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A COMPARISON OF MAXIMAL OXYGEN UPTAKE ON HORIZONTAL VS. INCLINED TREADMILL PROTOCOLS BEFORE AND AFTER AN INCLINED TERRAIN RUNNING PROGRAM

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A COMPARISON OF MAXIMAL OXYGEN UPTAKE ON HORIZONTAL VS. INCLINED TREADMILL PROTOCOLS BEFORE AND AFTER AN INCLINED TERRAIN RUNNING PROGRAM

by

Beau Jeffere Freund

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ABSTRACT

Twenty-two men, 17-27 years of age, volunteered to participate in a training program consisting of inclined terrain running. The purpose of this study was to, 1) compare $\dot{V}O_2$ max values in untrained subjects on both horizontal and inclined treadmill protocols, and 2) evaluate changes in $\dot{V}O_2$ max values consequent to inclined terrain run training to determine if a specificity of training to testing protocol occurred. Maximal oxygen uptake ($\dot{V}O_2$ max), maximal heart rate (HR max), maximal ventilation ($\dot{V}E$ max), maximal respiratory exchange ratio (RER max), and maximum treadmill time (MTT) were evaluated on both inclined (I) and horizontal (H) treadmill protocols, both pre-and post- training. Prior to training, there was no significant difference between protocols in $\dot{V}O_2$ max. However, RER max and $\dot{V}E$ max were significantly greater on the (I) protocol. The men were then randomly assigned to a control group (n=10) or an experimental group (n=12). The experimental group ran on an inclined terrain four times per week for 12 weeks, with each session lasting approximately 35 min. Training intensity was established at 65-85% of aerobic capacity, with an assigned training heart rate range which was monitored by the subject each training session. The training program resulted in no change in HR max, RER max, or body weight. $\dot{V}E$ max, MTT, and $\dot{V}O_2$ max increased 8.7%, 9.1% and 8.5% respectively on the inclined protocol and 5.8%, 6.8%, and 5.3% on the horizontal protocol respectively. All increases were statistically significant

at the .05 level. In addition, the post training $\dot{V}O_2$ max on the (I) protocol was significantly greater than the $\dot{V}O_2$ max obtained on the (H) protocol. This study demonstrates that training by inclined terrain running brings about specific physiological changes that are most clearly identified by using an inclined treadmill protocol. These results support the concept of specificity of training and indicate the importance of careful selection of both the test protocol as well as the test mode.

CHAPTER 1

INTRODUCTION

Maximal oxygen consumption ($\dot{V}O_2$ max) is the fundamental measure of cardiorespiratory endurance or aerobic work capacity. The measurement of $\dot{V}O_2$ max provides an estimate of an individual's capacity for aerobic energy transfer and is one of the more important factors in determining one's ability to sustain high-intensity exercise for an extended period of time (4,5,7,54).

$\dot{V}O_2$ max values are largely dependent on heredity and the subject's level of endurance fitness but are also influenced by a variety of factors including mode of testing and test protocol (9). To elicit maximal aerobic energy transfer, the investigator must insure that the exercise activates large muscle groups and is of sufficient intensity and duration. It is also important when assessing trained subjects or athletes that the exercise mode simulate as closely as possible the conditions of the subject's specific sport or activity (33,38,62). As an example, subjects trained by running should be tested on the treadmill (53,55,62).

The treadmill is the most frequently used ergometric device for evaluating $\dot{V}O_2$ max (1,2,16,65). Numerous protocols have been developed to elicit maximal values, and the majority of these protocols use both increases in speed and grade to achieve maximal levels of performance. The research is equivocal on whether an inclined or a horizontal protocol will elicit higher $\dot{V}O_2$ max values. Just as protocols vary, so does the terrain on which runners train. This is an important consideration when selecting a test protocol. Some runners incorporate hill running into their training, while others train solely on flat terrain. Subjects who train only on flat terrain may be limited by localized muscular fatigue when tested on an inclined protocol (27). These subjects may produce higher $\dot{V}O_2$ max values on a horizontal protocol due to local muscular adaptations developed through their specific training regimen (3,71). Conversely, in subjects who are not trained by running, the horizontal protocol may limit their $\dot{V}O_2$ max values by their inability to achieve or maintain the leg speed needed to elicit a maximum cardiovascular response. These subjects may, in fact, achieve their highest $\dot{V}O_2$ max values on an inclined protocol (34,64).

Therefore, training terrain is an important consideration when selecting a test protocol. Although some of the studies comparing horizontal and inclined protocols involved trained subjects, none were actually training studies. These previous studies have also failed to examine the possible interaction between the training terrain and the test protocol used to elicit $\dot{V}O_2$ max. Simply stated, if a person trains on hills or an inclined terrain, should he or she be tested with an inclined or a horizontal protocol in order to best document the subsequent changes in physiological function? Likewise, if an individual has trained on level terrain and has done little or no inclined or hill training, should he or she be tested with an inclined or horizontal test protocol, the latter being more specific to the actual training done?

Statement of the Problem

The purpose of this study was twofold: first, to compare $\dot{V}O_2$ max values in untrained subjects on horizontal and inclined treadmill protocols to determine the superiority, if existent, of one protocol over the other, second, to then train a group of these individuals to evaluate changes in $\dot{V}O_2$ max values following inclined run training to determine if there was a specificity of protocols for eliciting actual training responses.

CHAPTER 2

REVIEW OF LITERATURE

This review chapter concerns itself with three major areas. The first of these areas is a comparison of various modes of exercise testing that have been used to determine $\dot{V}O_2$ max. The second section examines training and testing specificity and their relationship to testing mode. The final section reviews the literature pertaining to inclined versus horizontal treadmill test protocols and the possible mechanisms responsible for the conflicting results reported in these studies.

Variations in $\dot{V}O_2$ max Determination With Different Modes of Exercise Testing

A variety of work modes have been used to determine $\dot{V}O_2$ max. Frequently used forms of exercise include treadmill walking and running, stationary cycling, and bench stepping. However, $\dot{V}O_2$ max has also been measured during swimming (6,36,37,38,47), skiing (6,62), rowing (14,62), kayaking (57,66), and arm ergometry (6,8,49).

Several studies have compared various work modes for determining aerobic power in untrained individuals. Treadmill tests have been compared to cycle ergometer tests relative to $\dot{V}O_2$ max, with higher values in most studies being reported for the treadmill (9,20,28,34,41,51,52,72). However, Åstrand (3) was unable to demonstrate any significant difference in maximal oxygen uptake in 67 subjects, comparing running on a treadmill (inclination 1.75%) and cycling on an ergometer. Step tests have been compared to treadmill tests relative to $\dot{V}O_2$ max, and again, higher values were reported for the treadmill (43,45). For skilled, but untrained swimmers, maximal oxygen uptake determined while swimming was generally about 20% below treadmill values (47,53,6). Arm ergometry (6,8,49) and rowing (14,62) have also been reported to elicit lower $\dot{V}O_2$ max values than those obtained on the treadmill.

Several investigators (3,29,61,64) have interpreted the above results to favor the concept of $\dot{V}O_2$ max being a function of the absolute muscle mass engaged in the exercise, i.e. treadmill exercise elicits higher $\dot{V}O_2$ max values consequent to the recruitment of a higher fraction of the body's total muscle mass. However, Astrand and Saltin (6), systematically compared different types of physical activites all of which engaged large muscle groups. They found no differences between the $\dot{V}O_2$ max obtained during cycling with the legs only or with arms and legs simultaneously, or with cross country skiing, yet a 4.5% higher oxygen uptake was found during uphill running (inclination $> 3^{o}$). They concluded that the amount of active muscle mass cannot completely explain higher $\dot{V}O_2$ max values with different modes of exercise testing, since the muscle mass active in cross country skiing and in simultaneous work with arms and legs is no doubt larger than the amount of muscle mass engaged in the uphill running, yet $\dot{V}O_2$ max was in all cases higher with the uphill running. Their conclusion was that the ceiling for $\dot{V}O_2$ max seems independent of the mass of muscle employed in the exercise as soon as that mass exceeds a certain amount. Conversely, Taylor et al. (64) cited a 0.2 $l\cdot min^{-1}$ increase in $\dot{V}O_2$ max for a single subject when arm ergometry was added to running on the treadmill. It was hypothesized that $\dot{V}O_2$ max is reached when the muscles become unable to accept supplementary blood flow. Gleser et al. (29) similarly added arm ergometry to maximal leg ergometry and found a 10% higher $\dot{V}O_2$ max as compared to maximal leg work alone. Therefore, they concluded that the ceiling for oxygen uptake is dependent on the mass of exercising muscle.

