CHAPTER THREE

JOURNAL MANUSCRIPT

PHYSIOLOGICAL AND METABOLIC RESPONSES TO CONSTANT-LOAD EXERCISE ON AN INCLINED STEPPER AND TREADMILL

by
Brian W. Rieger
Dr. Shala Davis, Chairman
Department of Human Nutrition, Foods, and Exercise
(ABSTRACT)

This study evaluated oxygen uptake (VO_2), heart rate (HR), and lactate [HLa] responses between the treadmill (TM) and the Cardiosquat™ 1650 LE™ inclined stepper by StairMaster™ (SM) during constant-load exercise. The slow component of VO_2 (SC) was a central variable assessed during exercise. Twenty-two healthy college-aged (18-30) subjects completed an incremental TM and SM exercise test to establish a workload equivalent to 70% VO_{2peak}. Following each incremental test, a 20-minute constant-load exercise bout was performed. Incremental and constant-load exercise bouts were separated by at least 48 hours. The order of the tests were randomized. VO_2, HR, and [HLa] were evaluated at 5, 10, 15, and 20 minutes of exercise. Expired gases were analyzed using a MedGraphics CPX/D metabolic cart. Blood samples were analyzed immediately for lactate concentration with an automated lactate analyzer (Yellow Springs Instrument Model 1500 Sport). A two-way ANOVA with repeated measures was performed on the rate of change between the treadmill and stepper for VO_2, HR, and [HLa]. No significant differences were found for any of the response variables ($P>0.05$). These results suggest at that the same relative workload, the SM does not elicit a more pronounced SC than the TM. Based on these findings, the SM appears to be an appropriate modality of exercise for various clinical populations.

Introduction

Stair climbing is an alternative to the more common modalities of exercise. The use of stair climbing as a mode of exercise has become increasingly popular with rehabilitation centers as well as the general public. In recent years, stair climbing devices have gone through a series of changes. One version utilizes pedal stepping to reduce the amount of weight-bearing action on the lower extremities. Most stair climbing devices allow for support of the upper body by use of handrails. Howley, Colacino, and Swensen (1992) reported that the degree to which an individual uses the railings for support affects both the VO_2 and HR responses.

Most recently, an inclined stepper has been introduced as a variation in stair climbing. This newest version of stair climbing, the Cardiosquat™ 1650 LE™ inclined stepper by StairMaster™ is designed to offer precise control over a wide range of loading levels and exercise by simulating an inclined stepping motion. It's design eliminates the use of handrails for support by providing an orthopedic position similar to that of a recumbent bicycle.

Other than a study by Davis and Sipe (in press), relatively little information pertaining to exercise on the inclined stepper is available. Results of that study indicate that for maximal exercise, the inclined stepper elicits a significantly lower (~15%) VO_2 response compared to the TM. While maximal response variables are important in determining fitness level and prescribing exercise, limitations to a typical exercise session can be obtained through submaximal constant-load testing

Constant-load testing allows for the examination of several response variables including the slow component of VO_2 (VO_2SC). The slow component (SC) is a variable that has recently gained attention from investigators. SC has been defined by Gaesser and Poole (1996) as the difference between end-exercise VO_2 and 3-min VO_2. The "excess" VO_2 during constant-load exercise can raise oxygen uptake to unexpected levels thus ending exercise prematurely. Evaluating SC can aid in determining the effectiveness as well as limitations of different modalities of exercise.

Exercise responses for the inclined stepper and treadmill have been studied under maximal exercise conditions. However, if the inclined stepper is to be used in fitness testing and training, the responses to submaximal exercise needs to be determined. The purpose of this study was to evaluate the changes in the slow component of VO_2, heart rate, and lactate for the inclined stepper and treadmill during constant-load submaximal exercise.

