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FINAL REPORT

Contact Number: NAS9-16136 "Analysis of Physical Exercises and Exercise Protocols for Space Transportation System Operation"

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The primary objective of this research project was to provide NASA with a quantitative evaluation of the Thornton-Whitmore treadmill so that informed management decisions regarding the role of this treadmill in operational flight crew exercise programs could be made. Specific tasks to be completed were:

(1) Evaluate the Thornton-Whitmore passive treadmill as an exercise device at one-g.

(2) Establish hardware, harness and restraint systems for use with the Thornton-Whitmore treadmill in the laboratory and in Shuttle flights.

(3) Determine the quantitative performance of subjects in the laboratory on the Thornton-Whitmore treadmill with forces in excess of one-g.

(4) Determine the qualitative performance of human subjects on the Thornton-Whitmore treadmill during brief zero-g exposure (via KC-135 aircraft parabolic flight).

(5) Determine the performance of human subjects on the Thornton-Whitmore treadmill in weightlessness (onboard Shuttle flights).

The principle product of these investigations was to be a substantial analysis supporting the usefulness of the Thornton-Whitmore treadmill as a zero-g exerciser. In addition, restraint systems were to be recommended together with protocols designed to maintain cardiopulmonary fitness and antigravity leg muscle strength. Approximately 2 months prior to the first Shuttle flight, a decision was made by NASA to fly the treadmill on STS-I or II. The treadmill, which had been refurbished during the first 6 months of the grant period, was subsequently returned to NASA where it was prepared for flight. Since the treadmill was a one of a kind item, it became impossible to complete the project as outlined. Steps one and two were initiated. In step one, the Thornton-Whitmore was compared with a motorized Quinton treadmill using a Bruce protocol and was observed to elicit similar physiological responses.

In step two, questions concerning the design and effectiveness of the proposed harness-restraint system were addressed. The proposed mechanical cinematographic and zero-g analyses were cancelled when the treadmill was returned.

Since the purpose of the project was to evaluate exercise devices and/or programs that might be used to support the U.S. manned spaceflight program, a third study was conducted in which an Omnikinetic exercise device designed to increase/maintain muscular strength and endurance was evaluated. The device, Hydrafitness Total Power, uses light-weight hydraulic cylinders to provide resistance, is compact, requires no external power and could be modified for use at zero-g.

This report covers 3 experiments conducted during a 16-month period beginning September 1, 1980. The initial 6 months of the study were devoted to obtaining, repairing and refuburshing the Thornton-Whitmore treadmill (TW) so that it could be used for experimental purposes. In Experiment I, 4 male astronauts were examined for physiological responses as they performed the Bruce protocol on the TW treadmill and a motor driven (Quinton) treadmill. The metabolic data indicated that the two devices elicited similar physiological responses for the speeds and elevations examined.

In Experiment II, the physiological responses of 4 college males were recorded as they walked and ran on a Quinton treadmill with varying g-loads. The g-loads were provided by a bungee harness restraint system used on Skylab IV and by a similarly weighted backpack. The data indicated that the physiological responses resulting for the bungee imposed workloads were significantly less than those observed with the backpack. Recordings of force in the bungee cords suggested that the force decreased as the center of gravity was lowered during the gait cycle. Additional analysis indicated that, for walking at 90 m/min, the bungee loads examined (1.4-1.7g) did not produce a sufficient physiological

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[1]See Appendix A

stress to meet the minimal criteria for aerobic training. Running (175 m/min) with the bungee loads did meet the minimal criteria for aerobic training, but elicited ankle, knee, shoulder and back pain.

In Experiment III, 7 college males trained 3 times per week for 8 weeks on an Omnikinetic exercise device (Hydrafitness Total Power) designed to enhance muscular strength. Test results indicated that the device produced significant increases in muscular strength and lean body mass. Aerobic capacity and treadmill performance were not enhanced. The data suggest that the device, when used in conjunction with an in-flight treadmill or ergometer, could enable crew members to improve and/or maintain total fitness during exposure to zero-g.

ANALYSIS OF PHYSICAL EXERCISES AND EXERCISE PROTOCOLS FOR SPACE TRANSPORTATION SYSTEMS OPERATION

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Experiment I: Comparison of Physiological Responses to Work on the Thornton-Whitmore (TW) and Active Treadmill (AT)

Experiment II: Physiological Effects of Bungee Load During Work on a Treadmill

Experiment III: Evaluation of Omnikinetic Training Device

INTRODUCTION

Prior to the first manned flight in 1961, it was uncertain whether man could survive launch vehicle thrust associated with lift-off and landing, even though early rocket powered airplane flights indicated that man could safely tolerate comparable stresses (Beischer and Frogly, 1961; Beyer and Sells, 1957). The successful Soviet flight of Yuri Gagarin was followed by the U.S. suborbital Mercury-Redstone Mission of Alan Shepard on May 5, 1961. Subsequent orbital flight by John Glen added confidence to the fledgling U.S. Space Program.

Operational constraints in the Mercury program precluded inflight measurements of cardiopulmonary response to exercise. Analysis of pre- and postflight physiological responses during Project Mercury indicated that man could safely exist for short durations in the space environment (Link, 1965). Decreased blood pressure and concomitant tachycardia were observed postflight. Changes following the 34-hour flight were of greater magnitude than those seen following the 9-hour flight; all returned to normal within 19 hours.

The principal objective of Project Gemini was to develop operational proficiency necessary to plan the Apollo Program. Gemini astronauts logged approximately 2000 man-hours of weightless experience; principal biomedical observations included:

(1) Man could tolerate limited exposure to the space environment without significant decrement in work performance.

(2) Orthostatic hypotension was present postflight and persisted for approximately 50 hours.

(3) Red cell mass decreased by 5 to 20 percent.

(4) Minor bone demineralization occurred.

(5) Psychological responses to confined spaceflight were normal.

(6) Vestibular disturbances were not present.

The Mercury and Gemini Projects led to the Apollo Program. Eleven successful manned flights were flown between 1968 and 1972, 29 astronauts spent a total of more than 7500 hours in flight, and 12 astronauts spent 4 man-weeks safely on the surface of the Moon.

Physical work performance tests utilizing a cycle ergometer were administered to the crews of Apollo missions 7 to 11 and 14 through 17 before flight, within 2-5 hours after splashdown and 24 to 48 hours postflight (Hoffler et al., 1974). Cycle ergometer testing was used to assess the effects of spaceflight upon parameters such as work heart rate, mechanical efficiency, and blood pressure. Prior to exercise, heart rate was increased approximately 20 beats per minute immediately postflight (2 to 5 hours after splashdown) and remained elevated for 1 to 2 days after splashdown. In addition, crew members exhibited significant reductions in oxygen consumption, oxygen pulse, systolic blood pressure and diastolic blood pressure in response to a standard workload.

Scientists concluded that changes in exercise response following periods of weightlessness were due to readjustments in cardiovascular mechanisms associated with maintenance of cardiac output. Postflight observations of tachycardia and reduced oxygen pulse were consistent with those reported during bedrest and were assumed to be compensatory responses to reductions in stroke volume (Birkhead et al., 1963; Cardus, 1966; Chase et al., 1966; Miller et al., 1965; Saltin et al., 1968).

Skylab Experience

Skylab, originally called the Apollo Applications Program, followed the Gemini and Apollo programs and utilized the spacecraft and launch vehicles developed during the Apollo missions. Three manned Skylab missions were flown during approximately 9 months with the flight crews spending progressively longer periods of time in a weightless environment (28, 59, and finally, 84 days flight duration). Skylab offered the first opportunity for acquiring quantitative exercise data in flight.

During the first manned Skylab mission (SL II, 28 days) each crew member was tested on a cycle ergometer before, at regular intervals during, and following recovery from the mission. These tests utilized 5-minute work intervals at levels approximating 25, 50 and 75 percent of each astronaut's maximum oxygen uptake as determined preflight. In addition to the preflight testing, each crewman was tested six times during the 28-day spaceflight. Monitored physiological parameters included oxygen consumption, carbon dioxide production, ventilation rate, vectorcardiograph/heart rate and blood pressure. Isokinetic strength (peak force) was determined preflight (F-18 days) and postflight (R+5 days) using a Cybex Isokinetic Dynamometer. Preflight to postflight changes reflected the combined influence of zero-g exposure and inflight exercise on muscular strength. Significant reductions in arm and leg strength occurred during flight (Thornton and Rummel, 1974).

Skylab II data (Michel et al., 1975) indicated no significant exercise response decrement during exposure to zero-g. Resting and recovery heart rates were slightly lower during flight in all crewmen. Postflight degradation in response to exercise was observed in all crewmen as evidenced by an increased heart rate for the same workload and oxygen consumption, a decreased cardiac output, and a decreased stroke volume at the same oxygen consumption level. These changes were similar in magnitude to those observed after Apollo flights, but did not return to normal as rapidly. Preflight fitness levels were regained approximately 3 weeks following recovery (Rummel et al., 1973; Rummel et al., 1975). The postflight tachycardia observed in Skylab II crewmen did not fully compensate for the reduced stroke volume as did the postflight tachycardia in Apollo crewmen.

Records of the three Skylab II crewmen suggested the existence of an inverse relationship between the quantity of inflight personal exercise and the observed postflight decrement in exercise response (Sawin et al., 1975). These observations were consistent with bedrest studies which suggested that heavy exercise during spaceflight might lessen the degradations in postflight response to exercise (Cardus, 1966; Saltin et al., 1968). Inflight exercise was increased during Skylab III (59 days). Crewmen trained 1 hour per day using a cycle ergometer, an isokinetic exercise device (Mini-Gym) and a commercially available spring set (Sears, Roebuck and Co.) designed to maintain muscular strength. Personal exercise logs indicated that Skylab III crewmen performed twice as much exercise as did previous Skylab crewmen (Sawin and Rummel, 1975). Each crewman was tested 24 times on a cycle ergometer for physiological response to exercise: 8 preflight tests, 8 inflight tests and 8 postflight tests. In addition, muscular strength of each crewman was evaluated pre- and postflight. No reduction in physical work capacity was observed inflight. Mean heart rate and oxygen consumption were slightly decreased for a given workload inflight; this is consistent with training and assumed to be the result of frequent, rigorous cycle ergometer exercise. Postflight cardiac responses were similar to those observed in Skylab II (i.e. - an elevated heart rate, significant increases in total systemic peripheral vascular resistance and reductions in stroke volume and cardiac output). These changes were transient and preflight values returned within 4 to 8 days postflight (Rummel et al., 1976). Skylab III data suggested inflight aerobic exercise could prevent physiological deterioration during flight (Johnston and Dietlein, 1977; Rummel et al., 1975; Buderer et al., 1976; Sawin et al., 1975). Analysis of pre- and postflight muscular strength data indicated that the inflight exercise performed by Skylab crewmen was effective in maintaining arm strength. Leg strength decreased during flight to a level approximately equal to that observed after only 28 days in Skylab II (Thornton and Rummel, 1974).

Similar medical evaluations were employed for Skylab IV (84 days). Crewmen were tested 28 times on the cycle ergometer (8 times postflight), plus pre- and postflight Cybex evaluations. A "treadmill" device was added for inflight exercise. Elastic bungee cords were attached to a shoulder and waist harness assembly which held the crewman against a small teflon pad. This configuration permitted the crewman to walk or run by slipping his stocking-covered feet across the teflon. While this exercise was only moderately aerobic (1.5 liters per minute oxygen consumption) it did provide a significant one-g type stress to the leg muscles.