On the conflicting results of Åstrand and Saltin (6) and Taylor et al. (64), Secher et al. (61) hypothesized that if an arm plus leg exercise will elicit higher $\dot{V}O_2$ max values than exercise with the legs alone, this difference will be more pronounced in subjects trained for arm exercise. Their results supported this hypothesis, and it was indicated that cardiac output was not maximal during maximal exercise with the legs alone, therefore $\dot{V}O_2$ max was limited by local factors in the exercising muscles (61).

Training and Testing Specificity

Besides the involvement of a different muscle mass when performing various modes or protocols employed to elicit $\dot{V}O_2$ max, several studies suggest that consideration should be given to the specificity of training and its effect on local muscle. Endurance training will invariably result in increases in $\dot{V}O_2$ max (13,24,45,46,56,70) and in order to elicit maximal cardiorespiratory values in these trained subjects, the work mode should engage those specific groups of muscles that were trained. Clausen et al. (15) and Davies and Sargeant (21) have reported that training by means of arm or leg exercise (15) or by one- and two-legged exercise (21) produces a training effect which is specific to the specific muscles trained. Others have reported that individuals trained on a cycle ergometer show greater improvements when tested on the cycle ergometer than on the treadmill. Likewise, subjects trained by running show greater $\dot{V}O_2$ max values when tested by running (53,55,62). Furthermore, the observations of Roberts and Alspaugh (58) and Pechar et al. (55), studying the cardioresiratory adaptation to bicycle and treadmill training, and those of Holmér and Åstrand (37) and Magel et al. (48), investigating the specificity of swim training on $\dot{V}O_2$ max, strongly suggest that the state of training and prior experience with a particular form of muscular activity may account for variations in maximal aerobic power when measurements are performed during different modes of testing.

Training of specific muscle groups may increase the $\dot{V}O_2$ max by facilitating oxygen transport and by local adaptive changes in the metabolic characteristics of the muscle fibers e.g., enzyme activities (17,35,60,67). This suggests that a test involving a large muscle mass and optimal use of the specifically trained muscle fibers may elicit the highest value for $\dot{V}O_2$ max when comparing the results obtained by different test protocols and modes. Therefore, when assessing trained individuals, the work mode should, if possible, closely duplicate the actual conditions of the sport or activity by which the individual was trained. Stromme et al. (62) reported that the highest $\dot{V}O_2$ max values for groups of athletes in several sports, i.e. skiers, rowers, cyclists, were obtained when the testing mode was similar or identical to their sport specialty when compared to incremental treadmill running. Therefore, as an example, when assessing a population that has been trained by running, the testing for $\dot{V}O_2$ max should be conducted on a treadmill (53,55,62).

Inclined Versus Horizontal Treadmill Test Protocols

The treadmill is the most frequently used ergometric device for evaluating $\dot{V}O_2$ max (1,2,16,65). The American Heart Association (2) and the

American College of Sports Medicine (1) recommend an incremental protocol when treadmill testing is performed to ensure maximal cardiorespiratory function.

The research is equivocal on whether an incline or a horizontal test protocol will elicit higher $\dot{V}O_2$ max values. In one of the first studies comparing horizontal and inclined protocols, Taylor et al. (64) reported that $\dot{V}O_2$ max values were significantly higher on the inclined protocol. As a reasonable explanation, they suggested that a larger muscle mass is working in uphill running and this increases the oxygen uptake provided the circulation can supply the oxygen. They concluded that the most satisfactory method of increasing the work load with the treadmill to attain $\dot{V}O_2$ max is to raise the grade, maintaining the speed constant. Åstrand and Saltin (6) conducted a study in which various work modes, i.e. cycle ergometry, swimming, cross-country skiing, simultaneous arm and leg work on cycle ergometers, arm work (cranking), and running on a treadmill, were compared. In addition, three of the subjects' treadmill runs were conducted on both an inclined (7.9%) and a horizontal protocol. The results showed higher $\dot{V}O_2$ max values elicited by the inclined protocol when compared to the horizontal protocol. This finding might be explained by a greater mass of muscle employed in uphill running compared to horizontal running. However, the active muscle mass is no doubt still larger for cross-country skiing and in simultaneous work with the arms and legs, yet $\dot{V}O_2$ max was in all cases highest in uphill running. In 1969, Hermansen and Saltin (34) confirmed these earlier results, reporting that $\dot{V}O_2$ max values for an inclined test (5.25%) were 0.2 $l \cdot min^{-1}$ higher than the mean $\dot{V}O_2$ max values attained on a horizontal test. Mayhew and Gross (50) also found slightly higher values (3.2%)

for an inclined protocol (4.5^{o}) as compared to a horizontal protocol. Their subjects were predominantely distance runners. However, their data reveals that the majority of these subjects failed to show a leveling off of their final $\dot{V}O_2$ values, raising the question as to whether their highest values truly represented $\dot{V}O_2$ max.

Other investigators have reported findings which demonstrate that for certain subject populations, mean $\dot{V}O_2$ max values for a horizontal protocol equal (44,63) or exceed (3,71) mean $\dot{V}O_2$ max values for an inclined protocol. Kasch et al. (44), using 12 well-trained and highly motivated male subjects, found no significant difference in $\dot{V}O_2$ max between protocols, i.e. inclined = 60.3 $ml \cdot kg^{-1} \cdot min^{-1}$ and horizontal = 60.2 $ml \cdot kg^{-1} \cdot min^{-1}$. Sucec (63) found similar results using trained male and female distance runners. Wilson et al. (45) found that 10 male competitive milers actually produced significantly higher $\dot{V}O_2$ max values on a horizontal protocol compared to an inclined protocol. Åstrand (3) found that the horizontal treadmill protocol elicited a higher maximal value for $\dot{V}O_2$ when compared to values obtained on an inclined protocol.

Training and testing specificity no doubt play an important role in $\dot{V}O_2$ max determination and may account for the discrepancies found in these previous studies which have compared horizontal and inclined test protocols. Subjects not trained by running or those not trained specifically for horizontal running may be limited on a horizontal protocol by an inability to achieve and maintain the leg speed required to elicit maximum cardiorespiratory function. Conversely, untrained subjects, or subjects who train solely on flat terrain, may be limited by local fatigue on an inclined protocol. Those subjects who do not incorporate hill running into their training program have probably failed to develop peripheral adaptations in the specific muscle groups that are used in inclined treadmill running. Therefore, it would appear that the treadmill protocol should match the type of terrain on which the training was conducted.

CHAPTER 3

METHODOLOGY

Subjects

Thirty male subjects from the University of Arizona volunteered to participate in this study. The experimental protocol had been previously approved by the University of Arizona's Human Subjects Committee, and all subjects provided informed consent (Appendices A and B). Criteria for subject selection dictated that the subject be healthy and physically active, but running less than 10 miles per week as determined by an activity questionnaire (Appendix C). Subjects were randomly assigned to either a control group (N=10) who underwent only pre-and post-testing, i.e. no training, and an exercise group (N=20). Of the 20 subjects in the exercise group, 12 completed the entire study. The remaining eight dropped out due to injury (n=3), leaving town (n=2), and problems of time commitment (n=3). The physical characteristics of the 10 control and the 12 experimental subjects are presented in Table 1.