Methodology

Subjects

Twenty-two college aged (18-30) males (n=11) and females (n=11) volunteered for this study. Descriptive statistics of the 22 subjects are presented in Table 1. Mean age for males (22.1 ± 3.3) was greater than females (20.2 ± 1.5) due to the influence of one 30 year-old subject. Although no subject had much experience on the SM, all were physically active. Subjects reported to the lab for an orientation session consisting of an oral explanation and to practice stepping on the SM and running on the treadmill (TM). Each subject completed a Physical Activity Readiness Questionnaire (PAR-Q) and gave written consent at this time. The study had the approval

Table 1.

Description of Subjects Characteristics

	MALES		**FEMALES**	
Characteristics	**M**	**SD**	**M**	**SD**
Age (years)	22.1	3.3	20.2	1.5
Height (cm)	180.3	6.1	167.7	5.9
Weight (kg)	77.9	9.9	63.2	7.0.
BMI (kg/m^2)	23.5	2.6	22.4	1.8
PkVO_2TM (ml)	4082	568	2892	379
PkHR (bpm)	198.3	6.6	190.1	7.6
Pk[HLa] (mMol/L)	12.0	1.6	8.34	1.9

of the Institutional Human Subjects Committee of Virginia Polytechnic Institute and State University. During the orientation session a self-selected running speed was chosen by each subject to be used in all TM exercise bouts

Inclined Stepper Design

The inclined stepper offers both strength and endurance in its design. Resistance and stepping rate can be manipulated to either make the exercise easier or harder. Resistance is determined by the number of 10 pound plates that are lifted. The plates range from 10 to 120 pounds. Stepping rate is determined by the levels of speed. There are 14 different levels of speed to chose from. The first level of speed was used in the warm-up while incremental tests began at the second level of speed. It had been predetermined from a previous study by Davis and Sipe (in press) that the first level of speed was not adequate for maintaining proper rhythm. Therefore, incremental exercise began at the second level of speed.

The training principle behind stepping on this device is to suspend the selected plates in a range that will maintain rhythm. Stepping too slow would cause the plates to drop below this range which would cause additional effort to recover. Stepping too fast would cause the plates to rise above the selected range resulting in a jerking of the pedals and once again loss of rhythm. Therefore, it was ideal to maintain a proper stepping rate so that rhythm is maintained and exercise performance will not be compromised. The only way to manipulate exercise intensity after the onset of exercise is to change the speed thereby altering the stepping rate. Resistance can only be changed by momentarily stopping exercise to increase the number of plates.

Experimental Procedures

Subjects performed maximal incremental treadmill and inclined stepper tests preceding constant-load exercise in order to establish a workload equal to that of 70% VO_{2peak}. Maximal tests were followed by 20-minute constant-load tests on the same device. Constant-load tests were administered at least 48 hrs following maximal testing.

For all tests heart rate was monitored via a three-lead electrode. Metabolic data was collected using open-circuit spirometry. Indirect calorimetry measurements were recorded every 15 seconds during exercise as the subject breathed through a mouthpiece and pneumotach into a Medical Graphics CPX/D metabolic cart. Blood lactate (25 *u*m) was collected via finger-stick and analyzed immediately. Ratings of perceived exertion (RPE) for overall effort were assessed every two minutes during maximal testing and every 5 minutes during constant-load exercise bouts. To account for the effect of test order, half the subjects (n=11) were tested on the treadmill and then the stepper, while half were tested on the stepper and then the treadmill.

Incremental Test Procedures

The purpose of the initial incremental exercise tests was to obtain a peak value for oxygen uptake in order to determine a workload equal to 70% of the subjects VO_{2peak}. Values for VO_2, HR, and [HLa] were recorded at rest. During exercise, VO_2 was collected continuously. HR and

RPE were recorded every one and two minutes of exercise, respectively. At end-exercise blood was collected for the analysis of lactate concentration. Maximal values are presented in Table 2. RPE and RER were recorded to ensure a maximal effort was given.

The incremental TM protocol (see Table 3) was performed on a Mortara™ Trackmaster™. Following a 5-minute warm-up at a speed of 3 mph and grade of 0%, the speed was increased to the subject's self-selected running pace. The speed remained constant throughout while the grade was increased 1% every minute until volitional exhaustion.