Data are available to document the amount of exercise necessary to develop and maintain an optimal level of cardiopulmonary endurance at one-g. These findings can be used as guidelines for determining optimal programs for zero-g. Pertinent findings at one-g include the influence of mode of exercise and duration of exercise on cardiopulmonary fitness. These findings are summarized in Appendix A.

U.S. astronauts prefer treadmill rather than cycle ergometer exercise because treadmill exercise closely approximates jogging and running. Previously discussed Skylab data documented the role of extensive cycle ergometer exercise in the maintenance of cardiopulmonary fitness. Quantitative data for flight treadmill exercise are limited to the minimal observations made on Skylab IV crewmen.

In 1978, Astronaut William Thornton, M.D. designed a mechanical treadmill for use during space flight. A prototype, machined and assembled by Whitmore Enterprises of San Antonio, Texas, was delivered in 1978 but never validated (Whitmore and Thornton, 1980). Since the treadmill had been proposed as an operational exercise device for use by Shuttle crewmen to maintain musculoskeletal and cardiorespiratory fitness, it was imperative that a quantitative evaluation of the treadmill be performed.

The primary objective of this research project was to provide NASA with a quantitative evaluation of the Thornton-Whitmore treadmill so that informed management decisions regarding the role of this treadmill in operational flight crew exercise programs could be made.

Data from the second Skylab mission (Thornton and Rummel, 1974) indicated that cycle ergometry was effective for maintenance of aerobic capacity, but relatively ineffective for the maintenance of leg strength. Results from the fourth Skylab mission (Thornton and Rummel, 1974) indicated that a treadmill designed to permit crewmen to walk and run under forces similar to gravity was an effective exercise device for the maintenance of leg strength. Observations in space and at 1-g (Pollock, et al., 1977) suggest that treadmill exercise performed in accordance with established ground-based training principles is effective for the development and maintenance of aerobic capacity and leg strength.

Laboratory treadmills employ motor driven belts and electromechanical increases in belt grade to elicit physiologic work. The Thornton-Whitmore treadmill is a passive mechanical device which is described in detail later in the text of this report. Loads or "mass" must be imposed during spaceflight via a bungee cord restraint system. Belt speed is controlled by a centrifugal brake. In order to conduct a thorough evaluation of the Thornton-Whitmore treadmill, the following research protocal was proposed:

(1) Evaluate the Thornton-Whitmore passive treadmill as an exercise device at one-g.

(2) Establish hardware, harness and restraint systems for use with the Thornton-Whitmore treadmill in the laboratory and in Shuttle flights.

(3) Determine the quantitative performance of subjects in the laboratory on the Thornton-Whitmore treadmill with forces in excess of one-g.

(4) Determine the qualitative performance of human subjects on the Thornton-Whitmore treadmill during brief zero-g exposure (via KC-135 aircraft parabolic flight).

(5) Determine the performance of human subjects on the Thornton-Whitmore treadmill in weightlessness (onboard Shuttle flights).

The principle products of these investigations was to be substantial analysis supporting the usefulness of the Thornton-Whitmore treadmill as a zero-g exerciser. Restraint systems were to be developed together with protocols designed to maintain cardiopulmonary fitness and antigravity leg muscle strength.

Approximately 2 months prior to the first Shuttle flight, a decision was made by NASA to fly the treadmill on STS-I or II. The treadmill, which had been refurbished by Whitmore[1], was subsequently returned to NASA where it was prepared for flight. Since the treadmill was a one of a kind item, it became impossible to complete the project as outlined. Steps one and two were initiated. In Experiment 1, the Thornton-Whitmore was compared with a motor driven Quinton treadmill using a Bruce protocol and was observed to elicit similar physiological responses. In Experiment II, questions concerning the design and effectiveness of the proposed harness-restraint system were addressed. The proposed mechanical, cinematographic and zero-g analyses were cancelled when the treadmill was returned.

Since the purpose of the project was to evaluate exercise devices and/or programs that might be used to support the U.S. manned spaceflight program, a third study (Experiment III) was conducted in which an Omnikinetic exercise device designed to increase/maintain muscular strength and endurance was evaluated. The device, Hydrafitness Total Power, uses light-weight hydraulic cylinders to provide resistance. This device which is compact and requires no external power could be modified for use at zero-g.

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[1]A large portion of the grant time was devoted to repairing the TW treadmill and preparing it for operation. The device was returned to the manufacturer where the rollers and belt were adjusted, a cranking device for elevation was designed and a governor was built to permit a wider range of belt speed and a more accurate assessment of velocity. Within 2 weeks after repairs were completed, the treadmill was returned to NASA for preparation for flight.

PURPOSE AND PROCEDURES

The purpose of this study was to compare the physiological responses to work on the passive Thornton-Whitmore (TW) treadmill with those during work on an active (Quinton) treadmill. Participants were 4 male members of the current Astronaut Corps, NASA-JSC. Mean age of the subjects was 37.5 ± 9.8 years. Mean weight was 77.0 ± 10.4. All subjects were tested in the Cardiopulmonary Lab at the Johnson Space Center between June 17 and June 19, 1981. Three subjects were tested twice per day. The fourth subject was tested over 2 days. One-half of the subjects walked on the TW first. Average rest between trials administered on the same day was 32.0 ± 15.0 minutes.

The test procedures required that subjects perform the first 3 stages of a modified Bruce treadmill test protocol on both the TW and active treadmill. The test protocol was modified to allow 4 minutes per stage to ensure the achievement of steady state. Cardiovascular and metabolic responses were monitored continuously throughout each test via EKG tracings and open circuit spirometry.

In order to achieve the required levels of elevation during work on the TW treadmill, the device was secured to the belt of the active treadmill. Final elevation was the sum of the elevation of the TW treadmill and the Quinton treadmill. Average elevation at each stage on the TW treadmill was approximately 1% less than that used during tests with the active treadmill. This slight discrepancy was attributable to compression of the wood structure designed to secure the TW treadmill to the active treadmill

RESULTS

A descriptive summary of the variables is presented in Tables 1-3. Average values for last 3 minutes of each 4 minute stage were calculated and are presented in Figures 1-4. No inferential statistics were calculated because of the small non-random nature of the group involved and the limited number of trails per subject.

Inspection of data indicate that every physiological variable monitored was slightly higher during work on the TW treadmill. Mean differences, in general, were slightly less for higher work loads, but inter-subject variability was high. This may be attributable in part to problems in walking at slower speeds. The belt of the TW is significantly shorter than that of the AT and subjects are accustomed to taking longer steps at slower speeds. Some amount of difference at all speeds would be expected because the subjects had to provide the force to propel the TW treadmill belt and maintain a constant belt speed. The correlation between treadmill time and oxygen uptake (ml/kg/min) for the TW was .94. The correlation for the AT was .95. These observations are comparable to those (r=.88) observed by Pollock, et al (1978) for the Bruce protocol.

CONCLUSIONS

The data suggest that the two devices elicit similar physiological results. Additional study with a larger sample size, completely random trials and expanded range of speeds and elevations are needed, before statistical conclusions can be drawn. Also needed are data on mechanical responses (force data and cinematagraphic analysis) to work on the treadmills. Additional study is required to determine the mechanical and physiological responses to (1) varying amounts of bungee load; and (2) differenet types of bungee restraint systems. Pilot data on the AT at 1.0-g suggest that proper weight load distribution is critical for optimal performance at higher work levels. Although the TW treadmill has been used on shuttle flights, no controlled studies have been conducted to examine the responses of walking on the TW treadmill under varying types and amounts of g-forces. Likewise, no research data are available concerning the performance characteristics of the TW treadmill at speeds in excess of 3.4 mph. Controlled studies at one and zero-g are needed.

The device is the only one in existance and will experience some form of mechanical failure requiring replacement in the future. Efforts should be made at this time to determine the effectiveness of this device. It would be foolish to wait for the system to fail and then be forced to replace it with an identical, untested model. Controlled, systematic evaluations will enable NASA to design an improved model that will overcome some of the limitations associated with the current model.

Table 1. Physiological responses to the Thornton-Whitmore (TW) and active (AT) treadmill at Stage 1.

Variables	TW $\bar{X}$	TW SD	AT $\bar{X}$	AT SD	Mean Difference
HR (bpm)	93.58	7.37	88.0	11.02	5.58
$\dot{V}O_2$ (L/min)	1.16	.21	1.04	.14	.12
ml/kg/min	15.36	1.52	13.43	.75	1.93
$\dot{V}CO_2$ (L/min)	1.06	.22	.895	.18	.165
VE (L/min)	30.71	7.64	26.00	7.25	4.71
RER	.911	.057	.858	.086	.053
fb	24.67	10.81	19.08	7.63	5.59
$MV/\dot{V}O_2$	26.29	2.79	24.72	3.98	1.57
MV/CO_2	28.92	2.93	28.68	2.42	.24
$\dot{V}O_2$/HR (ml/beat)	12.54	2.94	12.10	2.96	-.44

Table 2. Physiological responses to the Thornton-Whitmore (TW) and active (AT) treadmill at Stage 2.

	TW		AT		Mean
Variables	$\bar{X}$	SD	$\bar{X}$	SD	Difference
HR (bpm)	110.83	8.54	105.25	10.34	5.58
$\dot{V}O_2$ (L/min)	1.68	.24	1.55	.18	.13
ml/kg/min	21.87	1.84	20.22	.89	1.65
$\dot{V}CO_2$ (L/min)	1.64	.26	1.45	.24	.19
VE (L/min)	43.26	11.10	36.88	9.95	6.38
RER	.970	.034	.928	.050	.042
fb	28.00	10.53	21.67	8.52	6.33
$MV/\dot{V}O_2$	25.44	3.55	23.39	3.56	2.05
MV/CO_2	26.19	3.16	25.12	2.79	1.07
$\dot{V}O_2$/HR (ml/beat)	15.34	3.04	14.73	3.41	-.61

Table 3. Physiological responses to the Thornton-Whitmore (TW) and active (AT) treadmill at Stage 3.