Testing

All subjects were familiarized with the treadmill testing procedures and equipment and then signed a consent form prior to any data collection. Each subject was given four pre-training and two post-training tests to exhaustion (volitional fatigue). The four pre-training tests were randomly assigned so that all subjects performed two tests on each of two treadmill protocols, i.e. horizontal and inclined. Repeat tests were performed to establish reliability of the initial maximal tests. The criterion was established that the two

TABLE 1. **Physical characteristics of the subjects**

Training Group (N=12)				Control Group (N=10)			
Subject	**Age (yr)**	**Height (cm)**	**Weight (kg)**	**Subject**	**Age (yr)**	**Height (cm)**	**Weight (kg)**
SR	19	173.0	61.73	MH	25	179.0	77.21
JR	18	185.0	71.98	MB	22	190.5	73.79
JH	27	182.0	73.36	SD	25	183.0	77.16
MN	21	174.5	70.04	BM	20	178.0	59.37
SB	23	186.0	97.95	LT	21	183.0	89.91
DF	19	178.5	65.67	SG	26	180.0	72.05
SC	21	176.0	71.08	DP	18	186.0	71.81
RH	19	179.0	59.43	JW	22	176.5	66.76
PL	20	181.5	68.13	TK	20	183.0	84.60
BK	21	189.5	78.84	MA	23	178.0	61.86
RR	18	173.5	69.81				
SB	18	185.5	89.33				
$\bar{x}$	20.3	180.33	73.11	$\bar{x}$	22.2	181.70	73.45
S.D.	2.6	5.45	11.02	S.D.	2.5	4.29	9.46
$S\bar{x}$	0.7	1.57	3.18	$S\bar{x}$	0.8	1.36	2.99

determinations of $\dot{V}O_2$ max for each protocol must differ by less than 2 $ml \cdot kg^{-1} \cdot min^{-1}$ as outlined by Taylor et al. (64). If this criterion was not met, a third treadmill test was given for that specific protocol, and the values of the two closest tests were averaged. Each subject was given a minimum of 48 hours rest between maximal tests. The two post-training tests were performed, once on each protocol, in a randomized order to determine the significance of changes consequent to training.

All maximal tests were conducted on a Quinton motorized treadmill (Model 24-72). Metabolic and respiratory measurements were obtained using a Beckman Metabolic Measurement Cart (MMC) and included $\dot{V}O_2$, ventilation ($\dot{V}E$), and respiratory exchange ratio (RER), which were displayed every 60 seconds. Ratings of perceived exertion (RPE) were taken during the final 15 seconds of each stage, using the Borg Scale (10). Heart rate was monitored by an electrocardiogram on a Hewlett-Packard ECG/Phono System (Model 1514A), using a single lead (CM-5). Maximal treadmill time (MTT) was recorded for each test. Equipment calibration was conducted at regular intervals throughout the testing. In addition, pre- and post-test calibration of the gas analyzers were performed for each test to determine the potential drift in sensors, using standard gases previously calibrated by the micro-Scholander technique. All post-training tests were completed within a week of the final exercise session.

Protocols

The two protocols used in determining a subject's $\dot{V}O_2$ max were designed to elicit exhaustion in 8-12 minutes. The protocols were as follows.

Inclined Protocol (Modified Bruce--2 min. stages)

TIME	SPEED	GRADE
0-2 min.	1.7 mph	10%
2-4 min.	2.5 mph	12%
4-6 min.	3.4 mph	14%
6-8 min.	4.2 mph	16%
8-10 min.	5.0 mph	18%
10-12 min.	5.5 mph	20%
12-14 min.	6.0 mph	22%

Horizontal Protocol

TIME	SPEED	GRADE
0-2 min.	4 mph	0%
2-4 min.	6½ mph	0%
4-6 min.	7½ mph	0%
6-8 min.	8½ mph	0%
8-10 min.	9½ mph	0%
10-12 min.	10½ mph	0%
12-14 min.	11½ mph	0%

Training

The exercise group participated in a 12-week training program. The running program consisted of four sessions per week of approximately 35 min in length. The training took place at the same time each morning at the University of Arizona's stadium, using the concrete ramps as the inclined terrain. These ramps had a slope varying from 11% to 13%. The total elevation drop and gain in each lap was approximately 156 ft, and each lap was approximately 0.33 mi. Most subjects completed between 9 and 14 laps per training session. Some speed-play and interval training were incorporated in these 35 min exercise sessions. All subjects were familiarized with the technique of palpation in determining heart rate. Pulse was taken at either the carotid or the radial artery for a 10 s count. Each subject was given an individual training heart rate range based on the results of the initial testing. This range was determined by using 65% - 85% of the Karvonen (42) equation, i.e. .65x (HR max-HR rest) + HR rest and .85 x (HR max-HR rest) + HR rest. The highest heart rate recorded during the four maximal treadmill tests conducted prior to training was assumed to be the maximal value. Exercise heart rates were monitored by each subject at the 10th, 20th, and 35th min of the exercise session. Exercise intensity was continuously adjusted to maintain the training heart rate within its range. All training sessions were supervised by the principal investigator.

Statistical Analysis

All data were analyzed using a 3-factor mixed-design, analysis of variance and covariance with repeated measures using pre-training scores as the covariate (Bruning and Kintz, 1968). Dependent variables included $\dot{V}O_2$, $\dot{V}E$, RER, MHR, and MTT while the effects of test protocol (horizontal versus inclined) and training state (trained versus untrained) were the independent variables. Paired or independent *t*-tests were used for post hoc analyses to determine where significance between means occurred (Bruning & Kintz, 1968). The 0.05 level of significance was selected for all analyses.

CHAPTER 4

RESULTS

Initial Testing

Statistical analysis of the initial pre-training test results comparing the inclined and horizontal protocols indicated that RER max and $\dot{V}E$ max were significantly higher on the inclined protocol ($t=10.4$, $t=3.5$ respectively), while no differences were found for $\dot{V}O_2$ max or HR max (Table 2). Following the initial pre-training tests, the subjects were divided into two groups, i.e. training and control. Prior to training, no statistical differences between these two groups were found on any of the variables measured (Tables 3 and 4).

Post-Training Testing

When physiological changes consequent to training were examined, significant increases in $\dot{V}O_2$ max (Figure 1), MTT (Figure 2), and $\dot{V}E$ max (Figure 3) were found for both protocols ($F=20.6$, $F=33.4$, $F=18.0$ respectively). Body weight, RER max (Figure 4), and HR max did not change with training. These data are presented in Table 3.

Table 4 reveals that the only significant change in the control group was a reduction in $\dot{V}O_2$ max for the horizontal protocol at the conclusion of the study ($t=4.0$). Similarly, a reduction was found in $\dot{V}O_2$ max for the inclined protocol although this change was not statistically significant. While specific reasons for the reduction in $\dot{V}O_2$ max post-training are not obvious, it is possible

Table 2. PHYSIOLOGICAL COMPARISONS OF INCLINED VERSUS HORIZONTAL PROTOCOLS

(N=22)

$\bar{X} \pm$ S.D.	$\dot{V}O_2$ Max ($ml \cdot kg \cdot min^{-1}$)	$\dot{V}O_2$ Max ($l \cdot min^{-1}$)	$\dot{V}E$ Max ($l \cdot min^{-1}$)	RER Max	Heart Rate Max ($beats \cdot min^{-1}$)	Weight (kg)
Horizontal	53.1 ± 4.0	3.87 ± .42	147.6 ± 15.8	1.14 ± .06	191.7 ± 5.4	73.36 ± 10.28
Incline	53.6 ± 3.9	3.90 ± .47	154.8[a] ± 17.0	1.25[a] ± .07	190.0 ± 5.6	73.18 ± 10.34
Differences, Absolute						
	+ 0.5	+0.03	+6.4[a]	+.11[a]	-1.6	-.18
Differences, Relative						
	+0.9%	+0.8%	+4.7%[a]	+8.8%[a]	-0.8%	-0.25%

a = significant difference between means at the .05 level.

