order to capitalize on the pedaling advantage they were designed to provide.

Location effect

The seat location at 25^{o} gave a significant reduction in heart rate (during work) and in BPE rating (during all three periods) as compared to location

at 19°. There were no significant differences in heart rate between 25° and 31° but 25° was perceived (BPE) to be 3.8% less stressful than 31°. The semantic-differential factors showed that 25° was preferred over 19° by about 20% for all three factors. No significant difference was observed between 25° and 31°.

The above results indicate that the seat location should not be very close to the vertical through the pedal and the hub centerline but should be at about a 25° angle with the vertical. This compares well with the opinion of Hertzberg (1972) that the line from the pedal crank axis to the saddle should be inclined 20 to 30° behind the vertical.

Tilt effect

There were no significant differences in heart rates between the two tilt conditions. The no tilt condition was perceived to be about 3% less stressful than -7° tilt condition during the exercise period (the differences are "real") and by about 1% during rest (the differences must be "memory"). The no tilt condition was preferred by 20% for the comfort factor, by 13% for the difficulty factor, and by 15% for the usefulness factor.

The above results compared well with Baranet's (1973) opinion that the saddle should be horizontal or with a slight upward tilt.

The correlational analysis between heart rate and BPE rating indicated low correlation coefficients of 0.36 during exercise, 0.41 during rest, and 0.39 during the combined period. The values were lower as compared to Gross and Bennett (1976) who found the correlation coefficient to be 0.58 between heart rate and BPE rating.

The ratio of heart rate to BPE rating was found to be 9.6 during the exercise period and 8.3 during the recovery period. When compared with

the 10.0 ratio found by Borg (1962), the results compared well during exercise although the correlation was low. During recovery, BPE has a higher absolute error in predicting heart rate. Gamberale (1972) found that the RPE values he obtained were about one tenth of the corresponding heart rate values. Gamberale's results were in support of other studies which used this same measure (Borg, 1972).

The results indicated that, during work, subjects estimated their exertion level reasonably well and the mean values of BPE rating were generally close to one tenth of the corresponding mean heart rate values. During rest, they had the tendency to overestimate the level of their exertion (RPE X 10 was generally much higher than actual heart rate). This may be attributed to the muscular and joint discomfort experienced by the subjects while pedaling the bike.

There was a high correlation among the eight semantic scales and the ANOVA on the three factors (comfort, difficulty, and usefulness) showed similar results as found by the other measures. Location at 25^{o} (the best among the three locations) was given a 60% on the rating scale for comfort, 63% for difficulty, and 63% for usefulness. No tilt was given a 60% rating for comfort, 62% for difficulty, and 62% for usefulness.

The small differences between conditions in heart rates may be interpreted as that the responses emitted by the subject during tests on a stationary bike may change as a function of the change in skill of the subject. It may be necessary to minimize skill changes during a test by considerable pre-experimental practice prior to transfer to the experimental condition.

CONCLUSION

1. Use of toe clips while pedaling reduced the energy expenditure by about 3% as measured by heart rate; by about 1.7% as measured by BPE rating; and no significant effect was observed as measured by preference rating. It may be recommended that subjects should be given pre-experimental practice using toe clips to achieve greater differences.

2. Seat location at 25° reduced the heart rate by 1.3% during work as compared to 19°. Location at 25° was preferred (BPE) over 19° by 6.1% during work, by 6.3% during rest, and by 5.4% during the combined period. 25° was perceived to be 3.8% less stressful than 31° only during recovery. Also 25° was preferred over 19° by 23% for comfort, by 18% for difficulty, and by 19% for usefulness.

3. Heart rate was not affected by tilt. No tilt was perceived to be 3.4% less stressful than -7° tilt during work and by 1.2% during rest. Also, 0° tilt was preferred by 20% for comfort, by 13% for difficulty, and by 15% for usefulness.

4. The correlation coefficient between heart rate and BPE rating was 0.36 during work, 0.41 during rest, and 0.39 during the combined period.

5. The ratio of heart rate to BPE rating was 9.6 during work and 8.3 during rest.

This research was supported in part by a grant from the Federal Emergency Management Agency, Contract EMW - C - 0589.

REFERENCES

Astrand, Per-Olof., Saltin, B. Maximal oxygen uptake and heart rate in various types of muscular activity. Journal of Applied Physiology, 1961, 16(6), 977-981.

Astrand, Per-Olof., Hallback, I., Hedman, R., and Saltin, B. Blood lactates after prolonged severe exercises. Journal of Applied Physiology, 1963, 18, 619-621.

Astrand, Per-Olof., and Rodahl, K. Textbook of Work Physiology, New York: Mcgraw-Hill, 1970.

Baranet, N. N. Bicycling, New York: A. S. Barnes, 1973.

Borg, G. Physical performance and perceived exertion (Lund: Gleerups), 1962.

Clarke, H. H., Elkins, E. C., Martin, G. M., and Wakin, K. G. Relationship between body position and the application of muscle power to movements of the joints. Archives of Physical Medicine and Rehabilitation, 1950, 31, 81-89. Cited by R. A. Berger, Leg extension at three different angles. Research Quarterly of the American Association of Health and Physical Education, 1966, 37, 560-562.

Call, Frances. The Practical Book of Bicycling, New York: Elsevier Dutton Publishing Co. 1981.

Gunnar, Gaimby., Nils Johan Nilsson, and Harold Sanne. Repeated serial determination of cardiac output during 30 minute exercise. Journal of Applied Physiology, 1966, 21(6), 1750-1756.

Gamberale, F. Perceived exertion, heart rate, oxygen uptake and blood lactate in different work operations. Ergonomics, 1972, 15, 545-554.

Glesser, M. A., and Vogel, J. A. Endurance exercise: effect of work-rest schedules and repeated testing. Journal of Applied Physiology, 1971, 31(5), 735-739.

Gross, V. J., and Bennett, C. A. Bicycle crank length. Proceedings of 6th International Ergonomics Congress, College Park, Maryland, 1976.

Harrison, J. Y. Maximizing human power output by suitable selection of motion cycle and load. Human Factors, 1970, 12(3), 315-329.

Hamley, E. J., and Thomas, V. Physiological and postural factors in the calibration of the bicycle ergometer. Journal of Physiology, Proceedings of Physiological Society, 1967, 191, 55p-57p.

Hertzberg, H. T. E. Engineering anthropology. In H. P. Van Cott and R. G. Kinkade (ed.). Human Engineering Guide to Equipment Design. Washington D. C: U. S. Government Printing Office, 1972, 467-584.

Katch, F. I. Optimal duration of endurance performance on the cycle ergometer in relation to maximal oxygen intake. Ergonomics, 1973, 16(2), 227-235.

Konz, S. Work Design. Columbus: Grid 1979.

Linford, A. G., and Rarick, L. The effect of knee angle on the measurement of leg strength of college males. Research Quarterly of the American Association of Health and Physical Education, 1968, 39, 582-586.

Nordeen-Snyder Katherine, S. The effect of bicycle seat height variation upon oxygen consumption and lower limb kinematics. Medicine and Science in Sports, 1977, 9(2), 113-117.

Seabury, John J., Adams, William C., and Ramey, Melvin R. Influence of pedaling rate and power output on energy expenditure during bicycle ergometry. Ergonomics, 1977, 20(5), 491-498.

Shennum, Paul Lawrence, and Devries, Herbert A. The effects of saddle heights on oxygen consumption during ergometer work. Medicine and Science in Sports, 1976, 8(2), 119-121.

Sloane, Eugene A. The All New Complete Book of Bicycling. New York: Simon and Schuster, 1980.

Stamford, Bryant A. and Noble, Bruce J. Metabolic cost and perception of effort during bicycle ergometer work performance. Medicine and Science in Sports, 1974, 6(4), 226-231.

Tate, Judy and Shierman, Gail. Toe clips : How they increase pedaling efficiency. Bicycling, 1977, 18, 57.

Thomas, V. Scientific setting of saddle position. Bicycling Science, 1967, June, 12-13.

Whitt, F. R. A note on the estimation of the energy expenditure of sporting cyclists. Ergonomics, 1971, 14(3), 419-424.

Whitt, F. R. and Wilson, D. G. Bicycling Science, Cambridge, MA: MIT Press, 1974.

Wilkie, D. R. Man as a source of mechanical power. Ergonomics, 1960, 3, 1-8.

Woodson, W. E. and Conover, D. W. Human Engineering Guide for Equipment Designers (second ed.), Berkely: University of California Press, 1960.