	TW		AT		Mean
Variables	$\bar{X}$	SD	$\bar{X}$	SD	Difference
HR (bpm)	136.42	11.17	132.0	13.52	4.42
$\dot{V}O_2$ (L/min)	2.36	.41	2.33	.31	.03
ml/kg/min	30.59	2.60	30.29	2.58	.30
$\dot{V}CO_2$ (L/min)	2.53	.49	2.43	.35	.10
$\dot{V}E$ (L/min)	65.45	22.61	59.38	14.91	6.07
RER	1.07	.037	1.04	.026	.03
fb	33.42	11.45	28.17	9.03	5.25
$MV/\dot{V}O_2$	27.14	5.02	25.25	3.56	1.89
MV/CO_2	25.33	3.81	24.22	2.95	1.11
$\dot{V}O_2$/HR (ml/beat)	17.64	4.36	17.95	3.89	-.31

FIGURE 1. Oxygen Uptake on the Thornton-Whitmore (TW) and Active (AT) Treadmill

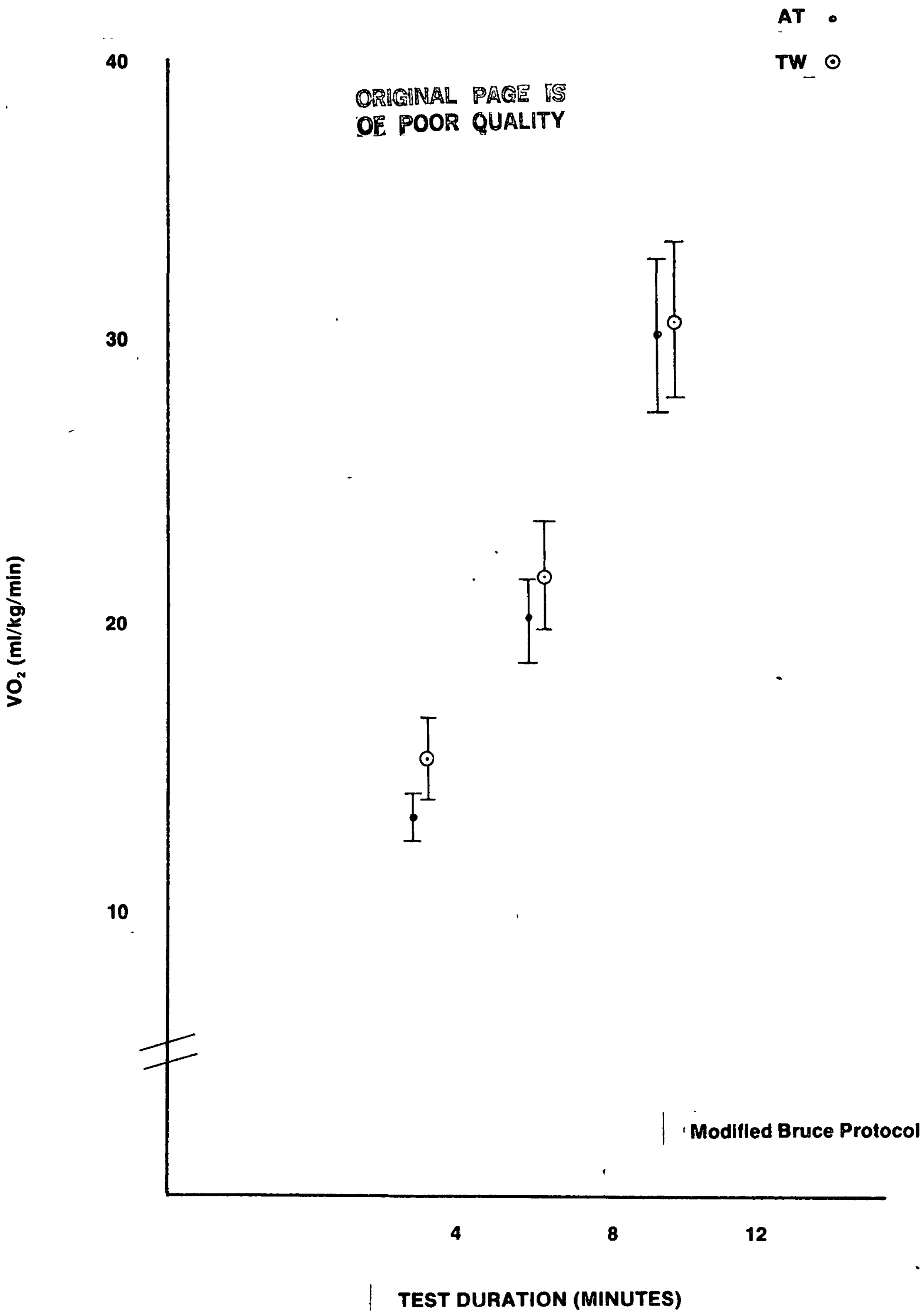


FIGURE 2. Heart Rate on TW and AT Treadmill

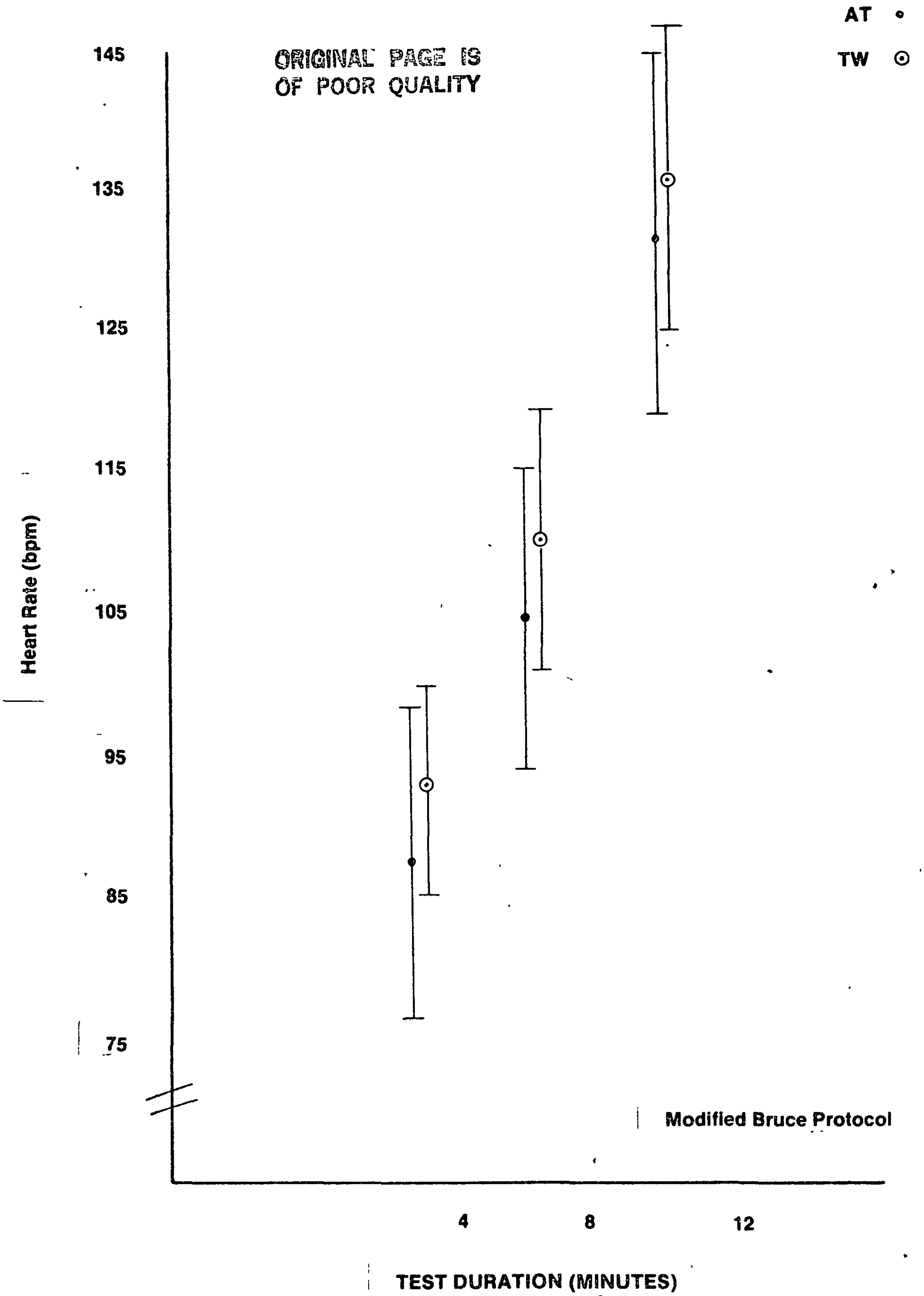


FIGURE 3. VE on the TW and AT Treadmill

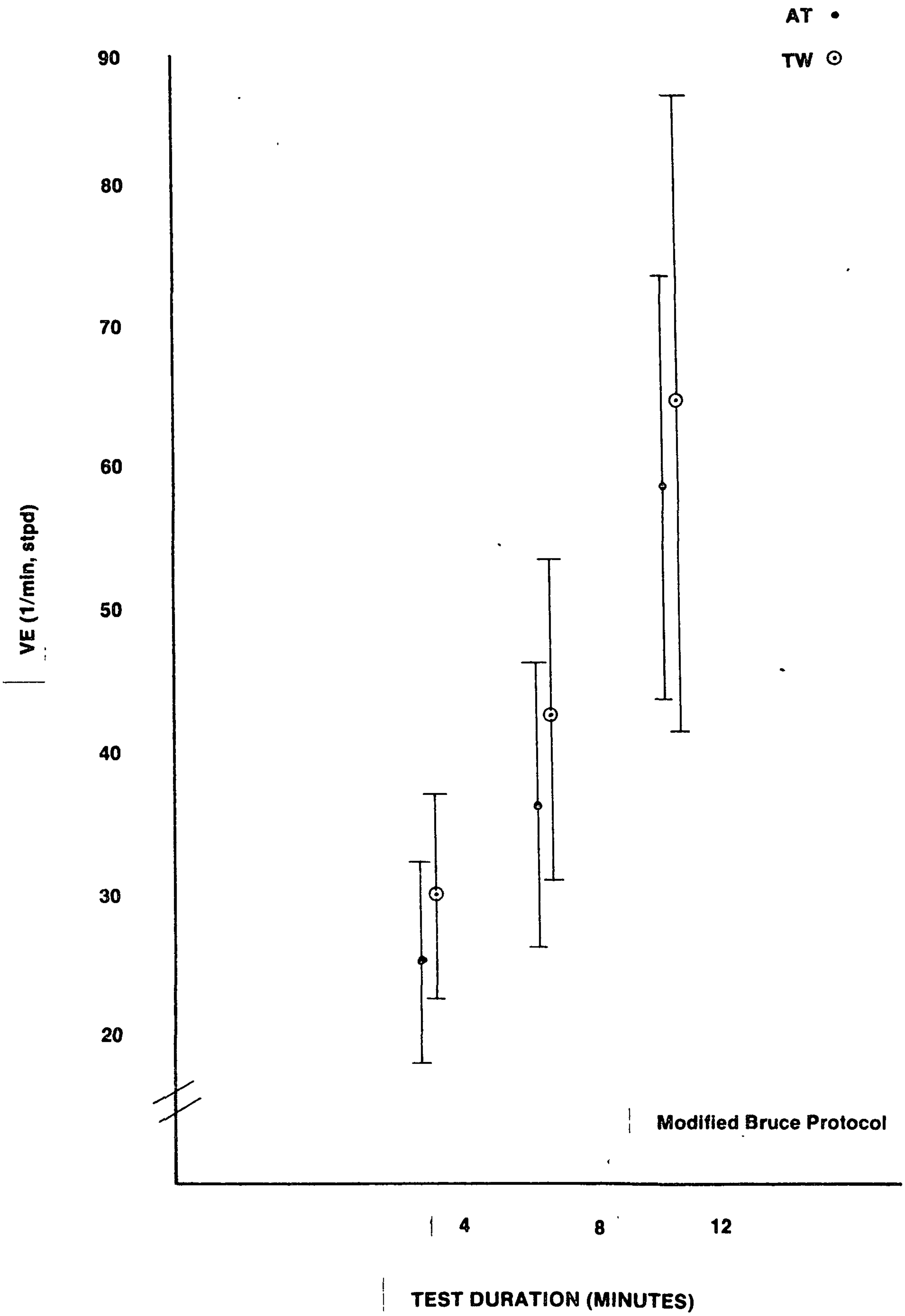
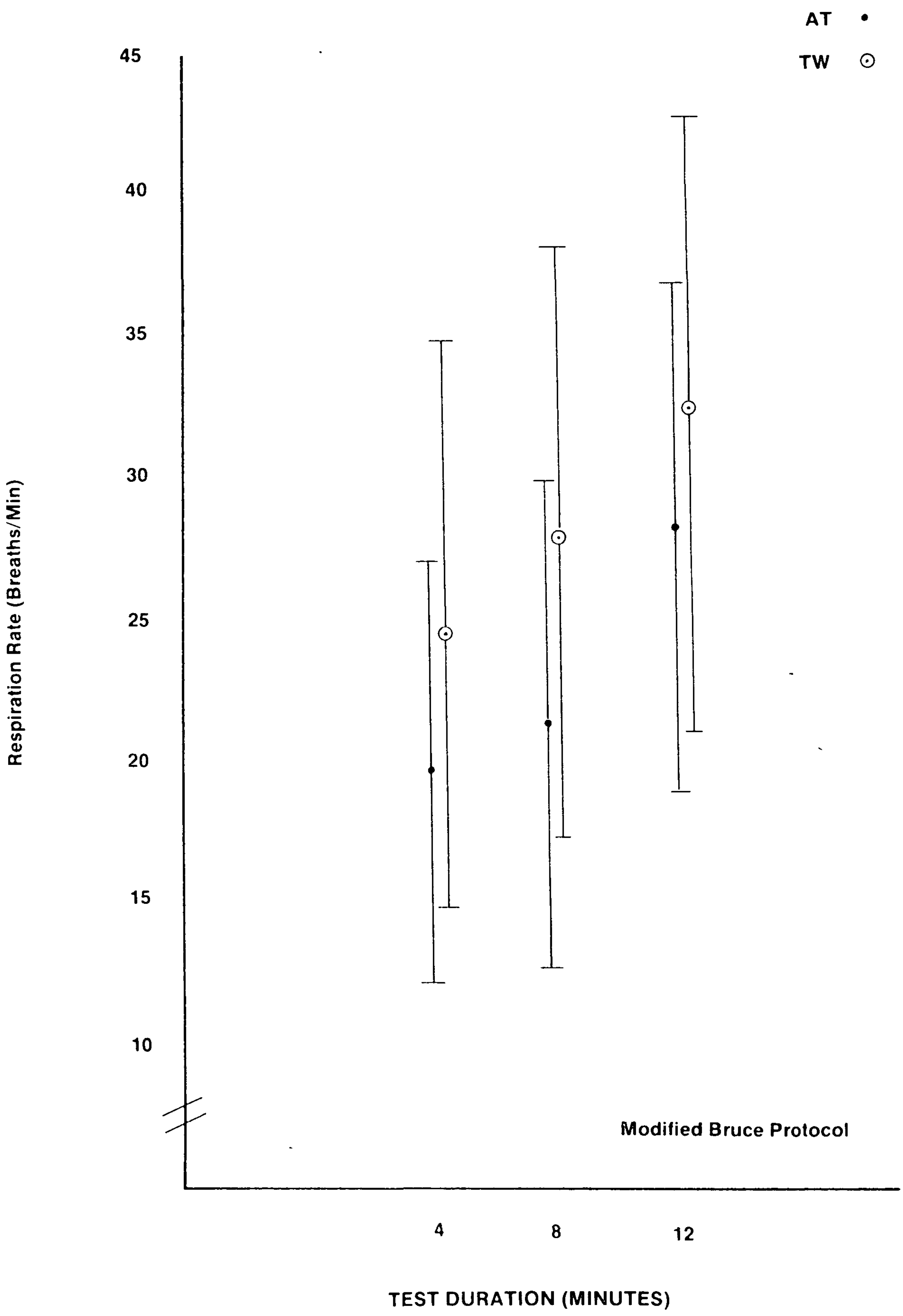


FIGURE 4. Respiration Rate on the TW and AT Treadmill



APPENDIX A

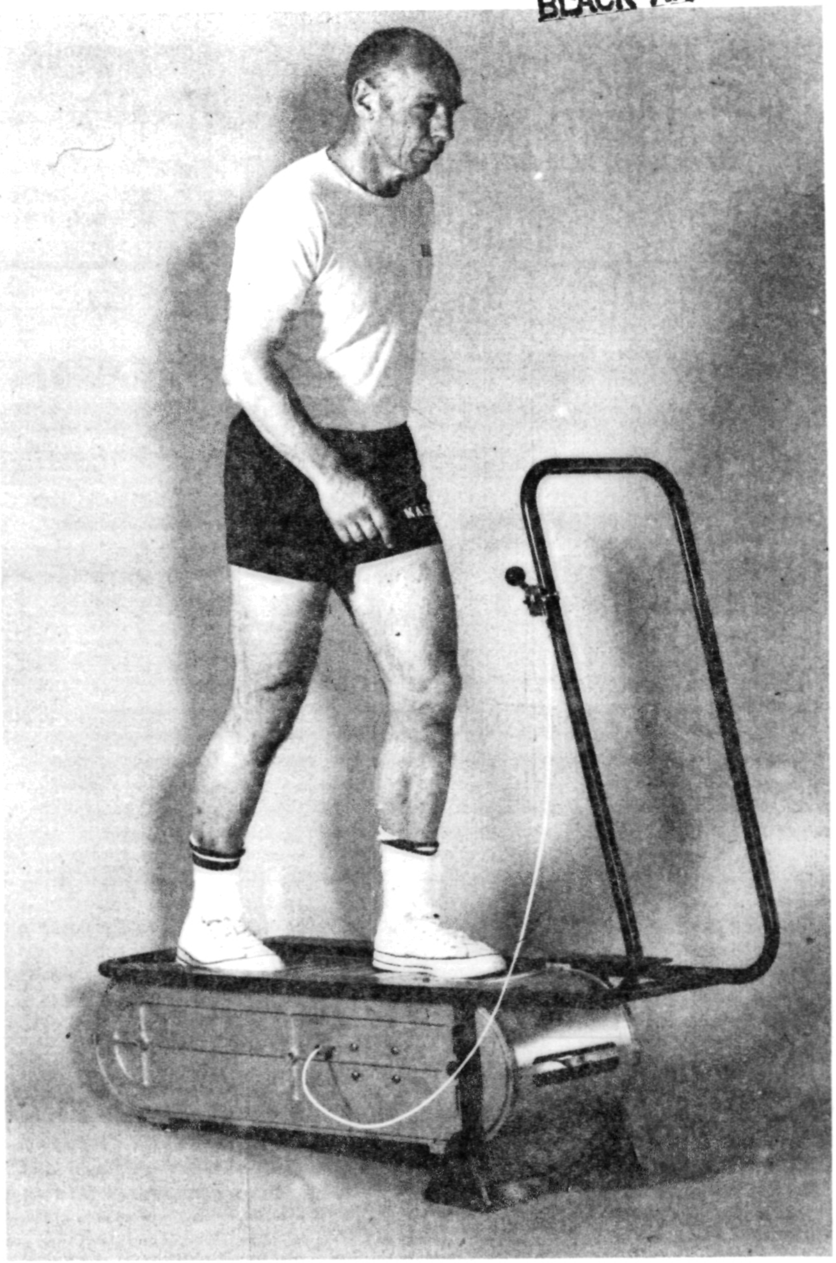
DESCRIPTION OF THE TW TREADMILL

The TW treadmill (Figure 4) is a passive treadmill, 109 cm long, 34 cm wide, 30 cm high and 20.5 kg in weight (Whitmore, 1980). The walking area is 31 cm wide and 71 cm long. The belt is mounted around two, low friction axles. This device is non-motorized and permits the user to generate low-friction belt speeds of 50 to 263 meters per minute. Average belt speed is determined by adjusting a variable threshold centrifugal governor. Belt speeds at or below the governor settings are essentially friction-free. Speeds in excess of maximal settings are met by internal roller resistance.

The various combinations of belt speed and belt grade permit workloads of 35 to 3754 kpm for a 70 kg subject working in an erect posture at one-g. The treadmill "grade" is determined by elevating the anterior framework of the device. The incline of the belt can be adjusted between 0 (horizontal) and 20 degrees.

The treadmill was designed to produce low to heavy workloads for individuals exercising in an erect posture at 1 or 0-g. At 1-g, workload is determined by varying belt speed and/or grade. At 0-g, the subject is held against the belt by elastic bungee cords. The force represented by these cords is a percentage of the subject's weight. External mechanical work is a function of varying belt speed, grade and/or bungee tension. Observations by the Soviets indicate that bungee tensions in excess of 55 kg might induce moderate to severe harness abrasion and skin chafing. These findings suggest the need to examine the range of bungee tension used to set workloads. Although the TW treadmill was designed to be effective at both 1 and 0-g, only limited pilot data have been collected and coefficients of validity and reliability have not been established for this device.