Table 3. PRE- AND POST-TRAINING DATA FOR

TRAINING GROUP (N=12)

$\bar{X}$ ± S.D.	$\dot{V}O_2$ Max ($ml \cdot kg^{-1} \cdot min^{-1}$)	$\dot{V}O_2$ Max ($l \cdot min^{-1}$)	$\dot{V}E$ Max ($l \cdot min^{-1}$)	RER	Heart Rate Max ($beats \cdot min^{-1}$)	Max Time (s)	Weight (kg)
Pre-Horizontal	53.7 ± 3.9	3.90 ± .47	151.3 ± 16.7	1.15 ± .06	190.7 ± 6.0	680.3 ± 81.8	73.22 ± 11.0
Pre-Incline	54.4 ± 3.2	3.95 ± .52	156.8 ± 17.3	1.25 ± .06	189.6 ± 5.7	605.8 ± 48.0	73.02 ± 11.03
Post-Horizontal	56.6[a] ± 4.5	4.09[a] ± .46	160.1[a] ± 16.2	1.13 ± .05	190.0 ± 7.2	726.3[a] ± 79.8	72.73 ± 10.85
Post-Incline	59.0[a] ± 5.6	4.24[a] ± .57	170.5[a] ± 21.9	1.22 ± .03	190.7 ± 8.1	661.1[a] ± 46.0	72.43 ± 10.75
<u>Differences, Absolute</u>							
Pre-Hor - Pre-Incl	-0.7	-0.05	-5.5	-0.10	+1.10	+74.5	+0.20
Post-Hor - Post-Incl	-2.4	-0.15	-10.4	-0.09	-.70	+65.2	+0.30
Post-Hor - Pre-Hor	+2.9	+0.19	+8.8	-0.02	-.70	+46.0	-0.49
Post-Incl - Pre-Incl	+4.6	+0.29	+13.7	-0.03	+1.10	+55.3	-0.59
<u>Differences, Relative %</u>							
Pre-Hor - Pre-Incl	-1.2%	-1.3%	-3.5%[b]	-9.1%[b]	+0.6%	10.9%[b]	+0.3%
Post-Hor - Post Incl	-4.27%[b]	-3.7%[b]	-6.5%[b]	-8.3%[b]	-0.4%	+9.0%[b]	+0.4%
Post-Hor - Pre-Hor	+5.3%[b]	+4.9%[b]	+5.8%[b]	-1.4%	-0.4%	+6.8%[b]	-0.7%
Post-Incl - Pre-Incl	+8.5%[b]	+7.3%[b]	+8.7%[b]	-2.1%	+0.6%	+9.1%	-0.8%

a = significantly different when compared to control group at 0.05 level
b = significant change or difference between means at the 0.05 level

Table 4. PRE- AND POST-TRAINING DATA FOR

CONTROL GROUP (N=10)

$\bar{X} \pm$ S.D.	$\dot{V}O_2$ Max ($ml \cdot kg^{-1} \cdot min^{-1}$)	$\dot{V}O_2$ Max ($l \cdot min^{-1}$)	$\dot{V}E$ Max ($l \cdot min^{-1}$)	RER	Heart Rate Max ($beats \cdot min^{-1}$)	Max Time (s)	Weight (kg)
Pre-Horizontal	52.4 ± 4.2	3.83 ± .37	143.1 ± 14.8	1.12 ± .05	192.6 ± 4.6	639.7 ± 96.9	73.53 ± 9.41
Pre-Incline	52.7 ± 4.7	3.84 ± .40	152.5 ± 16.6	1.25 ± .08	190.4 ± 5.5	594.9 ± 47.5	73.37 ± 9.51
Post-Horizontal	50.8[a] ± 4.6	3.68[a] ± .38	138.6[a] ± 15.3	1.13 ± .04	191.7 ± 4.8	630.3[a] ± 102.3	73.18 ± 9.13
Post-Incline	51.6[a] ± 5.5	3.75[a] ± .38	148.8[a] ± 18.4	1.21 ± .07	190.0 ± 6.1	581.5[a] ± 55.8	73.17 ± 9.27
Differences, Absolute							
Pre-Hor - Pre-Incl	-0.3	-0.01	-9.4	-0.13	+2.2	+44.8	+0.16
Post-Hor - Post-Incl	-0.8	-0.07	-10.2	-0.08	+1.7	+48.8	+0.01
Post-Hor - Pre-Hor	-1.6	-0.15	-4.5	+0.01	-0.09	-9.4	-0.35
Post-Incl - Pre-Incl	-1.1	-0.09	-3.7	-0.04	-0.4	-13.4	-0.20
Differences, Relative %							
Pre-Hor - Pre-Incl	-0.6%	-0.3%	-6.6%[b]	-11.6%[b]	+1.1%	+7.0%[b]	+0.2%
Post-Hor - Post Incl	-1.6%	-1.9%	-7.4%[b]	-7.1%[b]	+0.9%	+7.7%[b]	+0.0%
Post-Hor - Pre-Hor	-3.0%[b]	-3.9%[b]	-3.1%	+0.9%	-0.5%	-1.5%	-0.5%
Post-Incl - Pre-Incl	-2.1%	-2.3%	-2.4%	-3.2%	-0.2%	-2.3%	-0.3%

a = significantly different when compared to experimental group at 0.05 level
b = significant change or difference between means at the 0.05 level