APPENDICES

APPENDIX A

Paired observations for toe clip conditions during exercise

OBS	SUB	TC	LOC	TILT	HR0	BV0	HR1	BV1	HRDIFF	BVDIFF
1	1	1	1	0	102.864	10.5	102.045	9.5	0.818	1.0
2	1	1	1	1	102.773	11.0	103.818	9.0	-1.045	2.0
3	1	1	2	0	103.227	11.0	100.318	11.0	2.909	0.0
4	1	1	2	1	104.273	9.5	99.136	11.0	5.136	-1.5
5	1	1	3	0	103.273	10.0	101.000	10.0	2.273	0.0
6	1	1	3	1	104.045	10.5	100.591	11.5	3.455	-1.0
7	2	1	1	0	116.273	16.0	107.318	14.0	8.955	2.0
8	2	1	1	1	119.000	15.0	112.227	14.0	6.773	1.0
9	2	1	2	0	110.045	13.0	109.364	12.0	0.682	1.0
10	2	1	2	1	110.000	15.0	109.364	13.5	0.636	1.5
11	2	1	3	0	117.909	10.5	108.682	13.0	9.227	-2.5
12	2	1	3	1	108.000	14.5	108.864	13.0	-0.864	1.5
13	3	1	1	0	104.864	15.0	111.773	16.0	-6.909	-1.0
14	3	1	1	1	106.000	15.0	105.955	14.0	0.045	1.0
15	3	1	2	0	95.182	10.0	106.045	12.0	-10.864	-2.0
16	3	1	2	1	106.227	14.0	110.182	14.0	-3.955	0.0
17	3	1	3	0	98.818	12.5	110.409	14.5	-11.591	-2.0
18	3	1	3	1	102.773	12.0	107.273	13.5	-4.500	-1.5
19	4	1	1	0	116.182	13.0	100.182	11.0	16.000	2.0
20	4	1	1	1	116.545	15.0	100.000	13.0	16.545	2.0
21	4	1	2	0	112.091	14.0	101.273	11.0	10.818	3.0
22	4	1	2	1	116.364	14.0	107.955	12.0	8.409	2.0
23	4	1	3	0	117.318	14.5	107.000	14.0	10.318	0.5
24	4	1	3	1	118.000	14.0	103.818	14.5	14.182	-0.5
25	5	1	1	0	92.545	11.5	90.773	11.5	1.773	0.0
26	5	1	1	1	92.318	12.0	87.045	11.0	5.273	1.0
27	5	1	2	0	99.409	12.5	89.545	11.0	9.864	1.5
28	5	1	2	1	101.773	12.0	86.727	11.0	15.045	1.0
29	5	1	3	0	99.364	12.0	89.591	11.0	9.773	1.0
30	5	1	3	1	98.045	11.0	90.591	11.5	7.455	-0.5
31	6	1	1	0	112.409	12.0	107.318	12.0	5.091	0.0
32	6	1	1	1	114.773	15.0	108.182	11.0	6.591	4.0
33	6	1	2	0	110.818	14.0	108.727	11.0	2.091	3.0
34	6	1	2	1	109.409	12.0	107.045	11.5	2.364	0.5
35	6	1	3	0	112.773	12.5	106.500	12.0	6.273	0.5
36	6	1	3	1	112.364	14.5	110.000	13.0	2.364	1.5
37	7	1	1	0	117.500	13.5	110.364	13.5	7.136	0.0
38	7	1	1	1	117.727	13.5	109.318	13.5	8.409	0.0
39	7	1	2	0	115.955	13.5	102.318	13.5	13.636	0.0
40	7	1	2	1	115.045	13.0	108.909	13.5	6.136	-0.5
41	7	1	3	0	118.182	13.0	110.000	13.0	8.182	0.0
42	7	1	3	1	117.273	12.5	110.727	12.5	6.545	0.0
43	8	1	1	0	109.545	9.0	102.591	8.5	6.955	0.5
44	8	1	1	1	110.136	9.0	101.727	9.0	8.409	0.0
45	8	1	2	0	99.682	9.0	100.273	9.0	-0.591	0.0
46	8	1	2	1	106.636	8.5	102.636	7.5	4.000	1.0
47	8	1	3	0	101.409	8.0	99.045	7.5	2.364	0.5
48	8	1	3	1	108.682	8.0	98.636	8.5	10.045	-0.5
49	9	1	1	0	115.818	12.0	115.364	9.5	0.455	2.5
50	9	1	1	1	120.227	12.0	125.364	12.5	-5.136	-0.5
51	9	1	2	0	115.182	9.0	120.364	9.0	-5.182	0.0
52	9	1	2	1	111.727	10.5	121.409	11.5	-9.682	-1.0
53	9	1	3	0	112.591	8.0	125.409	13.0	-12.818	-5.0
54	9	1	3	1	116.682	10.5	120.136	13.0	-3.455	-2.5
55	10	1	1	0	107.727	11.0	104.045	11.0	3.682	0.0
56	10	1	1	1	107.909	12.0	103.818	10.0	4.091	2.0
57	10	1	2	0	108.273	8.5	104.273	11.5	4.000	-3.0
58	10	1	2	1	109.636	9.5	98.500	11.5	11.136	-2.0
59	10	1	3	0	107.682	9.0	105.136	11.5	2.545	-2.5
60	10	1	3	1	107.864	11.5	105.045	10.5	2.818	1.0

APPENDIX B

Paired observations for toe clip conditions during recovery

OBS	SUB	TC	LOC	TILT	HR0	BV0	HR1	BV1	HRDIFF	BVDIFF
1	1	1	1	0	63.4524	6.00	60.9524	6.25	2.500	-0.25
2	1	1	1	1	66.1190	6.00	63.8333	6.50	2.286	-0.50
3	1	1	2	0	62.4048	6.00	57.4286	6.00	4.976	0.00
4	1	1	2	1	68.4524	6.00	58.5000	6.00	9.952	0.00
5	1	1	3	0	58.4762	6.00	59.9286	6.00	-1.452	0.00
6	1	1	3	1	63.2619	6.00	56.6429	6.00	6.619	0.00
7	2	1	1	0	81.8810	12.50	71.9286	11.25	9.952	1.25
8	2	1	1	1	82.9762	10.50	76.8333	11.25	6.143	-0.75
9	2	1	2	0	76.2143	9.50	75.8571	10.75	0.357	-1.25
10	2	1	2	1	74.6429	10.75	72.2381	11.75	2.405	-1.00
11	2	1	3	0	87.5476	10.00	72.5000	10.25	15.048	-0.25
12	2	1	3	1	74.0714	10.00	76.2857	11.25	-2.214	-1.25
13	3	1	1	0	63.6905	12.50	68.7857	9.50	-5.095	3.00
14	3	1	1	1	65.7143	13.00	70.1190	8.00	-4.405	5.00
15	3	1	2	0	61.4524	9.75	68.7143	8.50	-7.262	1.25
16	3	1	2	1	66.5238	11.25	72.5952	9.75	-6.071	1.50
17	3	1	3	0	63.4286	12.75	68.0952	9.25	-4.667	3.50
18	3	1	3	1	67.9524	13.00	68.9524	8.75	-1.000	4.25
19	4	1	1	0	69.5238	11.00	60.2619	9.00	9.262	2.00
20	4	1	1	1	72.0476	10.50	66.5476	8.50	5.500	2.00
21	4	1	2	0	68.4762	11.00	62.0952	8.50	6.381	2.50
22	4	1	2	1	76.9286	11.25	65.7619	8.25	11.167	3.00
23	4	1	3	0	78.9048	12.00	68.2619	9.50	10.643	2.50
24	4	1	3	1	79.9286	12.50	62.7857	10.00	17.143	2.50
25	5	1	1	0	55.4524	6.00	55.8810	6.00	-0.429	0.00
26	5	1	1	1	55.1429	6.25	51.6667	6.00	3.476	0.25
27	5	1	2	0	56.4286	6.25	51.5952	6.00	4.833	0.25
28	5	1	2	1	55.1667	6.25	51.2143	6.00	3.952	0.25
29	5	1	3	0	61.5952	6.25	58.8095	6.50	2.786	-0.25
30	5	1	3	1	61.0238	7.00	56.1190	6.00	4.905	1.00
31	6	1	1	0	76.2381	8.75	69.4286	8.25	6.810	0.50
32	6	1	1	1	65.9524	8.25	71.4762	7.25	-5.524	1.00
33	6	1	2	0	65.7143	8.00	74.9524	9.25	-9.238	-1.25
34	6	1	2	1	66.0000	6.25	68.4286	7.75	-2.429	-1.50
35	6	1	3	0	67.7619	7.50	72.5238	8.25	-4.762	-0.75
36	6	1	3	1	70.6905	8.75	67.3095	7.25	3.381	1.50
37	7	1	1	0	72.6905	8.00	74.5714	7.75	-1.881	0.25
38	7	1	1	1	76.6667	8.25	71.2143	8.50	5.452	-0.25
39	7	1	2	0	78.9524	7.75	71.7857	8.00	7.167	-0.25
40	7	1	2	1	79.4524	8.00	74.3333	7.75	5.119	0.25
41	7	1	3	0	75.4048	7.75	71.8571	8.00	3.548	-0.25
42	7	1	3	1	80.6190	8.00	68.9524	8.00	11.667	0.00
43	8	1	1	0	59.8095	6.75	54.8810	7.25	4.929	-0.50
44	8	1	1	1	59.2857	6.75	54.7619	7.25	4.524	-0.50
45	8	1	2	0	60.5000	6.25	55.2857	7.75	5.214	-1.50
46	8	1	2	1	60.2857	6.75	56.8333	6.50	3.452	0.25
47	8	1	3	0	59.5476	6.25	55.6190	7.25	3.929	-1.00
48	8	1	3	1	59.4286	6.75	53.9048	7.25	5.524	-0.50
49	9	1	1	0	78.8571	8.25	86.9524	8.00	-8.095	0.25
50	9	1	1	1	83.7381	9.50	88.5714	7.75	-4.833	1.75
51	9	1	2	0	78.6190	7.75	87.4524	7.75	-8.833	0.00
52	9	1	2	1	75.5952	6.25	87.7143	8.50	-12.119	-2.25
53	9	1	3	0	74.7619	6.50	87.9524	6.75	-13.190	-0.25
54	9	1	3	1	84.8810	8.75	86.4762	7.75	-1.595	1.00
55	10	1	1	0	70.5952	8.00	66.9762	10.50	3.619	-2.50
56	10	1	1	1	67.5476	8.50	69.8571	8.00	-2.310	0.50
57	10	1	2	0	73.8571	7.50	65.8571	8.50	8.000	-1.00
58	10	1	2	1	72.7619	7.00	73.9286	8.00	-1.166	-1.00
59	10	1	3	0	72.3333	7.75	70.7143	8.00	1.619	-0.25
60	10	1	3	1	71.1190	9.00	71.0714	7.75	0.047	1.25