Fig. 4 THORNTON-WHITMORE TREADMILL



Experiment II: Physiological Effects of Bungee Load During Work on a Treadmill

PURPOSE AND PROCEDURES

The purpose of this study was to examine the effects of various bungee loads on the energy cost of treadmill walking and running. The subjects were four (N=4) young adult males who regularly engaged in strength training and distance running. Trained rather than untrained individuals were selected as subjects because it was assumed that they would have less probability of a training effect due to the testing or attrition due to injury or illness.

The experiment was conducted over an 8-week period. Anthropometric and body composition measures were made during week one. Body weight was made on an Accu-weigh bench beam scale. Percent fat (% fat) was estimated from body density (1) determined by underwater weighing using a Chatillon autopsy scale. Residual volume was measured using an oxygen-rebreathing, helium-dilution method (Wilmore, 1969).

A series of sub-maximal, single-stage treadmill bouts was administered on a Quinton 60-18 motorized treadmill. Treadmill bouts were administered in random order. During week one, in addition to becoming accustomed to walking/running on the treadmill and the testing equipment, the subjects performed a maximal Bruce treadmill stress test (Bruce 1971). During weeks 2 and 3, each subject was tested as he wore a bungee-harness restraint system similar to that worn on skylab IV (Thornton et al; 1976). Bungee loads evaluated were: (1) normal body weight (1.0g); (2) 40% added weight (1.4g); (3) 50% added weight (1.5g) and (4) 70% added weight (1.7g). Treadmill speed during this phase of testing was maintained at 90 ± .7 m/min, level grade.

During the second phase of the study, (weeks 4 and 5) the subjects wore a back pack weighted to 1.4g. Treadmill speed was maintained at 90 ± .6 m/min. The purpose of this phase of the study was to compare the effects of bungee and back pack loads.

During phase 3 (week 6), the subjects walked at 90± .7 m/min using a bungee-load of 1.4g. A Revere 1000-pound capacity load cell was systematically attached to each bungee cord during this phase in an attempt to measure the bungee load throughout the gait cycle. The superior end of the load cell was attached to a D-ring on the canvas belt. The inferior end was attached to the superior end of the bungee by means of a snap hook. Load cell capacity was set at 40-pounds.