The incremental SM protocol was performed on a StairMaster™ Cardiosquat™ 1650 LE™. The resistance remained the same throughout the test and was predetermined by gender. Resistance was set at 6 and 4 plates for males and females, respectively. Following a warm-up at a light intensity, subjects began the protocol at the second level of speed. Every minute the rate of stepping was increased by increasing the level of speed by one unit. Exercise was terminated when the subject could no longer keep the plates above the specified range or when volitional exhaustion occurred.

Constant-load Test Procedures

All constant-load tests were 20-minutes in duration. Values for VO_2, HR, [HLa], and RPE were collected at rest and minutes 5, 10, 15 and 20 of exercise. Blood lactate was analyzed immediately following collection. No warm-up was allowed. Subjects were instructed on the proper technique of maintaining rhythm while blood was collected at the finger. Maintenance of rhythm was important so that data obtained at each collection period was accurate. Subjects were instructed to exercise for the full 20-minutes. All subject's adhered to the previous request.

For the constant-load TM test, the speed and grade remained the same. The speed was the self-selected running pace that was used in the incremental tests. The grade used was that which equaled the grade that elicited 70% VO_{2peak} during incremental testing.

For the constant-load SM test, the resistance and rate of stepping remained the same. The resistance was predetermined by gender. The number of plates was 6 and 4 for males and females, respectively. The rate of stepping was that speed which elicited 70% VO_{2peak} for the incremental exercise bout.

Statistical Procedures

The subject sample was described using descriptive statistics. Maximal and submaximal response variables were also described using descriptive statistics. The rate of change for VO_2, HR, and [HLa] between modes (TM vs SM) during constant-load exercise was analyzed using a two-way analysis of variance (ANOVA) for repeated measures (condition x time). A simple main effects test (Bonferroni's method) was conducted to assess within mode differences at each minute (i.e. 5, 10, 15, and 20) of exercise. The statistical program used in all statistical procedures was the 1995 Jandel edition of SigmaSTAT (San Rafel, CA). Statistical significance was set at $P<0.05$.

Table 2.

Maximal Exercise Test Responses of Subjects

	Treadmill		Stepper	
Variable	**M**	**SD**	**M**	**SD**
VO_{2peak} (L/min)	3.49	0.8	2.75	0.6
Heart Rate (bpm)	194	8.1	180.7	9.7
Lactate (mMol/L)	10.2	2.5	8.9	2.2
RPE	18.3	0.8	18.0	0.7
RER	1.12	.04	1.22	.07

Table 3

Stepper Incremental Protocol

		FEMALE			MALE		
STAGE	**TIME**	**PLATES**	**SPEED**	**METS**	**PLATES**	**SPEED**	**METS**
1	1 min	4	2	*	6	2	*
2	2 min	4	3	*	6	3	*
3	3 min	4	4	*	6	4	*
4	4 min	4	5	*	6	5	*
5	5 min	4	6	*	6	6	*
6	6 min	4	7	*	6	7	*
7	7 min	4	8	*	6	8	*
8	8 min	4	9	*	6	9	*
9	9 min	4	10	*	6	10	*
10	10 min	4	11	*	6	11	*
11	11 min	4	12	*	6	12	*
12	12 min	4	13	*	6	13	*
13	13 min	4	14	*	6	14	*

* This measure is dependent on the body weight of the subject being tested

Results

Determination of maximal exercise included two of the following three criteria: HR$\geq$85% age predicted maximum, RER$\geq$1.10, and RPE$\geq$17. All subjects met criteria for maximal exercise (see Table 4). Compared to the stepper, the treadmill showed higher responses during maximal exercise for VO_2 (3847$\pm$164, 2747$\pm$587 ml/min), HR (194.0$\pm$8.1, 180.7$\pm$9.7 bpm), and [HLa] (10.2$\pm$2.5, 8.9$\pm$2.2 mMol/L).