APPENDIX C

Paired observations for toe clip conditions during combined period

OBS	SUB	TC	LOC	TILT	HR0	BV0	HR1	BV1	HRDIFF	BVDIFF
1	1	1	1	0	77.0000	7.5000	75.078	7.3333	1.922	0.1667
2	1	1	1	1	78.7188	7.6667	77.578	7.3333	1.141	0.3333
3	1	1	2	0	76.4375	7.6667	72.172	7.6667	4.266	0.0000
4	1	1	2	1	80.7656	7.1667	72.469	7.6667	8.297	-0.5000
5	1	1	3	0	73.8750	7.3333	74.047	7.3333	-0.172	0.0000
6	1	1	3	1	77.2813	7.5000	71.750	7.8333	5.531	-0.3333
7	2	1	1	0	93.7031	13.6667	84.094	12.1667	9.609	1.5000
8	2	1	1	1	95.3594	12.0000	89.000	12.1667	6.359	-0.1667
9	2	1	2	0	87.8438	10.6667	87.375	11.1667	0.469	-0.5000
10	2	1	2	1	86.7969	12.1667	85.000	12.3333	1.797	-0.1667
11	2	1	3	0	97.9844	10.1667	84.938	11.1667	13.047	-1.0000
12	2	1	3	1	85.7344	11.5000	87.484	11.8333	-1.750	-0.3333
13	3	1	1	0	77.8438	13.3333	83.563	11.6667	-5.719	1.6667
14	3	1	1	1	79.5625	13.6667	82.438	10.0000	-2.875	3.6667
15	3	1	2	0	73.0469	9.8333	81.547	9.6667	-8.500	0.1667
16	3	1	2	1	80.1719	12.1667	85.516	11.1667	-5.344	1.0000
17	3	1	3	0	75.5938	12.6667	82.641	11.0000	-7.047	1.6667
18	3	1	3	1	79.9219	12.6667	82.125	10.3333	-2.203	2.3333
19	4	1	1	0	85.5625	11.6667	73.984	9.6667	11.578	2.0000
20	4	1	1	1	87.3438	12.0000	78.047	10.0000	9.297	2.0000
21	4	1	2	0	83.4688	12.0000	75.563	9.3333	7.906	2.6667
22	4	1	2	1	90.4844	12.1667	80.266	9.5000	10.219	2.6667
23	4	1	3	0	92.1094	12.8333	81.578	11.0000	10.531	1.8333
24	4	1	3	1	93.0156	13.0000	76.891	11.5000	16.125	1.5000
25	5	1	1	0	68.2031	7.8333	67.875	7.8333	0.328	0.0000
26	5	1	1	1	67.9219	8.1667	63.828	7.6667	4.094	0.5000
27	5	1	2	0	71.2031	8.3333	64.641	7.6667	6.563	0.6667
28	5	1	2	1	71.1875	8.1667	63.422	7.6667	7.766	0.5000
29	5	1	3	0	74.5781	8.1667	69.391	8.0000	5.188	0.1667
30	5	1	3	1	73.7500	8.3333	67.969	7.8333	5.781	0.5000
31	6	1	1	0	88.6719	9.8333	82.453	9.5000	6.219	0.3333
32	6	1	1	1	82.7344	10.5000	84.094	8.5000	-1.359	2.0000
33	6	1	2	0	81.2188	10.0000	86.563	9.8333	-5.344	0.1667
34	6	1	2	1	80.9219	8.1667	81.703	9.0000	-0.781	-0.8333
35	6	1	3	0	83.2344	9.1667	84.203	9.5000	-0.969	-0.3333
36	6	1	3	1	85.0156	10.6667	81.984	9.1667	3.031	1.5000
37	7	1	1	0	88.0938	9.8333	86.875	9.6667	1.219	0.1667
38	7	1	1	1	90.7813	10.0000	84.313	10.1667	6.469	-0.1667
39	7	1	2	0	91.6719	9.6667	82.281	9.8333	9.391	-0.1667
40	7	1	2	1	91.6875	9.6667	86.219	9.6667	5.469	0.0000
41	7	1	3	0	90.1094	9.5000	84.969	9.6667	5.141	-0.1667
42	7	1	3	1	93.2188	9.5000	83.313	9.5000	9.906	0.0000
43	8	1	1	0	76.9063	7.5000	71.281	7.6667	5.625	-0.1667
44	8	1	1	1	76.7656	7.5000	70.906	7.8333	5.859	-0.3333
45	8	1	2	0	73.9688	7.1667	70.750	8.1667	3.219	-1.0000
46	8	1	2	1	76.2188	7.3333	72.578	6.8333	3.641	0.5000
47	8	1	3	0	73.9375	6.8333	70.547	7.3333	3.391	-0.5000
48	8	1	3	1	76.3594	7.1667	69.281	7.6667	7.078	-0.5000
49	9	1	1	0	91.5625	9.5000	96.719	8.5000	-5.156	1.0000
50	9	1	1	1	96.2813	10.3333	101.219	9.3333	-4.938	1.0000
51	9	1	2	0	91.1875	8.1667	98.766	8.1667	-7.578	0.0000
52	9	1	2	1	88.0156	7.6667	99.297	9.5000	-11.281	-1.8333
53	9	1	3	0	87.7656	7.0000	100.828	8.8333	-13.063	-1.8333
54	9	1	3	1	95.8125	9.3333	98.047	9.5000	-2.234	-0.1667
55	10	1	1	0	83.3594	9.0000	79.719	10.6667	3.641	-1.6667
56	10	1	1	1	81.4219	9.6667	81.531	8.6667	-0.109	1.0000
57	10	1	2	0	85.6875	7.8333	79.062	9.5000	6.625	-1.6667
58	10	1	2	1	85.4375	7.8333	82.375	9.1666	3.062	-1.3333
59	10	1	3	0	84.4844	8.1666	82.546	9.1666	1.937	-1.0000
60	10	1	3	1	83.7500	9.8333	82.750	8.6666	1.000	1.1667