During phase 4 (weeks 7 and 8) the subjects wore the bungee-harness restraint system and ran on the treadmill at a speed of 175± .4 m/min. Weight loads of 1.0, 1.4, 1.5 and 1.7g were utilized. During each phase, subjects worked for 8 minutes. Metabolic data were collected continuously. The criterion score for each phase was the mean for the last 6 minutes of effort. Oxygen uptake was measured each minute using a semi-automated gas collection system described by Wilmore and Costill (1974). Concentrations of oxygen and carbon dioxide in the expired air were measured with Applied Electro Chemistry S-3A and Beckman LB-2 gas analyzers, respectfully. Heart rate was obtained from electrocardigraph recordings. Ventilation rate was determined using a Hewlett Packard flow transducer and respiratory integrator.

A minimum of 24 hours of rest was allowed between trails. The bungee harness restraint system consisted of a padded canvas waist belt with D-rings and 2 padded shoulder straps. Four bungee cords were used, 2 anterior-lateral and 2 posterior-lateral. The cords were attached to the belt and treadmill bed by snap hooks. Bungee loads were determined by having the subject stand on a calibrated Accu-weigh scale as bungees were attached to the belt and treadmill. S-hooks, the width of the scale, were used as spacers during the determination of bungee loads. The spacers and scale were removed during the treadmill work bouts. Calibration procedures were consistent with those recommended by Whitmore (1981).

RESULTS

Physical characteristics of the subjects are presented in Table 1. Values for VO_2 max (ml/Kg/min) and body composition indicate that the subjects were homogenous. Means and standard deviations for oxygen uptake and related variables are presented in Figures 1-6. Inspection of Figures 1-3 indicates that the physiological measures of stress were positively related to increasing levels of bungee load. The levels attained at the highest load (1.7g), however, were moderate (6.5 - 7.0 mets and 95 - 105 bpm) and, under normal (sea level) conditions, would not produce an aerobic training effect. The minimal threshold for aerobic training/maintenance is an oxygen uptake of 60-80% aerobic capacity and/or a heart rate of 70-85% of maximal (Pollock, 1973, 1978). For the population examined, the work loads did not exceed these minimal threshold values.

The results of phase two (back pack load = 1.4g) are also presented in Figures 1-3. The data indicate that the stress of a 1.4g back pack load is similar to that produced by a 1.7g bungee load. Subjective evaluations of participants in this study were consistent with the physiological observations, i.e., walking with a 1.4g backpack was more stressful than walking with bungee loads. Since the subjects had trouble balancing the 1.4g backpack load (70 to 80 pounds), the investigator felt in unsafe to impose additional loads (1.5 or 1.7g) or faster treadmill speeds.

During phase 3, subjects wore the bungee-harness restraint system loaded to 1.4g. Force in each bungee cord was determined using a 40-pound capacity load cell and Brush recorder. Sample tracings of the force patterns in the right anterior bungee cord are presented in Figure 7. Similar patterns were observed in the other 3 cords. The data indicate that each cord (cords were not measured simultaneously) had approximately 22 pounds of force when the subject was standing erect, at rest. Total force of the 4 cords was estimated to be approximately 88 pounds. Total bungee force, according to calibration procedures, was approximately 80 pounds. Maximal force while walking during toe-off, i.e., as the center of gravity passed over the base of support, was approximately 25 pounds per cord. At heel contact, this force decreased to 20 pounds. This "unloading" of the bungee was expected since the center of gravity during walking will rise and fall approximately 2.5 inches (Slocum, 1962). Since the center of gravity rises and falls with each step and is maximal only during toe-off, the average bungee cord load during the walking cycle was less than that observed during calibration. If the 4 cords unloaded equally during the walking cycle, the total force lost due to unloading would be approximately 20 pounds or .2 - .3g. The similarity between physiological indicies of stress resulting from the 1.4g backpack load and 1.7g bungee load may be attributable, in part, to the unloading of the bungee cords. Additional research is recommended using 4 load cells simultaneously and cinematographic analysis. Filming the testing process would permit a more accurate assessment of bungee loading during the walking/running process.

During phase 4, subjects were required to run at 175 m/min while using bungee loads of 1.0, 1.4, 1.5 and 1.7g. Data (Figures 4-6) indicate that all work loads were of sufficient intensity to produce a training effect. Oxygen uptake values at 1.4, 1.5 and 1.7g exceeded expected values (1.0g) by approximately 40, 45 and 50%, respectfully and were consistent with those observed by Cureton, et al (1978) during pack carrying activities. These values were not achieved, however without problems. Subjects complained that the higher loads caused pain in the ankles and knees and extreme stress in the low back and shoulders. One subject complained that the 1.7g load occluded circulation and caused numbness in his arms.

CONCLUSIONS

Bungee loads of 1.4 to 1.7g provided minimal physiological stress at a speed of 90 m/min (3.3 mph). Responses to 1.7g bungee force were similar to those observed with a 1.4g backpack force load. Observation may be attributable, in part, to an unloading of bungee cords as the center of gravity changes during the walking process. The stress during running (175 m/min; 6.5 mph) with bungee imposed forces exceeded threshold level and should produce a training effect. Physical discomfort occurs during running with bungee loads in excess of 1.5g.

Additional research is needed at 1.0 and zero-g to determine minimal and optimal loads for the development/maintenance of aerobic fitness. Investigators should use multiple load cells and cinematographic techniques. Comparative data should be collected on motor-driven and the Thornton-Whitmore treadmill. Various bungee loads and treadmill speeds should be examined. Attempts should be made to design a more comfortable and effective harness-restraint system. A more accurate method of estimating bungee load should be developed.

The TW treadmill and previously described harness-restraint system have been used in shuttle flights. Little systematic scientific data have been recorded during exercise. Plans should be formulated with which the effectiveness of the current and alternate restraint systems can be evaluated. At this time, no data exist to indicate that the current system will involke threshold metabolic responses.

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FIGURE 1. Mean Oxygen Cost For Bungee and Backpack Load

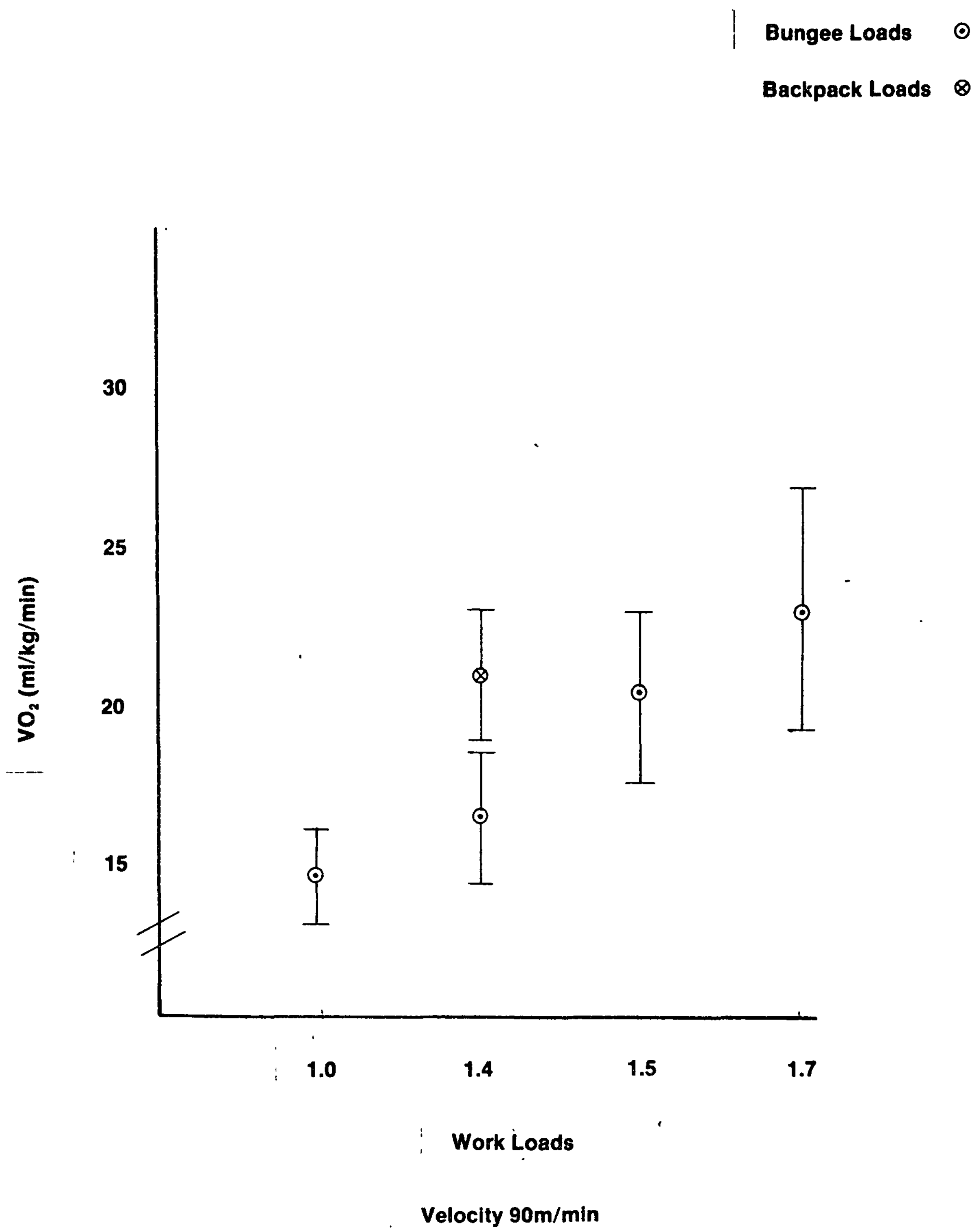

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FIGURE 2. Mean Ventilation Rate Bungee and Backpack Loads