Figure 1. PRE- AND POST-TRAINING

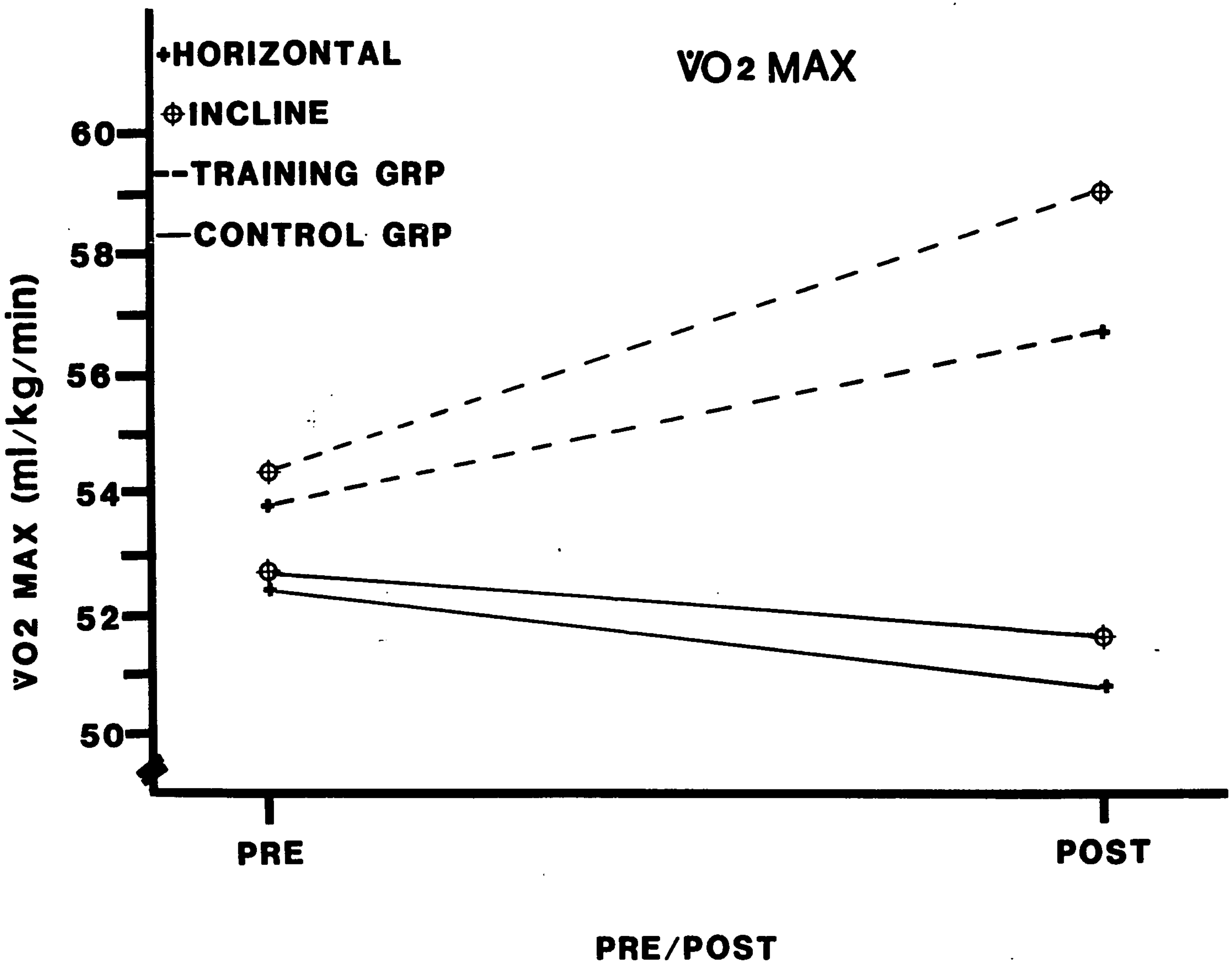


Figure 2. PRE- AND POST-TRAINING

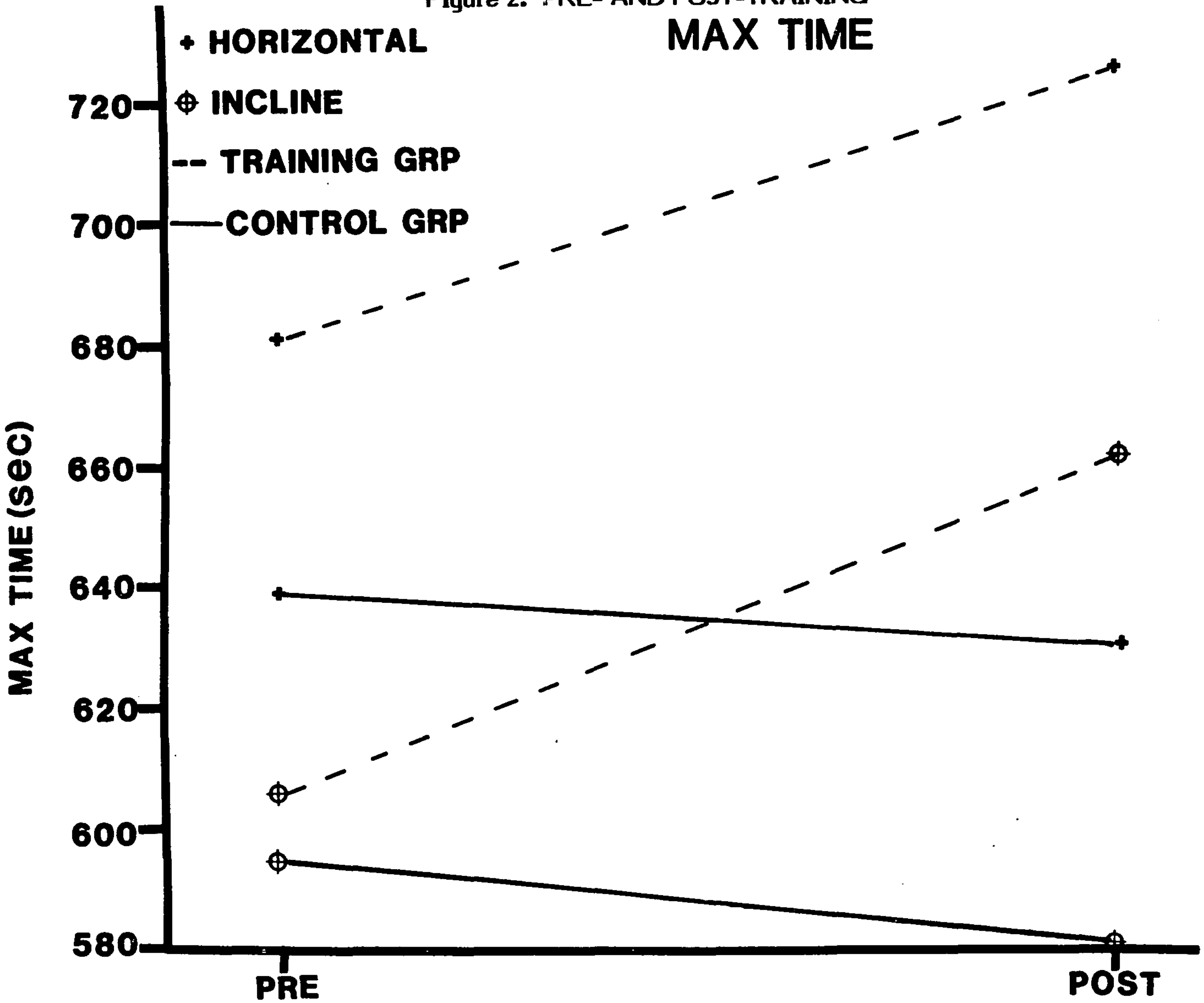


Figure 3. PRE- AND POST-TRAINING

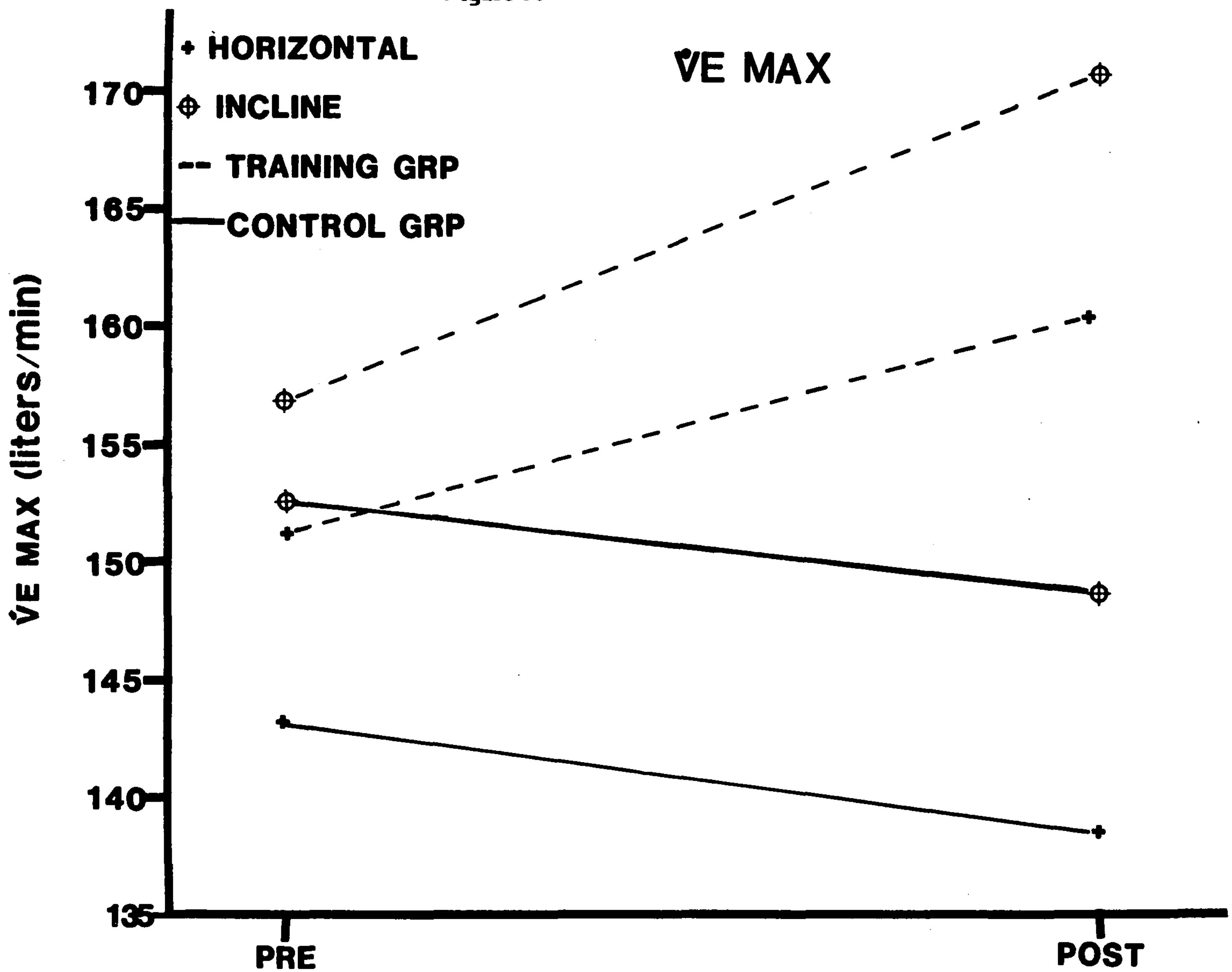
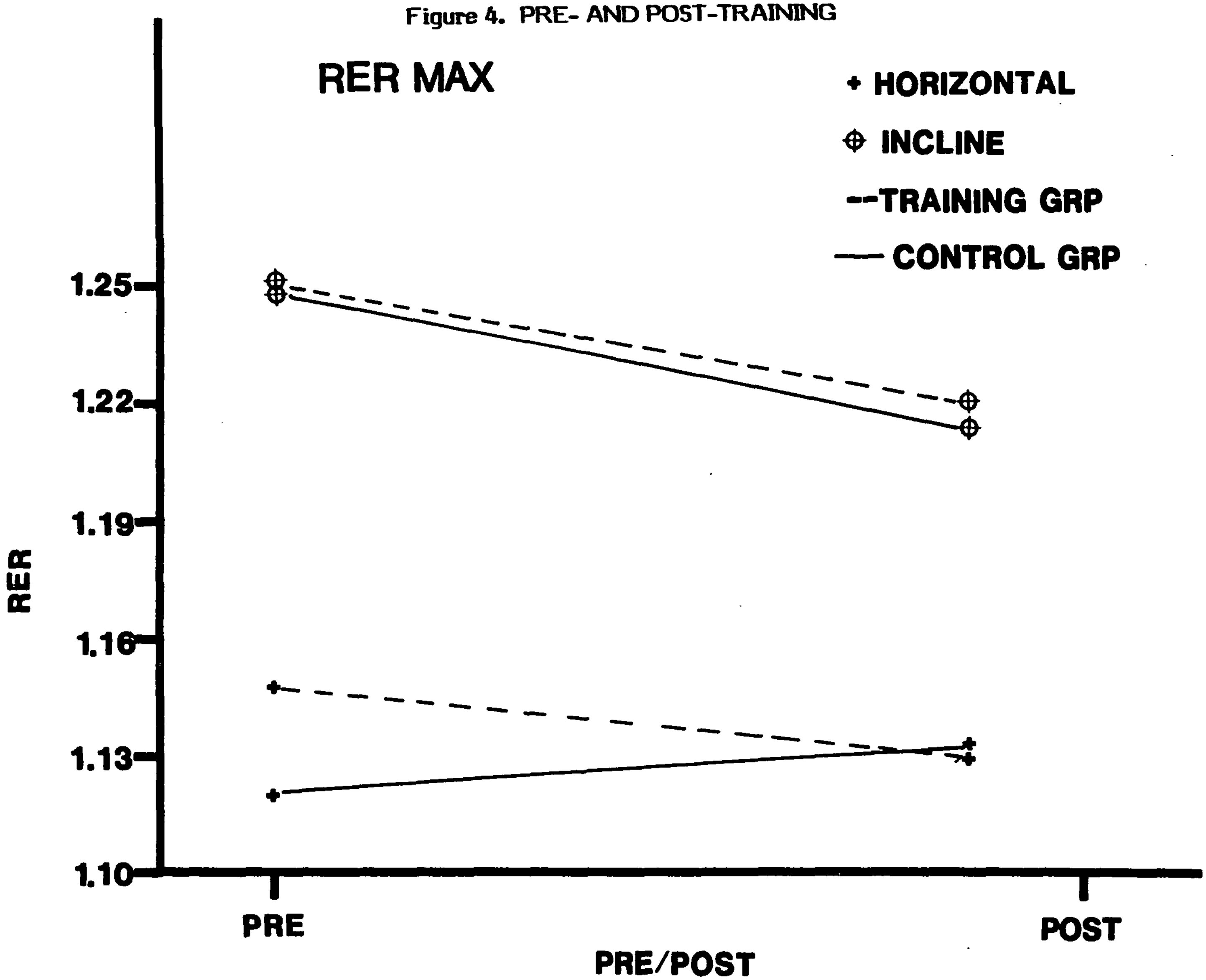


Figure 4. PRE- AND POST-TRAINING



that the activity habits of the control subjects were changed during the course of the study, i.e. less active. This premise is supported by the fact that MTT and $\dot{V}E$ max decreased for both protocols, although not significantly. Another possible mechanism for the finding of a significantly lower $\dot{V}O_2$ max on the horizontal protocol may have been a decreased motivation of the control subjects post-training. However, the RER max values for the horizontal treadmill protocol would not support this premise as no difference was found. Thus, it would appear that there was a slight change in the lifestyle or activity patterns of the control group over the course of this study.

As mentioned, training elicited significant improvements in $\dot{V}O_2$ max for both protocols. Most importantly, when these improvements for each protocol are compared, a significantly greater improvement on the inclined protocol when compared to the improvement on the horizontal protocol is found. This resulted in a significant difference in post-training $\dot{V}O_2$ max values between protocols, (T=3.3) i.e. the inclined protocol elicited significantly greater $\dot{V}O_2$ max values (Table 3 and Figure 1).

CHAPTER 5

DISCUSSION

Physiological Adaptations Consequent to Training

$\dot{V}E$ Max

Typical physiological adaptations resulted from this twelve week training program. One such change was an increase in $\dot{V}E$ max (Figure 3). This finding has been reported in numerous studies (22,30,32,59). The percentage improvement in $\dot{V}E$ max was almost identical to the improvement in $\dot{V}O_2$ max (Table 3). Many other investigators (30,32,59) have reported similar results and have stated or implied that, because $\dot{V}E/\dot{V}O_2$ at maximum exercise remained unchanged after training, the increase in $\dot{V}E$ max was directly related to the increase in $\dot{V}O_2$ max. Although increases in $\dot{V}E$ max are undoubtedly related to increases in $\dot{V}O_2$ max, Davis et al. (30) have found that this is only an indirect, not a cause-effect, relationship. They stated that increases in $\dot{V}E$ max resulting from endurance training, while related to increases in $\dot{V}O_2$ max and maximal work rate, results from the increased ventilatory demands required to effect the same degree of acid-base regulation at greater levels of $\dot{V}CO_2$. This would agree with previous work by Jones (40) and the conclusion by others (19,69) that changes in $\dot{V}E$ are more closely related to changes in $\dot{V}CO_2$ than to changes in $\dot{V}O_2$.

MTT

As anticipated, significant improvements in MTT on both protocols were found only in the experimental group (Figure 2). Caution must be taken not to compare the improvements in time between the two protocols, however, as the oxygen cost is not equivalent for equal improvement in time to exhaustion. In other words, a 30 s improvement on the horizontal protocol is not commensurate to a 30 s improvement on the inclined protocol.

$\dot{V}O_2$ max

When $\dot{V}O_2$ max is examined, the results show that prior to training no significant difference between groups or between protocols existed (Figure 1). Training elicited significant improvements in $\dot{V}O_2$ max, in agreement with previous studies (13,24,26,46,56,70). The improvements in $\dot{V}O_2$ max found in this study appear to be relatively small. However, when the relatively high pre-training $\dot{V}O_2$ max values are considered, these improvements seem much more reasonable. In fact, Saltin, et al. (59) have published a graph which estimates improvements in $\dot{V}O_2$ max from pre-training $\dot{V}O_2$ max values. The improvements found in the present study were almost identical to the predicted values from this graph.