APPENDIX D

Paired observations for location during exercise period

Paired observations for location during exercise period

OBS	SUB	TC	LOC	TILT	HR1	BV1	HR2	BV2	HRDIFF	BVDIFF
1	1	0	2	0	102.864	10.5	103.227	11.0	-0.3636	-0.5
2	1	0	2	1	102.773	11.0	104.273	9.5	-1.5000	1.5
3	1	1	2	0	102.045	9.5	100.318	11.0	1.7273	-1.5
4	1	1	2	1	103.818	9.0	99.136	11.0	4.6818	-2.0
5	2	0	2	0	116.273	16.0	110.045	13.0	6.2273	3.0
6	2	0	2	1	119.000	15.0	110.000	15.0	9.0000	0.0
7	2	1	2	0	107.318	14.0	109.364	12.0	-2.0455	2.0
8	2	1	2	1	112.227	14.0	109.364	13.5	2.8636	0.5
9	3	0	2	0	104.864	15.0	95.182	10.0	9.6818	5.0
10	3	0	2	1	106.000	15.0	106.227	14.0	-0.2273	1.0
11	3	1	2	0	111.773	16.0	106.045	12.0	5.7273	4.0
12	3	1	2	1	105.955	14.0	110.182	14.0	-4.2273	0.0
13	4	0	2	0	116.182	13.0	112.091	14.0	4.0909	-1.0
14	4	0	2	1	116.545	15.0	116.364	14.0	0.1818	1.0
15	4	1	2	0	100.182	11.0	101.273	11.0	-1.0909	0.0
16	4	1	2	1	100.000	13.0	107.955	12.0	-7.9545	1.0
17	5	0	2	0	92.545	11.5	99.409	12.5	-6.8636	-1.0
18	5	0	2	1	92.318	12.0	101.773	12.0	-9.4545	0.0
19	5	1	2	0	90.773	11.5	89.545	11.0	1.2273	0.5
20	5	1	2	1	87.045	11.0	86.727	11.0	0.3182	0.0
21	6	0	2	0	112.409	12.0	110.818	14.0	1.5909	-2.0
22	6	0	2	1	114.773	15.0	109.409	12.0	5.3636	3.0
23	6	1	2	0	107.318	12.0	108.727	11.0	-1.4091	1.0
24	6	1	2	1	108.182	11.0	107.045	11.5	1.1364	-0.5
25	7	0	2	0	117.500	13.5	115.955	13.5	1.5455	0.0
26	7	0	2	1	117.727	13.5	115.045	13.0	2.6818	0.5
27	7	1	2	0	110.364	13.5	102.318	13.5	8.0455	0.0
28	7	1	2	1	109.318	13.5	108.909	13.5	0.4091	0.0
29	8	0	2	0	109.545	9.0	99.682	9.0	9.8636	0.0
30	8	0	2	1	110.136	9.0	106.636	8.5	3.5000	0.5
31	8	1	2	0	102.591	8.5	100.273	9.0	2.3182	-0.5
32	8	1	2	1	101.727	9.0	102.636	7.5	-0.9091	1.5
33	9	0	2	0	115.818	12.0	115.182	9.0	0.6364	3.0
34	9	0	2	1	120.227	12.0	111.727	10.5	8.5000	1.5
35	9	1	2	0	115.364	9.5	120.364	9.0	-5.0000	0.5
36	9	1	2	1	125.364	12.5	121.409	11.5	3.9545	1.0
37	10	0	2	0	107.727	11.0	108.273	8.5	-0.5455	2.5
38	10	0	2	1	107.909	12.0	109.636	9.5	-1.7273	2.5
39	10	1	2	0	104.045	11.0	104.273	11.5	-0.2273	-0.5
40	10	1	2	1	103.818	10.0	98.500	11.5	5.3182	-1.5

APPENDIX D (continued)

OBS	SUB	TC	LOC	TILT	HR2	BV2	HR3	BV3	HRDIFF	BVDIFF
1	1	0	3	0	103.227	11.0	103.273	10.0	0.0455	-1.0
2	1	0	3	1	104.273	9.5	104.045	10.5	-0.2273	1.0
3	1	1	3	0	100.318	11.0	101.000	10.0	0.6818	-1.0
4	1	1	3	1	99.136	11.0	100.591	11.5	1.4545	0.5
5	2	0	3	0	110.045	13.0	117.909	10.5	7.8636	-2.5
6	2	0	3	1	110.000	15.0	108.000	14.5	-2.0000	-0.5
7	2	1	3	0	109.364	12.0	108.682	13.0	-0.6818	1.0
8	2	1	3	1	109.364	13.5	108.864	13.0	-0.5000	-0.5
9	3	0	3	0	95.182	10.0	98.818	12.5	3.6364	2.5
10	3	0	3	1	106.227	14.0	102.773	12.0	-3.4545	-2.0
11	3	1	3	0	106.045	12.0	110.409	14.5	4.3636	2.5
12	3	1	3	1	110.182	14.0	107.273	13.5	-2.9091	-0.5
13	4	0	3	0	112.091	14.0	117.318	14.5	5.2273	0.5
14	4	0	3	1	116.364	14.0	118.000	14.0	1.6364	0.0
15	4	1	3	0	101.273	11.0	107.000	14.0	5.7273	3.0
16	4	1	3	1	107.955	12.0	103.818	14.5	-4.1364	2.5
17	5	0	3	0	99.409	12.5	99.364	12.0	-0.0455	-0.5
18	5	0	3	1	101.773	12.0	98.045	11.0	-3.7273	-1.0
19	5	1	3	0	89.545	11.0	89.591	11.0	0.0455	0.0
20	5	1	3	1	86.727	11.0	90.591	11.5	3.8636	0.5
21	6	0	3	0	110.818	14.0	112.773	12.5	1.9545	-1.5
22	6	0	3	1	109.409	12.0	112.364	14.5	2.9545	2.5
23	6	1	3	0	108.727	11.0	106.500	12.0	-2.2273	1.0
24	6	1	3	1	107.045	11.5	110.000	13.0	2.9545	1.5
25	7	0	3	0	115.955	13.5	118.182	13.0	2.2273	-0.5
26	7	0	3	1	115.045	13.0	117.273	12.5	2.2273	-0.5
27	7	1	3	0	102.318	13.5	110.000	13.0	7.6818	-0.5
28	7	1	3	1	108.909	13.5	110.727	12.5	1.8182	-1.0
29	8	0	3	0	99.682	9.0	101.409	8.0	1.7273	-1.0
30	8	0	3	1	106.636	8.5	108.682	8.0	2.0455	-0.5
31	8	1	3	0	100.273	9.0	99.045	7.5	-1.2273	-1.5
32	8	1	3	1	102.636	7.5	98.636	8.5	-4.0000	1.0
33	9	0	3	0	115.182	9.0	112.591	8.0	-2.5909	-1.0
34	9	0	3	1	111.727	10.5	116.682	10.5	4.9545	0.0
35	9	1	3	0	120.364	9.0	125.409	13.0	5.0455	4.0
36	9	1	3	1	121.409	11.5	120.136	13.0	-1.2727	1.5
37	10	0	3	0	108.273	8.5	107.682	9.0	-0.5909	0.5
38	10	0	3	1	109.636	9.5	107.864	11.5	-1.7727	2.0
39	10	1	3	0	104.273	11.5	105.136	11.5	0.8636	0.0
40	10	1	3	1	99.500	11.5	105.045	10.5	5.5455	-1.0