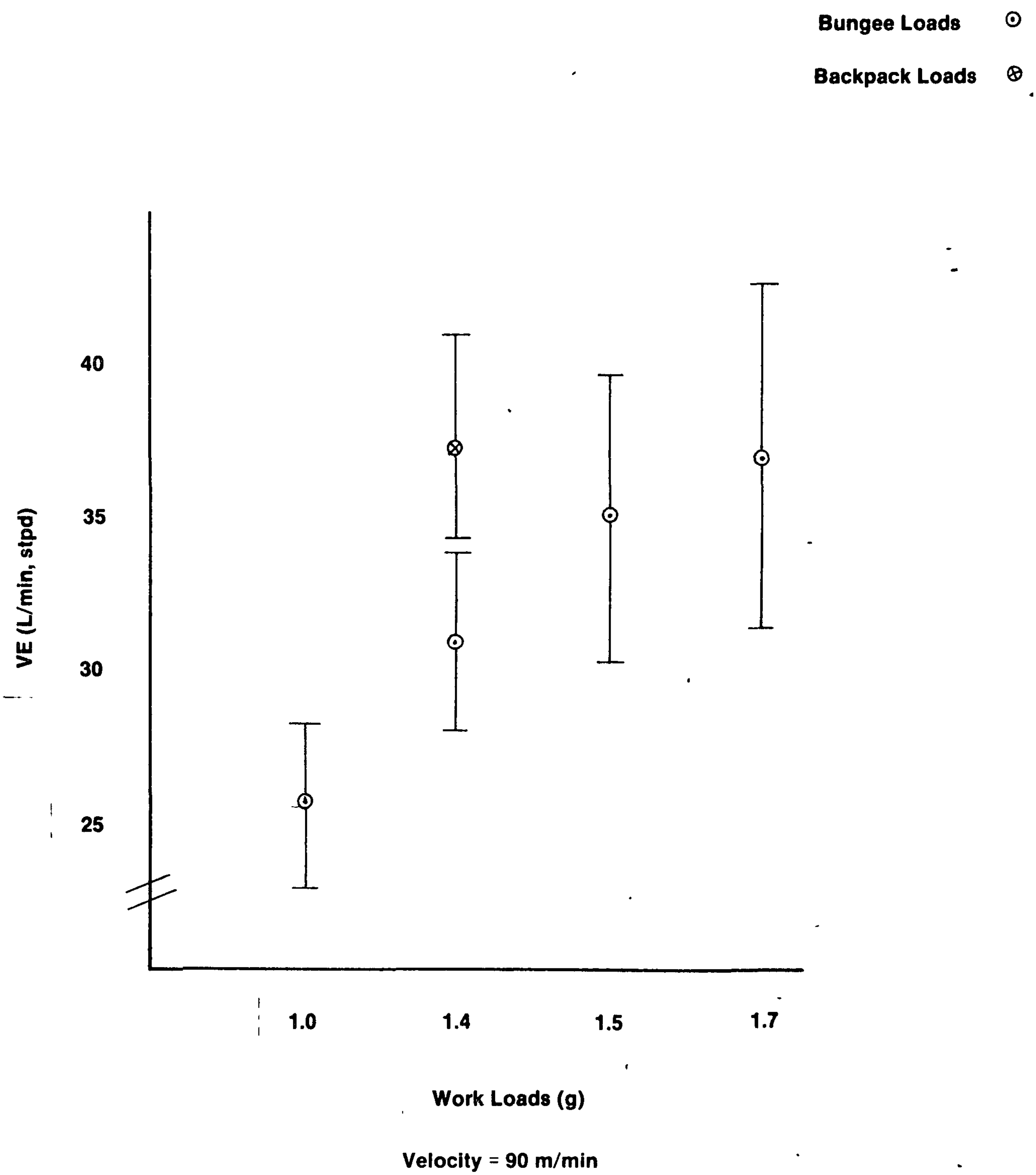


FIGURE 3. Heart Rate Response for Bungee and Backpack Loads.

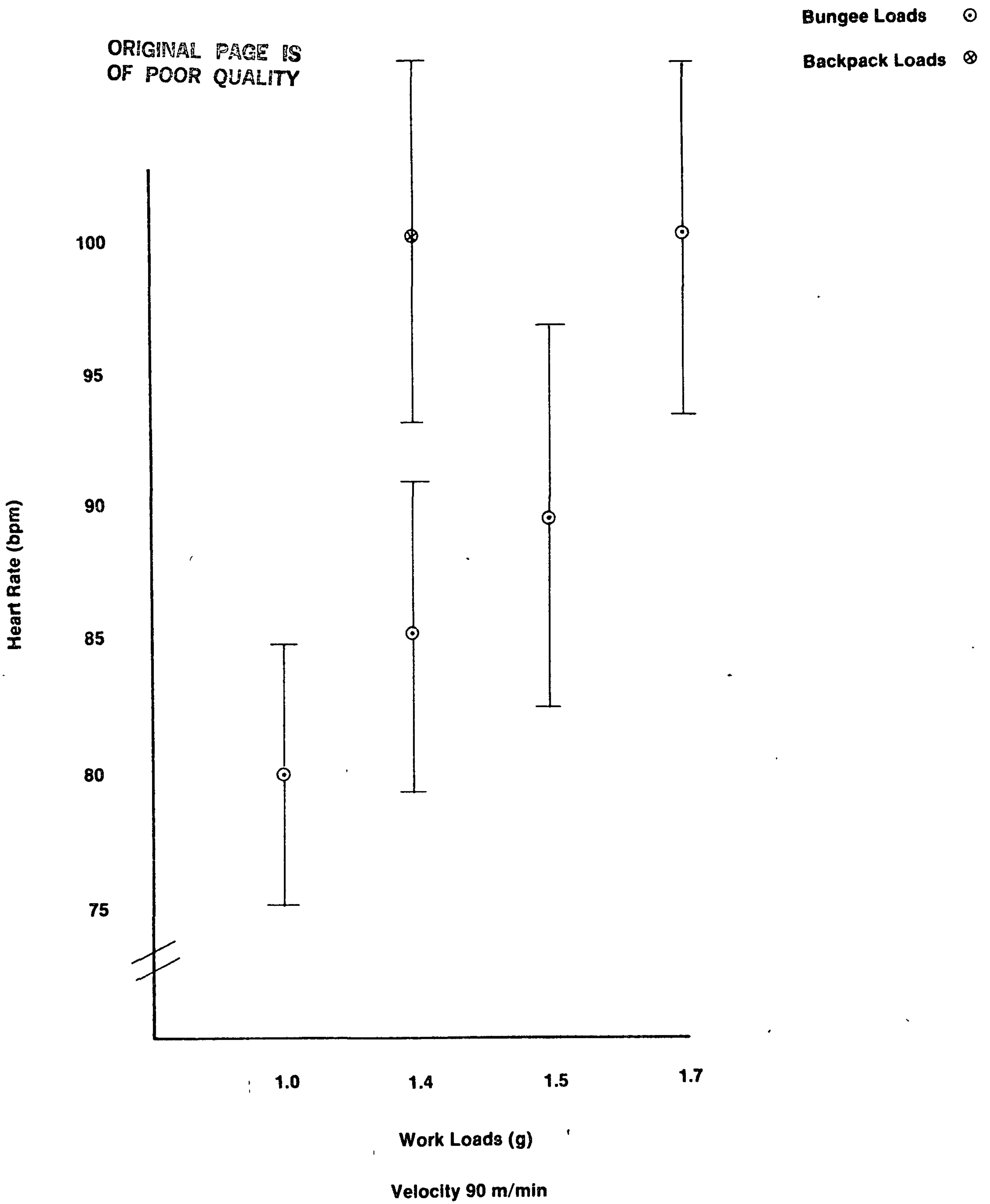
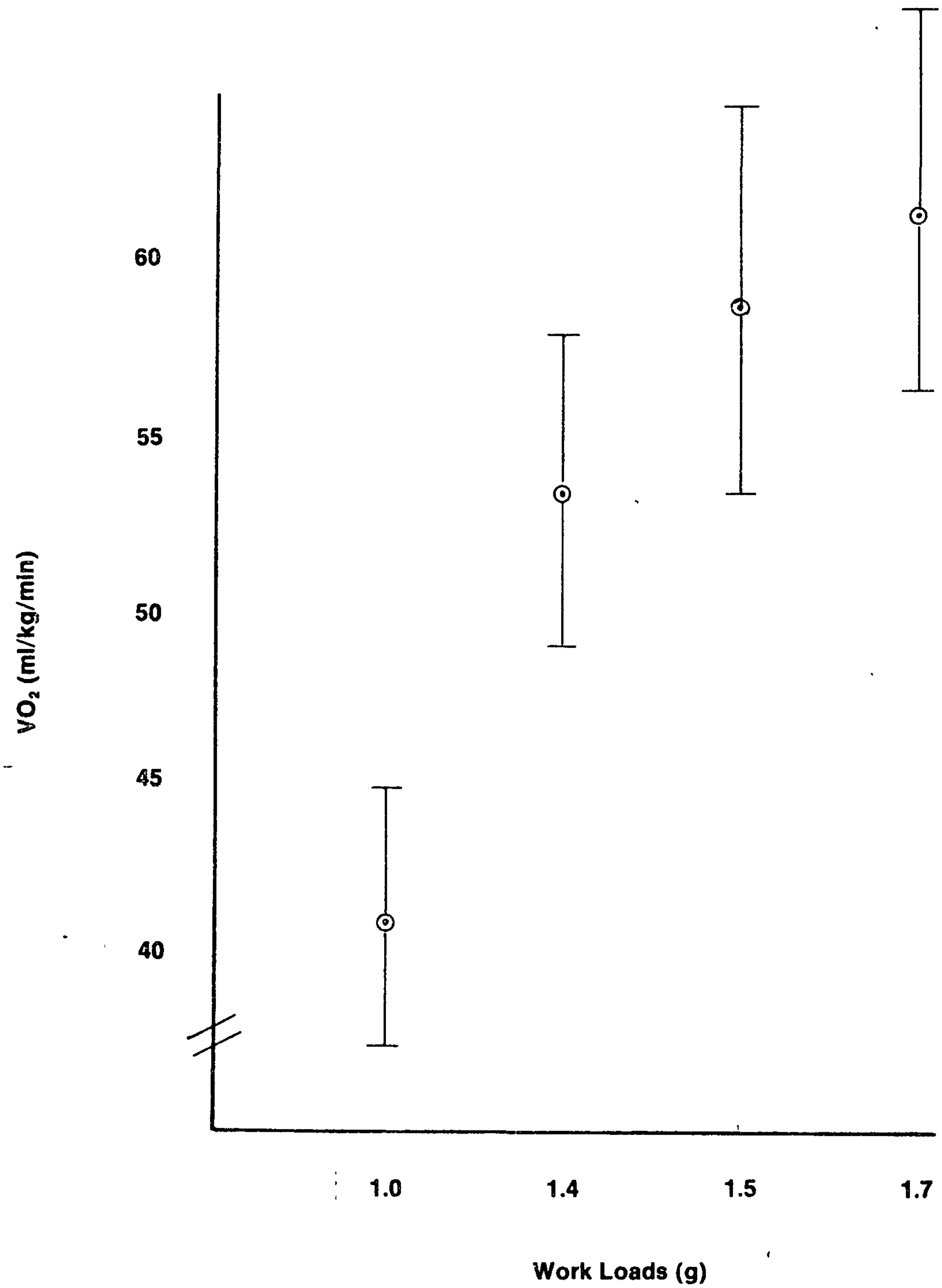


FIGURE 4. Mean Oxygen Cost for Bungee Loads During Jogging



Velocity = 175 m/min

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FIGURE 5. Mean Ventilation Rate for Bungee Loads During Jogging