The mean values for VO_2, HR, and [HLa] at each collection period during constant-load exercise are presented in Table 5. Between minutes 5 and 20 of exercise on the SM, VO_2 increased 116.5 ml/min compared to 59.0 ml/min on the TM. Between minutes 5 and 20, the SM had an average increase of 1.40 mMol/L compared to 0.78 mMol/L for the TM. A two-way ANOVA with repeated measures was performed to determine if the rate of change for VO_2 , HR, and [HLa] was significantly different for the SM vs TM exercise. No differences between the two modalities were found for any of the response variables ($P>0.05$).

The simple main effects test revealed within condition changes across the four collection periods for VO_2, HR, and [HLa] during constant-load testing. The constant-load SM exercise revealed changes in VO_2 from minutes 5 to 10, 5 to 15, and 5 to 20. No differences for VO_2 across time were found for the TM. All changes for simple main effects were significant at $P<0.05$.

Discussion

The purpose of this study was to compare the changes in VO_2 (SC), HR, and [HLa] during 20-minutes of constant-load exercise on an inclined stepper (SM) and treadmill (TM). The baseline maximal incremental exercise tests revealed higher values for VO_{2peak} (21.2%), HR (5.6%), and blood lactate (12.7%) for the TM compared to the SM. While this is the first study to examine blood lactate responses on the SM, similar results for VO_2 and HR were found using identical exercise equipment in the study by Davis and Sipe (in press). For that study, the TM elicited higher VO_{2peak} (15.6%) and HR (5.2%) values for college-aged (18-30 yrs) subjects. Although the present study supports the results from Davis and Sipe, it does not support the results from studies using different variations of stair climbing equipment. In a study by Holland, Hoffman, Vincent, Mayers, and Caston (1990), VO_2 and HR were evaluated during maximal exercise on a treadmill and a stair climber that utilized revolving steps in its design. Results from that study showed identical VO_2 and HR responses between the modalities. Because the mechanics of stepping on machines with revolving steps are different than the SM, direct comparison between the results of the present study and Holland and colleagues may not be appropriate. Reasons for the different responses between the two studies is not fully understood, but it could be hypothesized that body position may have been a factor. During stair climbing exercise, the body is in an upright position similar to treadmill exercise. Compared to exercise in a supine or inclined position such as on the SM, an upright position results in a smaller venous return of blood to the heart thereby increasing cardiovascular demand. As a result, physiological responses may be elevated on the TM and stair climber.

.The main variable assessed in this study was VO_2SC. Although not significant, the drift

Table 4.

Criteria for Determining Maximal Exercise

	#that met criteria	**%that met criteria**
Treadmill Results		
Heart Rate (HR>85% age pred. Max.)	**22/22**	**100%**
RPE (≥17)	**22/22**	**100%**
RER (>1.10)	**16/22**	**73%**
Stepper Results		
Heart Rate (HR>85% age pred. Max.)	**20/22**	**91%**
RPE (≥17)	**22/22**	**100%**
RER (>1.10)	**22/22**	**100%**

Table 5.

Descriptive Statistics on Submaximal Response Variables

	5 min		**10 min**		**15 min**		**20 min**	
Variable	**M**	**SD**	**M**	**SD**	**M**	**SD**	**M**	**SD**
VO_2 (ml/min)								
TM	2617.0	573	2656.0	604	2665.0	618	2676.0	620
SM	2069.6	401	2127.8	432	2165.3	445	2186.1	443
Heart Rate (bpm)								
TM	159	16	166	16	168	17	169	16
SM	149	11	156	13	159	15	162	15
HLa (mMol/L)								
TM	4.05	1.5	4.64	1.9	4.89	2.5	4.83	2.5
SM	4.67	1.0	5.58	1.5	5.94	2.0	6.07	2.3
RPE								
TM	9.8	1.6	11.8	1.6	12.6	1.9	13.2	2.2
SM	11.0	1.6	13.0	1.6	14.0	1.9	14.2	2.1
VE (ml/min)								
TM	71.6	22.2	75.2	19.6	75.4	24.0	77.3	22.2
SM	59.9	10.0	64.3	13.4	66.2	14.7	61.8	18.6