APPENDIX E

Paired observations for location during recovery period

OBS	SUB	TC	LOC	TILT	HR1	BV1	HR2	BV2	HRDIFF	BVDIFF
1	1	0	2	0	63.4524	6.00	62.4048	6.00	1.0476	0.00
2	1	0	2	1	66.1190	6.00	68.4524	6.00	-2.3333	0.00
3	1	1	2	0	60.9524	6.25	57.4286	6.00	3.5238	0.25
4	1	1	2	1	63.8333	6.50	58.5000	6.00	5.3333	0.50
5	2	0	2	0	81.8810	12.50	76.2143	9.50	5.6667	3.00
6	2	0	2	1	82.9762	10.50	74.6429	10.75	8.3333	-0.25
7	2	1	2	0	71.9286	11.25	75.8571	10.75	-3.9286	0.50
8	2	1	2	1	76.8333	11.25	72.2381	11.75	4.5952	-0.50
9	3	0	2	0	63.6905	12.50	61.4524	9.75	2.2381	2.75
10	3	0	2	1	65.7143	13.00	66.5238	11.25	-0.8095	1.75
11	3	1	2	0	68.7857	9.50	68.7143	8.50	0.0714	1.00
12	3	1	2	1	70.1190	8.00	72.5952	9.75	-2.4762	-1.75
13	4	0	2	0	69.5238	11.00	68.4762	11.00	1.0476	0.00
14	4	0	2	1	72.0476	10.50	76.9286	11.25	-4.8810	-0.75
15	4	1	2	0	60.2619	9.00	62.0952	8.50	-1.8333	0.50
16	4	1	2	1	66.5476	8.50	65.7619	8.25	0.7857	0.25
17	5	0	2	0	55.4524	6.00	56.4286	6.25	-0.9762	-0.25
18	5	0	2	1	55.1429	6.25	55.1667	6.25	-0.0238	0.00
19	5	1	2	0	55.8810	6.00	51.5952	6.00	4.2857	0.00
20	5	1	2	1	51.6667	6.00	51.2143	6.00	0.4524	0.00
21	6	0	2	0	76.2381	8.75	65.7143	8.00	10.5238	0.75
22	6	0	2	1	65.9524	8.25	66.0000	6.25	-0.0476	2.00
23	6	1	2	0	69.4286	8.25	74.9524	9.25	-5.5238	-1.00
24	6	1	2	1	71.4762	7.25	68.4286	7.75	3.0476	-0.50
25	7	0	2	0	72.6905	8.00	78.9524	7.75	-6.2619	0.25
26	7	0	2	1	76.6667	8.25	79.4524	8.00	-2.7857	0.25
27	7	1	2	0	74.5714	7.75	71.7857	8.00	2.7857	-0.25
28	7	1	2	1	71.2143	8.50	74.3333	7.75	-3.1190	0.75
29	8	0	2	0	59.8095	6.75	60.5000	6.25	-0.6905	0.50
30	8	0	2	1	59.2857	6.75	60.2857	6.75	-1.0000	0.00
31	8	1	2	0	54.8810	7.25	55.2857	7.75	-0.4048	-0.50
32	8	1	2	1	54.7619	7.25	56.8333	6.50	-2.0714	0.75
33	9	0	2	0	78.8571	8.25	78.6190	7.75	0.2381	0.50
34	9	0	2	1	83.7381	9.50	75.5952	6.25	8.1429	3.25
35	9	1	2	0	86.9524	8.00	87.4524	7.75	-0.5000	0.25
36	9	1	2	1	88.5714	7.75	87.7143	8.50	0.8571	-0.75
37	10	0	2	0	70.5952	8.00	73.8571	7.50	-3.2619	0.50
38	10	0	2	1	67.5476	8.50	72.7619	7.00	-5.2143	1.50
39	10	1	2	0	80.9762	10.50	65.8571	8.50	1.1190	2.00
40	10	1	2	1	69.8571	8.00	73.9286	8.00	-4.0714	0.00

APPENDIX E (continued)

OBS	SUB	TC	LOC	TILT	HR2	BV2	HR3	BV3	HRDIFF	BVDIFF
1	1	0	3	0	62.4048	6.00	58.4762	6.00	-3.9286	0.00
2	1	0	3	1	68.4524	6.00	63.2619	6.00	-5.1905	0.00
3	1	1	3	0	57.4286	6.00	59.9286	6.00	2.5000	0.00
4	1	1	3	1	58.5000	6.00	56.6429	6.00	-1.8571	0.00
5	2	0	3	0	76.2143	9.50	87.5476	10.00	11.3333	0.50
6	2	0	3	1	74.6429	10.75	74.0714	10.00	-0.5714	-0.75
7	2	1	3	0	75.8571	10.75	72.5000	10.25	-3.3571	-0.50
8	2	1	3	1	72.2381	11.75	76.2857	11.25	4.0476	-0.50
9	3	0	3	0	61.4524	9.75	63.4286	12.75	1.9762	3.00
10	3	0	3	1	66.5238	11.25	67.9524	13.00	1.4286	1.75
11	3	1	3	0	68.7143	8.50	68.0952	9.25	-0.6190	0.75
12	3	1	3	1	72.5952	9.75	68.9524	8.75	-3.6429	-1.00
13	4	0	3	0	68.4762	11.00	78.9048	12.00	10.4286	1.00
14	4	0	3	1	76.9286	11.25	79.9286	12.50	3.0000	1.25
15	4	1	3	0	62.0952	8.50	68.2619	9.50	6.1667	1.00
16	4	1	3	1	65.7619	8.25	62.7857	10.00	-2.9762	1.75
17	5	0	3	0	56.4286	6.25	61.5952	6.25	5.1667	0.00
18	5	0	3	1	55.1667	6.25	61.0238	7.00	5.8571	0.75
19	5	1	3	0	51.5952	6.00	58.8095	6.50	7.2143	0.50
20	5	1	3	1	51.2143	6.00	56.1190	6.00	4.9048	0.00
21	6	0	3	0	65.7143	8.00	67.7619	7.50	2.0476	-0.50
22	6	0	3	1	66.0000	6.25	70.6905	8.75	4.6905	2.50
23	6	1	3	0	74.9524	9.25	72.5238	8.25	-2.4286	-1.00
24	6	1	3	1	68.4286	7.75	67.3095	7.25	-1.1190	-0.50
25	7	0	3	0	78.9524	7.75	75.4048	7.75	-3.5476	0.00
26	7	0	3	1	79.4524	8.00	80.6190	8.00	1.1667	0.00
27	7	1	3	0	71.7857	8.00	71.8571	8.00	0.0714	0.00
28	7	1	3	1	74.3333	7.75	68.9524	8.00	-5.3810	0.25
29	8	0	3	0	60.5000	6.25	59.5476	6.25	-0.9524	0.00
30	8	0	3	1	60.2857	6.75	59.4286	6.75	-0.8571	0.00
31	8	1	3	0	55.2857	7.75	55.6190	7.25	0.3333	-0.50
32	8	1	3	1	56.8333	6.50	53.9048	7.25	-2.9286	0.75
33	9	0	3	0	78.6190	7.75	74.7619	6.50	-3.8571	-1.25
34	9	0	3	1	75.5952	6.25	84.8810	8.75	9.2857	2.50
35	9	1	3	0	87.4524	7.75	87.9524	6.75	0.5000	-1.00
36	9	1	3	1	87.7143	8.50	86.4762	7.75	-1.2381	-0.75
37	10	0	3	0	73.8571	7.50	72.3333	7.75	-1.5238	0.25
38	10	0	3	1	72.7619	7.00	71.1190	9.00	-1.6429	2.00
39	10	1	3	0	65.8571	8.50	70.7143	8.00	4.8571	-0.50
40	10	1	3	1	73.9286	8.00	71.0714	7.75	-2.8571	-0.25