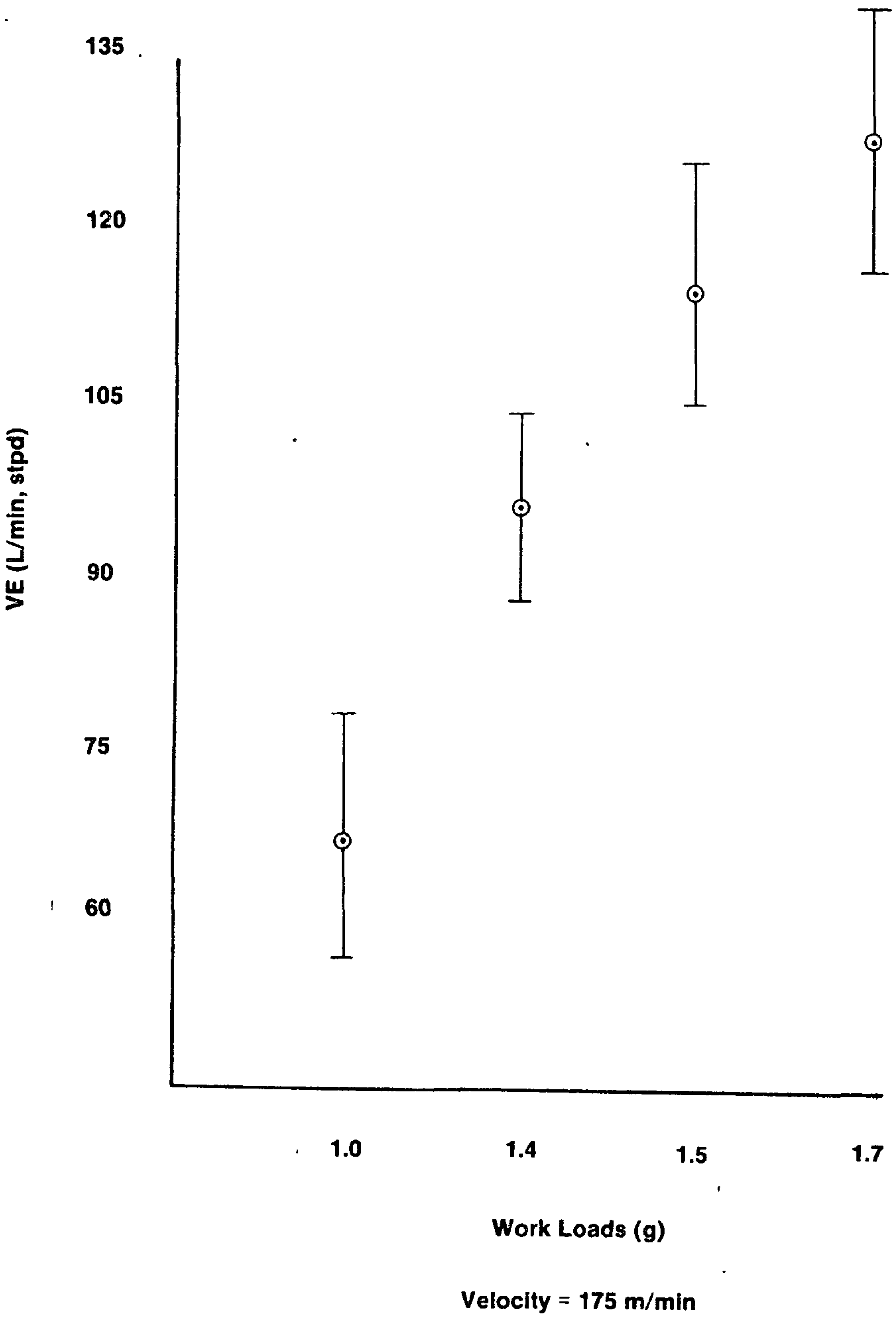

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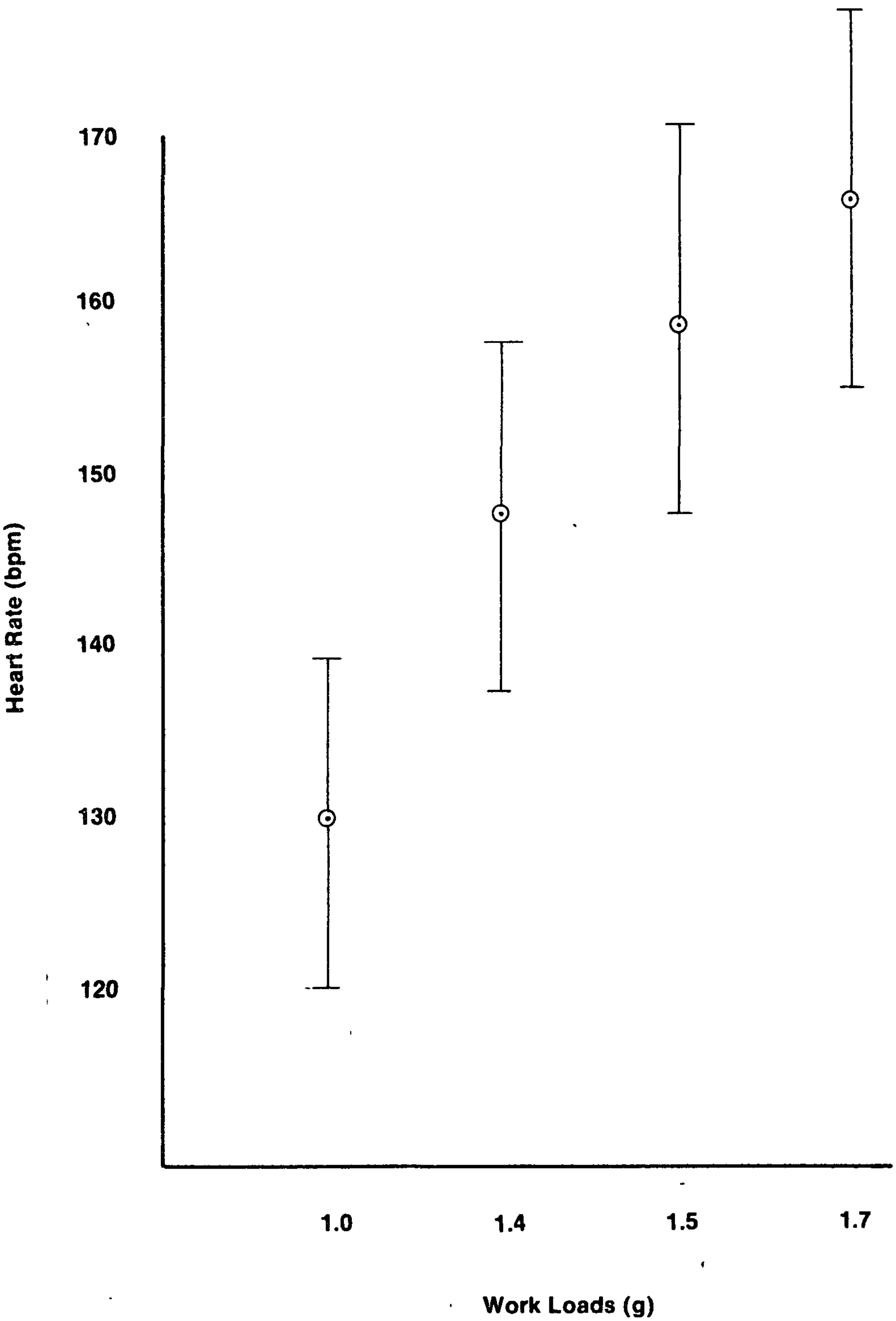
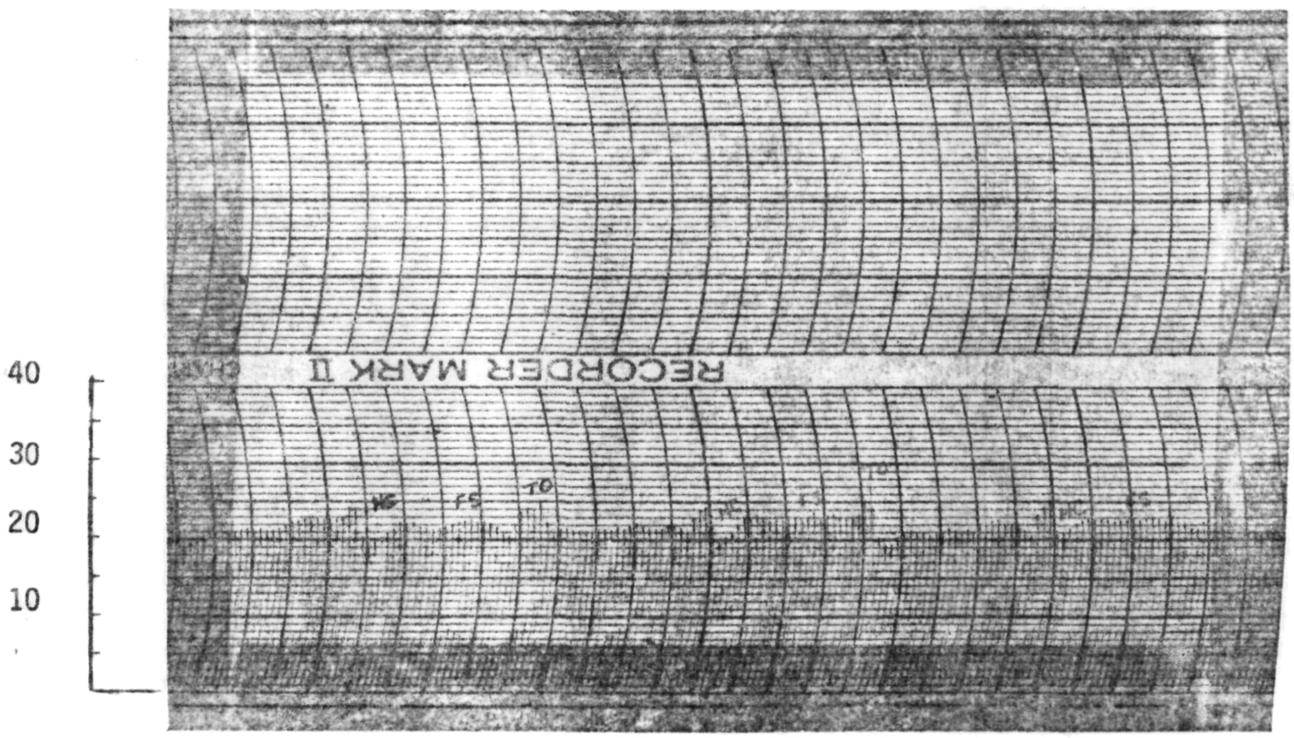
FIGURE 6. Heart Rate Response for Bungee Loads During Jogging



Velocity = 175 m/min

Figure 7. Force values during walking with bungee load of 1.4g.



HC = Heel contact

FS = Full support

TO = Toe off

Experiment III: Evaluation of Omnikinetic Training Device.

PURPOSE

The purpose of this study was to evaluate a physical training device that could enhance/maintain muscular strength while requiring minimal cabin space, weight, electrical power and subject time in flight. The specific exercise device evaluated was the Hydrafitness Total Power which utilizes Omnikinetics: dynamic accommodating resistive training with isotonic of isokinetic principles. Specifically, the purpose of this study was to examine the effectiveness of the aforementioned apparatus to enhance muscular strength, body composition, and aerobic capacity.

PROCEDURE

Subjects were 7 college male volunteers, mean age 22.4±2.1 years, from the student population of the University of Houston at Clear Lake City. Prior to training, each subject was evaluated for pulmonary function, aerobic capacity, body composition and muscular strength.