Horizontal Versus Inclined Treadmill Protocols

$\dot{V}E$ Max and RER Max

Statistical analysis revealed that inclined treadmill running produces significantly greater $\dot{V}E$ max values when compared to horizontal values. This finding was consistent both pre- and post-training (Figure 3). Mechanisms responsible for this finding are likely related to the increased strength and duration of contraction resulting from the increased time of foot contact associated with a decreased foot speed found on the inclined protocol (34). These slower and stronger contractions are similar to those found with cycle ergometry at speeds below 70 rpm in which $\dot{V}E$ max and blood lactic acid have been reported to be higher on the cycle ergometer compared to the treadmill (3^{o}) at the same metabolic rate (34).

During inclined treadmill running, the tension developed in the vastus lateralis increases as the grade increases (18). The increase in tension and duration of contraction is needed to elevate the body during uphill running. It is possible that this increase in strength and duration of contraction was associated with the finding of a local muscular fatigue associated with the inclined protocol reported by Gibson and Harrison (27). This localized fatigue may be elicited by an increase in lactic acid accumulation caused by the greater tension in the vastus lateralis muscle groups used in inclined running (18). This increase in lactic acid would stimulate ventilatory drive via the carotid and aortic bodies. If this were true, one would anticipate a higher RER max for the inclined protocol, indicative of an increased level of anaerobic metabolism (39,68). Figure 4 supports this premise. RER max values were much higher for both groups, pre-and post-training on the inclined protocol. These higher RER max values are possibly associated with the increased CO_2 production via lactic acid buffering. Similarly, McArdle et al. (52) found significantly higher RER max values on a cycle ergometer when compared to the treadmill at $\dot{V}O_2$ max. Hermansen and Saltin (34) found max $\dot{V}E$ values of 140.5 and 150.8 for a horizontal and an inclined protocol (3^{o}-4.5^{o}) respectively. These differences again are possibly due to an increased lactic acid formation and its subsequent effect on ventilation.

<u>$\dot{V}O_2$ Max</u>

Prior to training, no significant difference in $\dot{V}O_2$ max values between protocols was found. This contradicts the finding of Taylor et al. (64) who reported that $\dot{V}O_2$ max values were significantly higher on the inclined protocol and suggested that this was due to the larger muscle mass engaged in uphill running. Similarly, Åstrand and Saltin (6) tested three subjects on both an inclined and a horizontal protocol with the inclined test protocol producing higher $\dot{V}O_2$ max values. In the two aforementioned studies, the subjects were predominantly non-runners.

Conversely, other studies using trained runners have found that the $\dot{V}O_2$ max values for the horizontal protocol are equal (44,63) or greater (3,71) than those on the inclined protocol. Kasch et al. (28) using 12 well-trained and highly motivated male subjects found no significant difference in $\dot{V}O_2$ max between protocols. Similarly, Sucec (63) using trained male and female distance runners found no difference in $\dot{V}O_2$ max between protocols. The findings of these last two studies are in agreement with our study. Wilson et al. (71) found that 10 male milers actually produced significantly higher $\dot{V}O_2$ max values on the horizontal protocol, while Åstrand (3) found higher $\dot{V}O_2$ max values on the horizontal protocol.

These conflicting findings are likely the result of different subject populations as well as differences in protocols. In untrained subjects, the horizontal protocol may limit $\dot{V}O_2$ max values if subjects are unable to maintain the leg speed necessary to elicit maximum cardiorespiratory values. Likewise, an inclined protocol may cause a localized muscular fatigue which could also limit the untrained subject.

As stated earlier, training elicited significant improvements in $\dot{V}O_2$ max with both protocols (Figure 1). These improvements in $\dot{V}O_2$ max were comparable to improvements found in other studies that have used subjects of similar initial fitness levels (59). The initial testing revealed no significant difference in $\dot{V}O_2$ max obtained on our two protocols (Table 2). However, when post-training data is analyzed, it was found that the inclined protocol elicited significantly greater $\dot{V}O_2$ max values compared to those values obtained on the horizontal protocol (Table 3).

McArdle et al. (53), investigating the specificity of run training on $\dot{V}O_2$ max, concluded that the specificity of the metabolic adaptations to aerobic training is associated with local changes in the skeletal muscles trained. However, they also suggested that endurance running may produce central adaptations as well.

Costill et al. (18), investigating glycogen depletion during inclined and horizontal running, suggested that the involvement of leg muscles is different for horizontal and inclined running. During uphill running (6^{o}), glycogen breakdown was much greater, especially in the vastus lateralis muscle compared to running horizontally. This was explained by increased work done by the vastus lateralis in elevating the body during uphill running. Therefore, subjects trained on inclined terrain should not be tested on a horizontal protocol when examining changes consequent to training on inclined terrain, since the local metabolic adaptations would occur in the vastus lateralis, a muscle group not greatly used in horizontal running.

If intramuscular changes are to contribute to an increased $\dot{V}O_2$ max, then the work task must utilize these trained muscles (18,53,62). The results of Costill et al. point to the importance of knowing the relative involvement of diverse muscle groups in a variety of work tasks. Estimation of the relative involvement of each muscle group during a given exercise would be of great value for a better understanding of the local intramuscular and metabolic changes that occur with training. It is concluded from these results that the inclined protocol was more specific to the actual training regime, i.e. inclined running. Improvements on the horizontal protocol are likely due primarily to central factors while improvements on the inclined protocol are probably due to both central as well as peripheral changes, i.e. local adaptations within the specific muscles trained. Therefore, consideration of training, or lack of it, and training terrain, should be given when selecting a treadmill test protocol.

CHAPTER 6

SUMMARY

Twenty-two men, 17-27 years of age, volunteered to participate in a training program consisting of inclined terrain running. The purpose of this study was to, 1) compare $\dot{V}O_2$ max values in untrained subjects on both horizontal and inclined treadmill protocols and, 2) evaluate changes in $\dot{V}O_2$ max values consequent to inclined terrain run training to determine if a specificity of training to testing protocol occurred. Maximal oxygen uptake ($\dot{V}O_2$ max), maximal heart rate (HR max), maximal ventilation ($\dot{V}E$ max), maximal respiratory exchange ratio (RER max), and maximum treadmill time (MTT) were evaluated on both inclined (I) and horizontal (H) treadmill protocols, both pre-and post- training. Prior to training, there was no significant difference between protocols in $\dot{V}O_2$ max. However, RER max and $\dot{V}E$ max were significantly greater on the (I) protocol. The men were then randomly assigned to a control group (n=10) or an experimental group (n=12). The experimental group ran on an inclined terrain four times per week for 12 weeks, with each session lasting approximately 35 min. Training intensity was established at 65-85% of aerobic capacity, with an assigned training heart rate range which was monitored by the subject each training session. The training program resulted in no change in HR max, RER max, or body weight. $\dot{V}E$ max, MTT, and $\dot{V}O_2$ max increased 8.7%, 9.1% and 8.5% respectively on the inclined protocol and 5.8%, 6.8%, and 5.3% on the horizontal protocol respectively. All increases were statistically significant at the .05 level. In addition, the post training $\dot{V}O_2$ max on the (I) protocol was significantly greater than the $\dot{V}O_2$ max obtained on the (H) protocol. This study demonstrates that training by inclined terrain running brings about specific physiological changes that are most clearly identified by using an inclined treadmill protocol. These results support the concept of specificity of training and indicate the importance of careful selection of both the test protocol and the test mode.

APPENDIX A

UNIVERSITY OF ARIZONA, HUMAN SUBJECTS COMMITTEE APPROVAL LETTER

THE UNIVERSITY OF ARIZONA
TUCSON, ARIZONA 85724
HUMAN SUBJECTS COMMITTEE
ARIZONA HEALTH SCIENCES CENTER 2305
TELEPHONE: 626-6721 OR 626-7575

15 January 1982

Mr. R. Douglas Allen
Department of Physical Education
McKale Center, Room 228
MAIN CAMPUS

Dear Mr. Allen:

We are in receipt of the 13 January 1982 letter from Beau Freund and the accompanying additional consent form for your project, "A Comparison of Maximal Oxygen Uptake on Horizontal vs. Inclined Treadmill Protocol with Subjects Trained on Flat Terrain". The changes reflected in this revised consent form and letter are minor and pose no further risk to the subjects involved. Therefore, approval for these changes is granted effective 15 January 1982.