APPENDIX F

Paired observations for location during combined period

OBS	SUB	TC	LOC	TILT	HR1	BV1	HR2	BV2	HRDIFF	BVDIFF
1	1	0	2	0	77.000	7.50	76.4375	7.66	0.5625	-0.16
2	1	0	2	1	78.719	7.66	80.7656	7.16	-2.0469	0.50
3	1	1	2	0	75.078	7.33	72.1719	7.66	2.9063	-0.33
4	1	1	2	1	77.578	7.33	72.4688	7.66	5.1094	-0.33
5	2	0	2	0	93.703	13.66	87.8438	10.66	5.8594	3.00
6	2	0	2	1	95.359	12.00	86.7969	12.16	8.5625	-0.16
7	2	1	2	0	84.094	12.16	87.3750	11.16	-3.2813	1.00
8	2	1	2	1	89.000	12.16	85.0000	12.33	4.0000	-0.16
9	3	0	2	0	77.844	13.33	73.0469	9.83	4.7969	3.50
10	3	0	2	1	79.563	13.66	80.1719	12.16	-0.6094	1.50
11	3	1	2	0	83.563	11.66	81.5469	9.66	2.0156	2.00
12	3	1	2	1	82.438	10.00	85.5156	11.16	-3.0781	-1.16
13	4	0	2	0	85.563	11.66	83.4688	12.00	2.0938	-0.33
14	4	0	2	1	87.344	12.00	90.4844	12.16	-3.1406	-0.16
15	4	1	2	0	73.984	9.66	75.5625	9.33	-1.5781	0.33
16	4	1	2	1	78.047	10.00	80.2656	9.50	-2.2188	0.50
17	5	0	2	0	68.203	7.83	71.2031	8.33	-3.0000	-0.50
18	5	0	2	1	67.922	8.16	71.1875	8.16	-3.2656	0.00
19	5	1	2	0	67.875	7.83	64.6406	7.66	3.2344	0.16
20	5	1	2	1	63.828	7.66	63.4219	7.66	0.4063	0.00
21	6	0	2	0	88.672	9.83	81.2188	10.00	7.4531	-0.16
22	6	0	2	1	82.734	10.50	80.9219	8.16	1.8125	2.33
23	6	1	2	0	82.453	9.50	86.5625	9.83	-4.1094	-0.33
24	6	1	2	1	84.094	8.50	81.7031	9.00	2.3906	-0.50
25	7	0	2	0	88.094	9.83	91.6719	9.66	-3.5781	0.16
26	7	0	2	1	90.781	10.00	91.6875	9.66	-0.9063	0.33
27	7	1	2	0	86.875	9.66	82.2813	9.83	4.5938	-0.16
28	7	1	2	1	84.313	10.16	86.2188	9.66	-1.9063	0.50
29	8	0	2	0	76.906	7.50	73.9688	7.16	2.9375	0.33
30	8	0	2	1	76.766	7.50	76.2188	7.33	0.5469	0.16
31	8	1	2	0	71.281	7.66	70.7500	8.16	0.5313	-0.50
32	8	1	2	1	70.906	7.83	72.5781	6.83	-1.6719	1.00
33	9	0	2	0	91.563	9.50	91.1875	8.16	0.3750	1.33
34	9	0	2	1	96.281	10.33	88.0156	7.66	8.2656	2.66
35	9	1	2	0	96.719	8.50	98.7656	8.16	-2.0469	0.33
36	9	1	2	1	01.219	9.33	99.2969	9.50	1.9219	-0.16
37	10	0	2	0	83.359	9.00	85.6875	7.83	-2.3281	1.16
38	10	0	2	1	81.422	9.66	85.4375	7.83	-4.0156	1.83
39	10	1	2	0	79.719	10.66	79.0625	9.50	0.6563	1.16
40	10	1	2	1	81.531	9.66	82.3750	9.16	-0.8438	-0.50

APPENDIX F (continued)

OBS	SUB	TC	LOC	TILT	HR2	BV2	HR3	BV3	HRDIFF	BVDIFF
1	1	0	3	0	76.4375	7.66	73.875	7.33	-2.5625	-0.33
2	1	0	3	1	80.7656	7.16	77.281	7.50	-3.4844	0.33
3	1	1	3	0	72.1719	7.66	74.047	7.33	1.8750	-0.33
4	1	1	3	1	72.4688	7.66	71.750	7.83	-0.7188	0.16
5	2	0	3	0	87.8438	10.66	97.984	10.16	10.1406	-0.50
6	2	0	3	1	86.7969	12.16	85.734	11.50	-1.0625	-0.66
7	2	1	3	0	87.3750	11.16	84.938	11.16	-2.4375	0.00
8	2	1	3	1	85.0000	12.33	87.484	11.83	2.4844	-0.50
9	3	0	3	0	73.0469	9.83	75.594	12.66	2.5469	2.83
10	3	0	3	1	80.1719	12.16	79.922	12.66	-0.2500	0.50
11	3	1	3	0	81.5469	9.66	82.641	11.00	1.0938	1.33
12	3	1	3	1	85.5156	11.16	82.125	10.33	-3.3906	-0.83
13	4	0	3	0	83.4688	12.00	92.109	12.83	8.6406	0.83
14	4	0	3	1	90.4844	12.16	93.016	13.00	2.5313	0.83
15	4	1	3	0	75.5625	9.33	81.578	11.00	6.0156	1.66
16	4	1	3	1	80.2656	9.50	76.891	11.50	-3.3750	2.00
17	5	0	3	0	71.2031	8.33	74.578	8.16	3.3750	-0.16
18	5	0	3	1	71.1875	8.16	73.750	8.33	2.5625	0.16
19	5	1	3	0	64.6406	7.66	69.391	8.00	4.7500	0.33
20	5	1	3	1	63.4219	7.66	67.969	7.83	4.5469	0.16
21	6	0	3	0	81.2188	10.00	83.234	9.16	2.0156	-0.83
22	6	0	3	1	80.9219	8.16	85.016	10.66	4.0938	2.50
23	6	1	3	0	86.5625	9.83	84.203	9.50	-2.3594	-0.33
24	6	1	3	1	81.7031	9.00	81.984	9.16	0.2813	0.16
25	7	0	3	0	91.6719	9.66	90.109	9.50	-1.5625	-0.16
26	7	0	3	1	91.6875	9.66	93.219	9.50	1.5313	-0.16
27	7	1	3	0	82.2813	9.83	84.969	9.66	2.6875	-0.16
28	7	1	3	1	86.2188	9.66	83.313	9.50	-2.9063	-0.16
29	8	0	3	0	73.9688	7.16	73.938	6.83	-0.0313	-0.33
30	8	0	3	1	76.2188	7.33	76.359	7.16	0.1406	-0.16
31	8	1	3	0	70.7500	8.16	70.547	7.33	-0.2031	-0.83
32	8	1	3	1	72.5781	6.83	69.281	7.66	-3.2969	0.83
33	9	0	3	0	91.1875	8.16	87.766	7.00	-3.4219	-1.16
34	9	0	3	1	88.0156	7.66	95.813	9.33	7.7969	1.66
35	9	1	3	0	98.7656	8.16	100.828	8.83	2.0625	0.66
36	9	1	3	1	99.2969	9.50	98.047	9.50	-1.2500	0.00
37	10	0	3	0	85.6875	7.33	84.484	8.16	-1.2031	0.33
38	10	0	3	1	85.4375	7.83	83.750	9.83	-1.6875	2.00
39	10	1	3	0	79.0625	9.50	82.547	9.16	3.4844	-0.33
40	10	1	3	1	82.3750	9.16	82.750	8.66	0.3750	-0.50