TM=treadmill
SM=StairMaster^{TM} inclined stepper

in VO_2 from minutes 5 to 20 of constant-load exercise was greater for the SM (116.5 ml/min) compared to the TM (59.0 ml/min). Constant-load exercise on the SM at 70% of peak oxygen uptake resulted in an additional 02 consumption of 57.5 ml/min compared to the TM. According to Gaesser and Poole (1996), it is not uncommon to observe a SC range of 500 ml/min to 1000 ml/min during heavy (i.e. above LT) constant-load exercise. A SC with the magnitude suggested by Gaesser and Poole would compromise performance and eventually result in early-onset fatigue. The magnitude of SC found in the present study does not correspond to the magnitude found in previous studies. Exact reasons for the differences are not known, but it could be hypothesized that the uniqueness of the SM does not place a greater demand on VO_2 than the TM.

A two-way ANOVA with repeated measures revealed no differences between the two modalities for VO_2, HR, and [HLa] during constant-load exercise ($P>0.05$). These findings suggest that at the same relative workload, the SM and TM elicit similar responses. The main finding of this study was that the rate of change in VO_2 over the 20-minutes of exercise was not significantly greater than the TM ($P= .096$). One factor that was not identified for this study was the lactate threshold. In order for SC to become evident during exercise, individuals must be working above their lactate threshold (Gaesser & Poole, 1996). Past literature has defined the lactate threshold as a lactate concentration above 4 mMol/L during constant-load exercise. For this study, lactate concentrations were above 4 mMol/L for each collection period). However, it should not be assumed that every subject was exercising above their LT. Recently, it has been shown that LT is specific to the individual and that the 4 mMol/L level chosen to define LT is obscure. It may also be pointed out though that the workload selected for this study has been shown to be adequate in pushing exercise above the LT (Hagberg, Mullin, & Nagle).

The results of this study also point out that HR and [HLa] values were not significantly different between the two modalities. These findings were not unexpected since no difference was found for VO_2. Had there been a difference in the rate of change for VO_2, then a concomitant change in HR and [HLa] were hypothesized.

The simple main effects test revealed within group changes for VO_2, HR and [HLa] during constant-load exercise. Most notably, there was a difference ($P<0.05$) between minutes 5 and 20 for the SM. However, no change in VO_2 was evident for any of the collection periods during TM exercise. Although an exact reason for the change in VO_2 from minutes 5 to 20 on the SM is unknown, it may be hypothesized that the magnitude of the VO_2 response was a factor. The SM elicited approximately a 20% less VO_2 response than the TM which may have been the reason for the significant change in VO_2 from minutes 5 to 20.

REFERENCES

Davis, S.E., & Sipe, C. (1995). Stability reliability for determination of peak VO_2 in young adults on an inclined stepper and treadmill. Unpublished manuscript.

Gaesser, G.A., & Poole, D.C. (1996). The slow component of oxygen uptake kinetics in humans. Exercise and Sport Science Reviews, 24, 35-70.

Hagberg, J.M., Mullin, J.P., & Nagle, F.J. (1978). Oxygen consumption during constant-load exercise. Journal of Applied Physiology, 45, 381-384.

Holland, G.J., Hoffman, J.J., Vincent, W., Mayers, M.A., & Caston, A. (1990). Treadmill and steptreadmill ergometry. The Physician and Sportsmedicine, 18, 79-85.

Howley, E.T., Colacino, D.L., & Swensen, T.C. (1992). Factors affecting the oxygen cost of stepping on an electronic stepping ergometer. Medicine and Science in Sports and Exercise, 24, 1055-1058.

Poole, D.C., Barstow T.J., Gaesser, G.A., Willis, W.T., & Whipp, B.J. (1994). VO_2 slow component: Physiological and functional significance. Medicine and Science in Sports and Exercise, 26, 1354-1358.