The changes approved are:

1. Addition of Beau J. Freund as co-investigator;

2. Expansion of the study population to include an additional 20 subjects to be trained on inclined terrain and who will not be asked to give blood.

Approval of these changes is granted with the understanding that no further changes will be made in either the procedures followed or in the consent forms used (copies of which we have on file) without the knowledge and approval of the Human Subjects Committee and the Departmental Review Committee. Any physical or psychological harm to any subject must also be reported to each committee.

A university policy requires that all signed subject consent forms be kept in a permanent file in an area designated for that purpose by the Department Head or comparable authority. This will assure their accessibility in the event that university officials require the information and the principal investigator is unavailable for some reason.

Sincerely yours,

Milan Novak

Milan Novak, M.D., Ph.D.
Chairman

MN/jm

cc: Patricia C. Fairchild, Ph.D.
Departmental Review Committee

Beau J. Freund ✓
Co-Investigator

APPENDIX B

Subject Consent Form

"A Comparison of Maximal Oxygen Uptake on Horizontal vs. Inclined Treadmill Protocols Before and After an Inclined Terrain Running Program"

I have received an oral explanation of the training study. I understand the following:

Purpose: The purpose of the study is to analyze the relationship between the subject's maximal oxygen consumption on a horizontal treadmill test verses an inclined treadmill test when the subject is trained specifically on inclined terrain.

Exercise: Subjects will participate in a twelve week training program that involves running on inclined terrain. Ramps located at the University of Arizona's Football Stadium, with an approximate grade of 10% - 15%, will be used as the inclined terrain. Subjects will train four days per week for 35 minutes a day at approximately the same time each day. Subjects will also participate in a stretching/flexibility program for a minimum of 10 minutes prior to each training session. During each training session, subjects will run at an intensity such that their heart rates will remain within a range obtained by adding 65% of the difference between their heart rate (HR) max and HR rest to HR rest for the lower limit of the range and by adding 85% of the difference between HR max and HR rest to HR rest for the upper limit of the range. Exercise heart rates will be monitored by the subject at approximately the 10th, 20th, and 35th minute of each training session. Subjects involved in the training program are to record the length of each training session (to the nearest minute), approximate distance covered each session, the date and time when each session took place, and the heart rate attained at each of the three designated times during the session. Training sessions will take place from January through April, 1982.

Control subjects will not participate in the exercise portion of this study and will not engage in any training programs during the course of the study.

Respiratory Calorimetry (Maximal Treadmill Tests): Each subject will complete a minimum of 6 and a maximum of 8 treadmill tests to exhaustion. A treadmill test involves running, with the speed and/or grade of the treadmill increasing gradually until the subject is too fatigued to continue. Each test will last between 8 and 14 minutes.

Prior to the twelve week training program, each subject will undergo a minimum of 4 and a maximum of 6 maximal treadmill tests. Two treadmill tests will be conducted where the treadmill speed is incrementally increased, but where there is no increase in the grade (this is called a horizontal test). Two more treadmill tests will be conducted where the treadmill speed and grade are incrementally increased (this is called an inclined test). An additional maximal treadmill test will be conducted in either of the two modes if the maximal oxygen consumption values obtained for that particular mode are not within five percent of each other.

After the twelve week training program, each subject will undergo two maximal treadmill tests, one of which will be a horizontal test and the other an inclined test. Both of these post training tests will be performed within one week of the last day of training.

The maximal treadmill tests require all subjects to wear 3 electrodes in order to record heart rate and be connected to a Beckman Metabolic Cart via a tube connected to a mouth piece and supported by a head brace. The nose will be closed to breathing by means of a nose clip while the mouthpiece is in place to force breathing to take place through the mouth.

There will be a minimum of 48 hours rest between maximal treadmill tests.

Miscellaneous:

1. Subjects may not take any prescribed or over-the-counter drugs or other drugs on days when they are to perform maximal treadmill tests. No drugs may be taken on days preceeding the maximal treadmill tests if such drugs have effects that last long enough to affect performance during testing sessions.

2. It is estimated that subjects will spend a total of 42 hours on activities related to the study.

3. No medical coverage will be provided by the investigator except for first aid for minor injuries.

4. Subjects are to provide their own clothing and shoes for all training and testing sessions.

5. The investigator will at any time answer any questions concerning procedures to be used.

6. Any subject is free to withdraw from the study at any time and for any reason without ill will on the part of the investigator.

7. The subjects will be anonymous in any publication(s) of the results of this study.

Physical Examinations: Physical exams will not be given to the subjects. If at any time a participant or the investigator believes that the health of a subject may be impaired, the subject may drop or be asked to drop from the study.

Risks: Potential risks are considered to be minimal. Subjects may experience minor inconvenience and discomfort due to wearing the head brace during testing in the lab. Muscle soreness may occur in some subjects as a result of training and/or testing. While soreness may be uncomfortable to some subjects, it is not expected to present undue difficulty. Warm-up exercises will be performed prior to each training session in order to loosen-up muscles to be exercised; this should reduce the possibility of both muscle soreness and injury.

Benefits: Subjects will gain special understanding of the scientific methods as applied to Exercise Physiology research. Subjects involved in the training program will receive instruction in the areas of flexibility drills, effective training methods as applied to running, proper running form, and how to use target heart rate range for training. Subjects invovled in the training program will also benefit from an increased level of fitness. All subjects will receive valuable fitness testing and interpretation of the results.

Compensation for Injuries: I understand that in the event of physical injury resulting from the research procedures, financial compensation for wages or for time lost is not available, and the costs of medical care and hospitalization is not available and must be borne by the subject. I undersand that Beau Jeffere Freund (626-3407 or 325-7765) will provide information that is needed upon my request.

I have read the above, and the nature, demands, risks, and benefits of the study have been explained to me. I understand that I may ask questions and that I am free to withdraw from the study at any time without causing any ill will or without affecting my University standing. I also understand that this consent form will be filed in an area designated by the Human Subjects Committee with access restricted to the principle investigators or authorized representatives of the particular department. A copy of this consent form is available to me upon request. I also understand that my data will be kept in strict confidence with only the principle investigators having access to my files.

__________________________________ ________________
Subject's Signature Date

APPENDIX C

PHYSICAL ACTIVITY PARTICIPATION QUESTIONNAIRE

DIRECTIONS: Please answer the following questions as accurately as possible. Place a circle around the appropriate letter or number for each question.

1. Which of these exercises are you doing on a regular basis?
    a. None
    b. Walk for exercise
    c. Ride a bicyle
    d. Swim
    e. Do Calisthenics
    f. Jogging
    g. Lift weights
    h. Taekwondo, karate, or judo
    i. Competitive sports (List__________)
    j. Other (List______________________)

2. How many days per week do you exercise?
    a. None
    b. One
    c. Two
    d. Three
    e. Four
    f. Five
    g. Six
    h. Seven

3. How much time do you spend on exercise each day?
    a. None
    b. Less than 15 minutes
    c. 15 to 30 minutes
    d. 30 to 45 minutes
    e. 45 to 60 minutes
    f. 60 to 75 minutes
    g. 75 to 90 minutes
    h. 90 minutes or more

4. If you exercise select the odd or even number which best describes the intensity (how hard) of your work outs.

6	14
7 Very, very light	15 Hard
8	16
9 Very light	17 Very hard
10	18
11 Fairly light	19 Very, very hard
12	20
13 Somewhat hard	

5. Indicate the MAJOR or MAIN reason why you exercise (Select one answer).
    a. I do not exercise
    b. It makes me feel good
    c. I am trying to lose weight
    d. It is good for your health
    e. I am required to exercise
    f. My doctor told me to exercise
    g. Other (Explain____)

6. Have you ever had a physical injury as a result of participating in sports or an exercise program?
    a. Yes (Explain____)
    b. No

7. Have you ever had any back, hip, knee, ankle, or foot problems while participating in an exercise program?
    a. Yes (Explain____)
    b. No

8. Have you ever been advised by a physician not to exercise because of a medical problem?
    a. Yes (Explain____)
    b. No

NAME____

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