APPENDIX G

Paired observations for tilt during exercise

OBS	SUB	TC	LOC	TILT	HR0	BV0	HR1	BV1	HRDIFF	BVDIFF
1	1	0	1	1	102.864	10.5	102.773	11.0	0.091	-0.5
2	1	0	2	1	103.227	11.0	104.273	9.5	-1.045	1.5
3	1	0	3	1	103.273	10.0	104.045	10.5	-0.773	-0.5
4	1	1	1	1	102.045	9.5	103.818	9.0	-1.773	0.5
5	1	1	2	1	100.318	11.0	99.136	11.0	1.182	0.0
6	1	1	3	1	101.000	10.0	100.591	11.5	0.409	-1.5
7	2	0	1	1	116.273	16.0	119.000	15.0	-2.727	1.0
8	2	0	2	1	110.045	13.0	110.000	15.0	0.045	-2.0
9	2	0	3	1	117.909	10.5	108.000	14.5	9.909	-4.0
10	2	1	1	1	107.318	14.0	112.227	14.0	-4.909	0.0
11	2	1	2	1	109.364	12.0	109.364	13.5	0.000	-1.5
12	2	1	3	1	108.682	13.0	108.864	13.0	-0.182	0.0
13	3	0	1	1	104.864	15.0	106.000	15.0	-1.136	0.0
14	3	0	2	1	95.182	10.0	106.227	14.0	-11.045	-4.0
15	3	0	3	1	98.818	12.5	102.773	12.0	-3.955	0.5
16	3	1	1	1	111.773	16.0	105.955	14.0	5.818	2.0
17	3	1	2	1	106.045	12.0	110.182	14.0	-4.136	-2.0
18	3	1	3	1	110.409	14.5	107.273	13.5	3.136	1.0
19	4	0	1	1	116.182	13.0	116.545	15.0	-0.364	-2.0
20	4	0	2	1	112.091	14.0	116.364	14.0	-4.273	0.0
21	4	0	3	1	117.318	14.5	118.000	14.0	-0.682	0.5
22	4	1	1	1	100.182	11.0	100.000	13.0	0.182	-2.0
23	4	1	2	1	101.273	11.0	107.955	12.0	-6.682	-1.0
24	4	1	3	1	107.000	14.0	103.818	14.5	3.182	-0.5
25	5	0	1	1	92.545	11.5	92.318	12.0	0.227	-0.5
26	5	0	2	1	99.409	12.5	101.773	12.0	-2.364	0.5
27	5	0	3	1	99.364	12.0	98.045	11.0	1.318	1.0
28	5	1	1	1	90.773	11.5	87.045	11.0	3.727	0.5
29	5	1	2	1	89.545	11.0	86.727	11.0	2.818	0.0
30	5	1	3	1	89.591	11.0	90.591	11.5	-1.000	-0.5
31	6	0	1	1	112.409	12.0	114.773	15.0	-2.364	-3.0
32	6	0	2	1	110.818	14.0	109.409	12.0	1.409	2.0
33	6	0	3	1	112.773	12.5	112.364	14.5	0.409	-2.0
34	6	1	1	1	107.318	12.0	108.182	11.0	-0.864	1.0
35	6	1	2	1	108.727	11.0	107.045	11.5	1.682	-0.5
36	6	1	3	1	106.500	12.0	110.000	13.0	-3.500	-1.0
37	7	0	1	1	117.500	13.5	117.727	13.5	-0.227	0.0
38	7	0	2	1	115.955	13.5	115.045	13.0	0.909	0.5
39	7	0	3	1	118.182	13.0	117.273	12.5	0.909	0.5
40	7	1	1	1	110.364	13.5	109.318	13.5	1.045	0.0
41	7	1	2	1	102.318	13.5	108.909	13.5	-6.591	0.0
42	7	1	3	1	110.000	13.0	110.727	12.5	-0.727	0.5
43	8	0	1	1	109.545	9.0	110.136	9.0	-0.591	0.0
44	8	0	2	1	99.682	9.0	106.636	8.5	-6.955	0.5
45	8	0	3	1	101.409	8.0	108.682	8.0	-7.273	0.0
46	8	1	1	1	102.591	8.5	101.727	9.0	0.864	-0.5
47	8	1	2	1	100.273	9.0	102.636	7.5	-2.364	1.5
48	8	1	3	1	99.045	7.5	98.636	8.5	0.409	-1.0
49	9	0	1	1	115.818	12.0	120.227	12.0	-4.409	0.0
50	9	0	2	1	115.182	9.0	111.727	10.5	3.455	-1.5
51	9	0	3	1	112.591	8.0	116.682	10.5	-4.091	-2.5
52	9	1	1	1	115.364	9.5	125.364	12.5	-10.000	-3.0
53	9	1	2	1	120.364	9.0	121.409	11.5	-1.045	-2.5
54	9	1	3	1	125.409	13.0	120.136	13.0	5.273	0.0
55	10	0	1	1	107.727	11.0	107.909	12.0	-0.182	-1.0
56	10	0	2	1	108.273	8.5	109.636	9.5	-1.364	-1.0
57	10	0	3	1	107.682	9.0	107.864	11.5	-0.181	-2.5
58	10	1	1	1	104.045	11.0	103.818	10.0	0.227	1.0
59	10	1	2	1	104.273	11.5	98.500	11.5	5.772	0.0
60	10	1	3	1	105.136	11.5	105.045	10.5	0.090	1.0

APPENDIX H

Paired observations for tilt during recovery

OBS	SUB	TC	LOC	TILT	HR0	BV0	HR1	BV1	HRDIFF	BVDIFF
1	1	0	1	1	63.4524	6.00	66.1190	6.00	-2.667	0.00
2	1	0	2	1	62.4048	6.00	68.4524	6.00	-6.048	0.00
3	1	0	3	1	58.4762	6.00	63.2619	6.00	-4.786	0.00
4	1	1	1	1	60.9524	6.25	63.8333	6.50	-2.881	-0.25
5	1	1	2	1	57.4286	6.00	58.5000	6.00	-1.071	0.00
6	1	1	3	1	59.9286	6.00	56.6429	6.00	3.286	0.00
7	2	0	1	1	81.8810	12.50	82.9762	10.50	-1.095	2.00
8	2	0	2	1	76.2143	9.50	74.6429	10.75	1.571	-1.25
9	2	0	3	1	87.5476	10.00	74.0714	10.00	13.476	0.00
10	2	1	1	1	71.9286	11.25	76.8333	11.25	-4.905	0.00
11	2	1	2	1	75.8571	10.75	72.2381	11.75	3.619	-1.00
12	2	1	3	1	72.5000	10.25	76.2857	11.25	-3.786	-1.00
13	3	0	1	1	63.6905	12.50	65.7143	13.00	-2.024	-0.50
14	3	0	2	1	61.4524	9.75	66.5238	11.25	-5.071	-1.50
15	3	0	3	1	63.4286	12.75	67.9524	13.00	-4.524	-0.25
16	3	1	1	1	68.7857	9.50	70.1190	8.00	-1.333	1.50
17	3	1	2	1	68.7143	8.50	72.5952	9.75	-3.881	-1.25
18	3	1	3	1	68.0952	9.25	68.9524	8.75	-0.857	0.50
19	4	0	1	1	69.5238	11.00	72.0476	10.50	-2.524	0.50
20	4	0	2	1	68.4762	11.00	76.9286	11.25	-8.452	-0.25
21	4	0	3	1	78.9048	12.00	79.9286	12.50	-1.024	-0.50
22	4	1	1	1	60.2619	9.00	66.5476	8.50	-6.286	0.50
23	4	1	2	1	62.0952	8.50	65.7619	8.25	-3.667	0.25
24	4	1	3	1	68.2619	9.50	62.7857	10.00	5.476	-0.50
25	5	0	1	1	55.4524	6.00	55.1429	6.25	0.310	-0.25
26	5	0	2	1	56.4286	6.25	55.1667	6.25	1.262	0.00
27	5	0	3	1	61.5952	6.25	61.0238	7.00	0.571	-0.75
28	5	1	1	1	55.8810	6.00	51.6667	6.00	4.214	0.00
29	5	1	2	1	51.5952	6.00	51.2143	6.00	0.381	0.00
30	5	1	3	1	58.8095	6.50	56.1190	6.00	2.690	0.50
31	6	0	1	1	76.2381	8.75	65.9524	8.25	10.286	0.50
32	6	0	2	1	65.7143	8.00	66.0000	6.25	-0.286	1.75
33	6	0	3	1	67.7619	7.50	70.6905	8.75	-2.929	-1.25
34	6	1	1	1	69.4286	8.25	71.4762	7.25	-2.048	1.00
35	6	1	2	1	74.9524	9.25	68.4286	7.75	6.524	1.50
36	6	1	3	1	72.5238	8.25	67.3095	7.25	5.214	1.00
37	7	0	1	1	72.6905	8.00	76.6667	8.25	-3.976	-0.25
38	7	0	2	1	78.9524	7.75	79.4524	8.00	-0.500	-0.25
39	7	0	3	1	75.4048	7.75	80.6190	8.00	-5.214	-0.25
40	7	1	1	1	74.5714	7.75	71.2143	8.50	3.357	-0.75
41	7	1	2	1	71.7857	8.00	74.3333	7.75	-2.548	0.25
42	7	1	3	1	71.8571	8.00	68.9524	8.00	2.905	0.00
43	8	0	1	1	59.8095	6.75	59.2857	6.75	0.524	0.00
44	8	0	2	1	60.5000	6.25	60.2857	6.75	0.214	-0.50
45	8	0	3	1	59.5476	6.25	59.4286	6.75	0.119	-0.50
46	8	1	1	1	54.8810	7.25	54.7619	7.25	0.119	0.00
47	8	1	2	1	55.2857	7.75	56.8333	6.50	-1.548	1.25
48	8	1	3	1	55.6190	7.25	53.9048	7.25	1.714	0.00
49	9	0	1	1	78.8571	8.25	83.7381	9.50	-4.881	-1.25
50	9	0	2	1	78.6190	7.75	75.5952	6.25	3.024	1.50
51	9	0	3	1	74.7619	6.50	84.8810	8.75	-10.119	-2.25
52	9	1	1	1	86.9524	8.00	88.5714	7.75	-1.619	0.25
53	9	1	2	1	87.4524	7.75	87.7143	8.50	-0.262	-0.75
54	9	1	3	1	87.9524	6.75	86.4762	7.75	1.476	-1.00
55	10	0	1	1	70.5952	8.00	67.5476	8.50	3.048	-0.50
56	10	0	2	1	73.8571	7.50	72.7619	7.00	1.095	0.50
57	10	0	3	1	72.3333	7.75	71.1190	9.00	1.214	-1.25
58	10	1	1	1	66.9762	10.50	69.8571	8.00	-2.881	2.50
59	10	1	2	1	65.8571	8.50	73.9286	8.00	-8.071	0.50
60	10	1	3	1	70.7143	8.00	71.0714	7.75	-0.357	0.25