Pulmonary function (FVC, $FEV_{1.0}$, TLC and residual volume) was determined using a Collins Modular Lung Analyzer and Collins Helium Analyzer according to procedures outlined by W.E. Collins, Inc. Aerobic capacity was determined from results of a maximal treadmill test using the Bruce protocol. Heart rate and blood pressure were continuously monitored at rest (5 minutes), during exercise and following exercise (5 minutes) using a 6-lead ECG system and sphygmomanometer. Oxygen uptake was determined by open circuit methods using a semi-automated system as described by Wilmore and Costill (1974). Hydrostatic weighing was conducted in a 6 x 6 foot redwood tank. The hydrostatic weighing procedure was repeated 10 times until 3 similar readings to the nearest 20g were obtained. The 3 values were averaged. The technique for determining body density followed the method outlined by Goldman and Buskirk (1961), and the calculation of body density from the equation of Brozek et al (1963). Density was converted to percent body fat by Siri's equation (1956). Absolute body fat was determined from the product of relative body fat and total body weight. Lean body weight was the difference between total body weight and absolute body fat.

Unilateral upper and lower body strength were determined on a Cybex II machine (Thornton and Rummel 1974; Coleman 1982). Arm and shoulder strength was assessed by measuring the maximal flexion and extension force the subject could generate during a rowing motion. The rowing motion consisted of a pushing and a pulling phase. During the pushing phase (shoulder flexion), the subject simultaneously flexed the shoulder joint and extended the elbow joint in a horizontal plane. Shoulder extension was measured as the maximal force exerted by the shoulder and arm during the pulling phase of the rowing motion (extension of the shoulder and flexion of the elbow).

Unilateral strength of the quadriceps (knee extension) and hamstring (knee flexion) muscles was determined as the subject extended and flexed the lower leg at the knee joint. Each strength test was repeated three times, with each contraction conducted at a velocity of 60°/sec. The score for each test was the mean of the three trials.

The subjects trained three times per week for a period of 8 weeks. Training sessions were approximately 30 minutes in length and were conducted on alternate days. Training sessions consisted of 6 basic exercises: knee extension-knee flexion, chest press-rowing, shoulder press-lat pull. Three sets of 10 maximal repetitions of each exercise were performed daily with approximately 3 minutes of rest between sets. A self re-setting timer (0 to 20 seconds) attached to the exercise device was used to pace each subject. Movement time was set at approximately 60°/second and subjects were asked to perform 10 maximal repetitions per set in 20 seconds. Hydraulic guages attached to the device were used to provide feedback concerning the maximal force generated per contraction. Daily records of the peak force generated in each lift were reported by each subject. These data were tabulated weekly and used for motivational purposes.

Correlated t-tests were used to determine the significance of differences between pre and post training scores. The .05 level of confidence was used as the index of significance.

RESULTS

Changes consequent to training in body composition are presented in Table 1. No significant changes were observed in total body weight, absolute fat and relative fat. A significant increase was observed in lean body weight. Alterations in cardiovascular parameters both at rest and during exercise following training are presented in Table 2. No significant improvements in treadmill time to exhaustion, VO_2 max or VE max were observed. Changes in muscular strength are presented in Table 3. All subjects exhibited significant increases in each of the 6 movements tested.

DISCUSSION

Although total body weight did not change significantly, there were obvious changes in body composition. The subjects demonstrated a significant increase in lean body weight (2.8%) and decrease in absolute (-2.1%) and relative body fat (-4.6%) that were not significant. The fact that the decreases in fat weight were not statistically significant was probably attributable to the relative short duration of the study. Research by Pollock (1973) suggests that programs of 8 to 10 weeks duration generally result in less changes in body composition parameters. These changes are consistent with those of other studies involving strength training. Coleman (1977) reported reductions in total body weight (-2.4%), relative body fat (-9.1%) and absolute body fat (-6.9%) and increases in lean body mass (=3.9%) in college males who trained isotonically for 10 weeks. Similar results were observed by Gettman et al (1978) following 20 weeks of circuit weight training and by Wilmore (1974) following 10 weeks of weight training and 10 weeks of circuit weight training (Wilmore et al, 1978).

No significant improvements in VO_2 max, VE max, max heart rate or total treadmill time were observed following training. The mean improvement in VO_2 max (1.9 ml/Kg/mim, 42%) was comparable to that observed in other studies utilizing strength training programs. Previous research by Wilmore et al (1978) and Gettman et al (1978) indicate that strength training alone is not a sufficient stimulus to enhance aerobic capacity. Improvements following strength training are, in general, approximately 5% while those following running are 10 to 20%. Initial and final strength scores are presented in Table 3. Significant increases in strength for all exercise movements were observed. These findings were, in general, expected since previous studies involving weight training have shown similar results (Berger, 1962, 1965; Coleman 1972, 1977, 1982). While the changes in strength were significant, they were not as large as those observed for other studies utilizing isotonic training. Berger (1962; 1965) and Johnson (1972) have reported increases in arm and shoulder strength as large as 23 and 29 percent, respectfully for college males who trained isotonically. Likewise, Coleman (1977), Wilmore (1974) and O'Shea (1968) observed increases in leg strength in excess of 17 percent in isotonically trained college males. Few studies have been completed using isokinetic training and isokinetic testing protocols. Pipes and Wilmore (1975) trained and tested 36 male volunteers at low and high speed resistance loads on isokinetic devices. After 8 weeks, they observed a 5 percent and 25 percent increase in arm strength in the groups that trained using slow and fast repetitions, respectively. Increases in leg strength in these groups were similar to those observed in the present study (6 and 15%). The discrepancy in the magnitude of strength gains observed in the present study and previous data may be due, in part, to differences in the duration of the studies. Subjects in the present study trained for a period of 8 weeks, while those in the referred studies trained for 10 to 20 weeks. Data indicate that the magnitude of strength gained is related to the duration of training i.e., the longer the training period (weeks), the greater the gains.

The popularity of most omnikinetic (isokinetic) training devices is due more to their simplicity of design and operation, low cost and promotional program, than to proven scientific merit. Theoretically, the operation of these devices is sound, i.e., they offer variable resistance throughout the full range of muscular movement. Manufacturers contend that since acceleration is controlled within the device, more energy is available for producing muscular force. Likewise, they contend that the isokinetic device permits a muscle to maintain a maximal state of contraction throughout it's range of motion, a condition not possible in isotonic or isometric contraction.

The wholesale adoption of the omnikinetic (isokinetic) training principle is not to be accepted without reservation. As mentioned earlier, little scientific evidence exists to attest to the validity of the claims of the various manufacturers. The data that exists are mostly testimonial and opinion rather that the result of scientific study. The supportive data cited in the Pipes and Wilmore (1975) study were obtained on isokinetic devices manufactured by Cybex, not Hydrafitness. Furthermore, there exists a cloud of doubt as to the authenticity of the Pipes and Wilmore date (Wilmore, 1979).

Data obtained in the present study were obtained using a Hydrafitness Total Power. While the results of the study indicated that the Hydrafitness device will produce significant improvements in strength, this writer still has some reservations concerning the practically of this device. First, the governor used to regulate the speed of movement is not precise from machine to machine. Utilization of a given speed setting will not ensure uniform movement time between different machines. Second, the principle of variable resistance allows an individual to "let - up" or exert less muscular force as he becomes fatigued. While manufacturers attest this to be an advantage of the device, i.e., it accomodates the maximal resistance that an individual is capable of producing at a given time, there exists no method to ensure that the effort given is maximal. Psychological data indicate that man quits psychologically before reaching his physiological limit (Coleman and Carver, 1976). Utilization of variable resistance devices permit individuals, especially those who are not highly motivated, to give less than maximal effort. The manufacturers have attempted to eliminate this problem by installing pressure guages on each device. The guages are a realistic approach, but unfortunately, it is not possible to calibrate a unit and the guages have no fixed pointers. The electronic pacer is a helpful device. The pacer, as used in this investigation, facilitated maximal effort by encouraging the participants to move as rapidly as possible in order to complete the prescribed number of repetitions in the alloted time. To better ensure maximal effort, each device should be equipped with a strip recorder or LED display that would present feedback concerning the maximal force generated per contraction.

A third objection to the Hydrafitness device is that it does not permit eccentric contractions. While the manufacturers attest that eccentric contractions contribute to muscle soreness, ample data exist to indicate that eccentric contractions are as effective as concentric contractions for developing muscular strength. Studies by Johnson (1972) suggest that training programs utilizing both concentric and eccentric contractions will produce larger increases in muscular strength than programs utilizing only concentric or eccentric contractions.

Finally, most movements required of man at work or play at 1-g require both eccentric and concentric contractions. Therefore, it seems prudent to recommend both concentric and eccentric contractions for maximal muscular development and function.

CONCLUSIONS

In conclusion, the Hydrafitness does appear to be an efficient mode of training for altering body composition and muscular strength. This device is not as effective as running or cycling for the development of aerobic capacity and thus should not be expected to produce total fitness. The hydraulic cylinders are small, sturdy, light-weight, adaptable to numerous movement patterns and require no electrical power. These devices could be mounted to the walls of a space craft in various configuations so as to occupy a minimal amount of cabin space and permit a wide variety of exercise movements. Small exercise circuits could be formed within the craft so that several crew members could exercise simultaneously. When used in conjunction with an in-flight treadmill or bicycle ergometer, these devices should enable crew members to improve and/or maintain total fitness during exposure to zero-g.

Table 1

Changes in body composition with training.

Variable	Initial	Final	Change	%Change
Height (cm)	175.4±3.3	175.±3.4	.01	--
Weight (Kg)	73.7±6.1	75.2±5.5	1.5	2.0
Lean Weight (Kg)	64.2±3.4	66.0±3.9	1.8[a]	2.8
Fat Weight (Kg)	9.5±4.5	9.3±3.7	-.2	-2.1
Relative Fat (%)	12.9±4.7	12.3±4.2	-.6	-4.6

[a] Significant at .05 level of confidence.

Table 2

Changes in aerobic capacity with training.

Variable	Initial	Final	Change	% Change
Rest HR (bpm)	73.0±8.8	71.6±9.1	1.4	1.9
SBP (mmHg)	114.9±9.5	114.0±8.7	- .9	- .8
DBP (mmHg)	69.6±6.6	68.7±7.1	- .9	-1.2
VO_2 max (L/min)	3.3± .5	3.4± .6	.1	3.0
VO_2 max (ml/Kg/min)	44.3±5.6	46.1±6.1	1.8	4.1
Tmill Time (min)	12.6±1.3	13.3±1.2	.7	5.6
HR max (bpm)	194.3±4.5	195.7±4.8	1.4	.7
VE max (L/min)	131.3±11.7	135.2±12.8	3.9	3.0

Table 3

Changes in strength with training.

	Initial (Kg)	Final (Kg)	Change (Kg)	Change (%)
R Arm Flex	41.5±6.5	46.5±7.1	5.0[a]	12.1
R Arm Ext	46.0±8.4	52.9±8.6	6.9[a]	15.0
L Arm Flex	40.9±4.4	46.2±3.1	5.3[a]	13.1
L Arm Ext	44.5±7.4	50.7±7.8	6.2[a]	13.9
R Leg Flex	43.0±5.1	53.8±6.1	10.8[a]	25.1
R Leg Ext	67.5±8.7	82.4±8.5	14.9[a]	22.1
L Leg Flex	42.6±6.5	52.6±9.3	10.0[a]	23.5
L Leg Ext	68.5±8.6	84.3±5.4	15.8[a]	23.1

[a] Significant at .05 level of confidence

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