APPENDIX I

Paired observations for tilt during combined period

OBS	SUB	TC	LOC	TILT	HR0	BV0	HR1	BV1	HRDIFF	BVDIFF
1	1	0	1	1	77.000	7.5000	78.719	7.6667	-1.7188	-0.1667
2	1	0	2	1	76.438	7.6667	80.766	7.1667	-4.3281	0.5000
3	1	0	3	1	73.875	7.3333	77.281	7.5000	-3.4063	-0.1667
4	1	1	1	1	75.078	7.3333	77.578	7.3333	-2.5000	0.0000
5	1	1	2	1	72.172	7.6667	72.469	7.6667	-0.2969	0.0000
6	1	1	3	1	74.047	7.3333	71.750	7.8333	2.2969	-0.5000
7	2	0	1	1	93.703	13.6667	95.359	12.0000	-1.6563	1.6667
8	2	0	2	1	87.844	10.6667	86.797	12.1667	1.0469	-1.5000
9	2	0	3	1	97.984	10.1667	85.734	11.5000	12.2500	-1.3333
10	2	1	1	1	84.094	12.1667	89.000	12.1667	-4.9063	0.0000
11	2	1	2	1	87.375	11.1667	85.000	12.3333	2.3750	-1.1667
12	2	1	3	1	84.938	11.1667	87.484	11.8333	-2.5469	-0.6667
13	3	0	1	1	77.844	13.3333	79.563	13.6667	-1.7188	-0.3333
14	3	0	2	1	73.047	9.8333	80.172	12.1667	-7.1250	-2.3333
15	3	0	3	1	75.594	12.6667	79.922	12.6667	-4.3281	0.0000
16	3	1	1	1	83.563	11.6667	82.438	10.0000	1.1250	1.6667
17	3	1	2	1	81.547	9.6667	85.516	11.1667	-3.9688	-1.5000
18	3	1	3	1	82.641	11.0000	82.125	10.3333	0.5156	0.6667
19	4	0	1	1	85.563	11.6667	87.344	12.0000	-1.7813	-0.3333
20	4	0	2	1	83.469	12.0000	90.484	12.1667	-7.0156	-0.1667
21	4	0	3	1	92.109	12.8333	93.016	13.0000	-0.9063	-0.1667
22	4	1	1	1	73.984	9.6667	78.047	10.0000	-4.0625	-0.3333
23	4	1	2	1	75.563	9.3333	80.266	9.5000	-4.7031	-0.1667
24	4	1	3	1	81.578	11.0000	76.891	11.5000	4.6875	-0.5000
25	5	0	1	1	68.203	7.8333	67.922	8.1667	0.2813	-0.3333
26	5	0	2	1	71.203	8.3333	71.188	8.1667	0.0156	0.1667
27	5	0	3	1	74.578	8.1667	73.750	8.3333	0.8281	-0.1667
28	5	1	1	1	67.875	7.8333	63.828	7.6667	4.0469	0.1667
29	5	1	2	1	64.641	7.6667	63.422	7.6667	1.2188	0.0000
30	5	1	3	1	69.391	8.0000	67.969	7.8333	1.4219	0.1667
31	6	0	1	1	88.672	9.8333	82.734	10.5000	5.9375	-0.6667
32	6	0	2	1	81.219	10.0000	80.922	8.1667	0.2969	1.8333
33	6	0	3	1	83.234	9.1667	85.016	10.6667	-1.7813	-1.5000
34	6	1	1	1	82.453	9.5000	84.094	8.5000	-1.6406	1.0000
35	6	1	2	1	86.563	9.8333	81.703	9.0000	4.8594	0.8333
36	6	1	3	1	84.203	9.5000	81.984	9.1667	2.2188	0.3333
37	7	0	1	1	88.094	9.8333	90.781	10.0000	-2.6875	-0.1667
38	7	0	2	1	91.672	9.6667	91.688	9.6667	-0.0156	0.0000
39	7	0	3	1	90.109	9.5000	93.219	9.5000	-3.1094	0.0000
40	7	1	1	1	86.875	9.6667	84.313	10.1667	2.5625	-0.5000
41	7	1	2	1	82.281	9.8333	86.219	9.6667	-3.9375	0.1667
42	7	1	3	1	84.969	9.6667	83.313	9.5000	1.6563	0.1667
43	8	0	1	1	76.906	7.5000	76.766	7.5000	0.1406	0.0000
44	8	0	2	1	73.969	7.1667	76.219	7.3333	-2.2500	-0.1667
45	8	0	3	1	73.938	6.8333	76.359	7.1667	-2.4219	-0.3333
46	8	1	1	1	71.281	7.6667	70.906	7.8333	0.3750	-0.1667
47	8	1	2	1	70.750	8.1667	72.578	6.8333	-1.8281	1.3333
48	8	1	3	1	70.547	7.3333	69.281	7.6667	1.2656	-0.3333
49	9	0	1	1	91.563	9.5000	96.281	10.3333	-4.7188	-0.8333
50	9	0	2	1	91.188	8.1667	88.016	7.6667	3.1719	0.5000
51	9	0	3	1	87.766	7.0000	95.813	9.3333	-8.0469	-2.3333
52	9	1	1	1	96.719	8.5000	101.219	9.3333	-4.5000	-0.8333
53	9	1	2	1	98.766	8.1667	99.297	9.5000	-0.5313	-1.3333
54	9	1	3	1	100.828	8.8333	98.047	9.5000	2.7813	-0.6667
55	10	0	1	1	83.359	9.0000	81.422	9.6667	1.9375	-0.6667
56	10	0	2	1	85.688	7.8333	85.438	7.8333	0.2500	0.0000
57	10	0	3	1	84.484	8.1667	83.750	9.8333	0.7344	-1.6667
58	10	1	1	1	79.718	10.6667	81.531	8.6666	-1.8125	2.0000
59	10	1	2	1	79.062	9.5000	82.375	9.1666	-3.3125	0.3333
60	10	1	3	1	82.546	9.1667	82.750	8.6666	-0.2031	0.5000

EFFECT OF SADDLE SETTINGS AND TOE CLIPS ON EXERCISE BIKES IN REDUCING ENERGY EXPENDITURE

by

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AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Industrial Engineering

KANSAS STATE UNIVERSITY

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1983

ABSTRACT

The study investigated the effect of toe clips, seat location, and seat tilt for a stationary bicycle.

The experiment had 10 male subjects pedal on a stationary bicycle against a constant load at 60 rpm on a 10 min work 20 min rest schedule once in each of the 12 conditions. The 12 conditions were all combinations of: (a) toe clips vs no toe clips, (b) seat horizontal vs seat tilted -7° forward, and (c) center of seat at 19, 25 or 31° angle vs a vertical through the hub centerline. Heart rate was determined every 30 s. A Borg Perceived Exertion (BPE) vote was taken every 5 min. A semantic-differential scale on seat-pedal comfort was given once/condition; a principal component (factor) analysis divided it into factors of comfort, difficulty, and usefulness.

Using toe clips was beneficial (heart rate was reduced by about 3% during exercise, recovery, and combined periods and BPE by 1.7% during exercise period); comfort, difficulty, and usefulness factors were not affected. Seat position of 25° was the best. Heart rate was reduced by 1.3% during exercise (as compared to 19°); the difference between 25° and 31° was not statistically significant. Location at 25° was perceived (BPE rating) to be about 6% less stressful than location at 19° during both work and rest; the 25° location had a 3.8% lesser BPE rating than 31° during rest. Location at 25° was preferred over 19° by 23% for comfort, 18% for difficulty, and 19% for usefulness. Tilt did not affect heart rate but the no tilt condition had a BPE rating 3.4% less during work and 1.2% less during rest. The no tilt condition was preferred by 20% for comfort, by 13% for difficulty, and by 15% for usefulness.

The correlation coefficient between the heart rate and BPE was 0.36 during exercise, 0.41 during recovery, and 0.39 during the combined period. The heart rate was predicted by HR = 9.6 * BPE during exercise and by HR = 8.3 * BPE during the recovery period.