ABSTRACT

GERHARDS, M. D. Handrail assisted versus nonhandrail assisted StairMaster Gauntlet ergometry. MS in Adult Fitness/Cardiac Rehabilitation, 1991, 64pp. (N. Butts)

This study was designed to determine if sig diff existed in physiological responses (VO_2, V_E, METs, R, kcal, HR, and RPE) between handrail assisted (HA) and nonhandrail assisted (NHA) StairMaster Gauntlet (SG) exercise. Twenty males, ages 21-30, performed 2 exercise tests on the SG. The tests consisted of 4, 4 min stages, representing the SG's predicted MET values of 8, 11, 14, and 17, for each of the handrail assisted conditions. Expired gases were analyzed with the Quinton Q-Plex I and HRs were monitored with UNIQ-CIC heartwatches. Individual ANOVAs revealed sig ($p < .05$) higher values for the NHA method for oxygen consumption (VO_2, METS, kcal) and V_E. Variables not exhibiting sig ($p < .05$) diff included HR, R, and RPE. Individual t-tests revealed that values obtained for oxygen consumption were sig ($p < .01$) higher under the NHA condition for all stages of testing. V_E and RPE values were sig ($p < .01$) higher under the NHA condition for stages 3 and 4 of the tests. Values representing R were sig ($p < .01$) higher for the NHA condition for stage 4 only. No sig ($p > .01$) diff were observed between conditions for HR. The SG's estimated MET levels sig ($p < .01$) overestimated actual MET expenditure when compared to the HA condition in stages 2 through 4. The NHA condition resulted in a sig ($p < .01$) overestimation of MET levels during Stage 1, but not for Stages 2 through 4, when compared to the SG's estimated MET levels. Further studies are needed to evaluate the possible inherent differences among sexes and fitness levels in regard to hand support variations on the StairMaster Gauntlet and 4000 PT.

HANDRAIL ASSISTED VERSUS NONHANDRAIL ASSISTED STAIRMASTER GAUNTLET ERGOMETRY

A THESIS PRESENTED

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CHAPTER I

INTRODUCTION

During the decade of the 1980's there was a dramatic increase in the fitness industry with numerous health clubs and aerobic centers coming into existence. Several corporations (i.e., Texaco and Xerox) have built their own fitness centers to promote the health of their employees. This increase in the popularity of fitness and health has also promoted the expansion of athletic equipment with several innovative exercise devices being introduced. One type of exercise equipment which has experienced growth in popularity is the StairMaster Gauntlet stairclimbing ergometer.

The StairMaster is an exercise machine which simulates actual stairclimbing. Two types of StairMaster machines are available. The first type contains full-size stairs which revolve on a treadmill (i.e., the StairMaster Gauntlet and StairMaster 6000 PT). The other type, the 4000 PT, utilizes pedals which alternate positions in an up and down fashion to simulate stairclimbing. The StairMaster Gauntlet, the type used for this study, also has a computer which displays estimated MET level energy expenditure, elapsed time, caloric expenditure, floors climbed, and equivalent miles traveled. Specific workload protocols can also be programmed into the computer's memory.

The increase in popularity of the StairMaster has promoted an extensive amount of research regarding its use as an exercise mode. Due to the relative infancy of the StairMaster, however, the scope of this research has been limited. Studies have been conducted to evaluate the training effectiveness of the StairMaster (DeBenedette, 1990; Holland et al., 1988; Rosentsweig, Verstraete, & Basset, 1986; Verstraete & Ben-Ezra, 1987;). Other studies have compared the physiological responses elicited on the StairMaster to those elicited on the treadmill (Ben-Ezra & Verstraete, 1988; Riddle & Orringer, 1990). Research in regard to body positioning and hand placement on the StairMaster is quite limited, however. The concept of physiological response differences existing between handrail assisted and nonhandrail assisted StairMaster climbing has yet to be investigated, thus, further research is clearly warranted in this area.

Statement of the Problem

The purpose of this study was to determine if significant differences existed in oxygen consumption variables, heart rate, ventilation, respiratory exchange ratio, caloric expenditure, and rating of perceived exertion between handrail assisted and nonhandrail assisted StairMaster ergometry. In addition, a validation of the StairMaster Gauntlet's estimated MET levels was examined to determine the extent of its accuracy.

Hypotheses

The major hypotheses of this study were:

1. There is no significant difference in physiological response, including oxygen consumption variables, heart rate, ventilation, respiratory exchange ratio, and caloric expenditure elicited during handrail assisted and nonhandrail assisted exercise on the StairMaster Gauntlet. Furthermore, there is no difference in rating of perceived exertion between the two modes.
2. There is no significant difference between the manufacturer's estimated MET level values and the actual measured values attained during exercise on the StairMaster Gauntlet.

Assumptions

The following assumptions were made in this study:

1. All subjects were relatively healthy and free of cardiovascular problems.
2. The Quinton Q-Plex, after calibration, functioned properly.
3. The practice sessions on the StairMaster Gauntlet were sufficient for the subjects to feel comfortable with the exercise equipment and procedures.
4. The first test did not influence the second test.

5. The subjects performed to the best of their abilities during all tests.
6. The subjects' physiological and functional capacities did not change in the period between the two tests.
7. Test administration and procedures were consistent from subject to subject and test to test.
8. Values representing each variable during the fourth minute of each stage were representative of a physiological steady state by all subjects.

Delimitations

The delimitations of the study were:

1. The subjects ($N = 20$) were college age male volunteers from the University of Wisconsin-La Crosse community.
2. The StairMaster Gauntlet had a maximal workload capacity of 17 METS (59.5 $ml \cdot kg^{-1} \cdot min^{-1}$).
3. No method was used to determine the intensity of the subjects' grips during the handrail assisted StairMaster tests.

Limitations

The limitations of the study were:

1. The researcher had no control over the motivation and attitude of the subjects during any of the tests.

2. The researcher had no control over any biological variations within the subjects which may have occurred during the testing period.

Definition of Terms

StairMaster Gauntlet (Randal Sports Medical Products; Kirkland, Washington) - is a stairclimbing simulator which is used as an exercise modality. The Gauntlet is a type of StairMaster in which one simulates stairclimbing on a revolving staircase and was the type of machine used in the study.

Oxygen Consumption (VO_2) - is the amount of oxygen required by the body to complete specific bouts of work or exercise. For this study, oxygen consumption was represented as both absolute and relative VO_2. Absolute VO_2 is the total amount of oxygen consumed, regardless of one's body weight. Absolute VO_2 was measured by the Q-Plex I as $l \cdot min^{-1}$ at STPD. Relative VO_2 is derived by dividing the absolute VO_2 value by one's body weight in kilograms and is expressed as $ml \cdot kg^{-1} \cdot min^{-1}$.

MET - is the metabolic equivalent of oxygen required by the body to maintain bodily functions at rest. This amount is 3.5 $ml \cdot kg^{-1} \cdot min^{-1}$. During exercise, the oxygen requirements increase, therefore, the MET level required to sustain activity increases. The MET values were derived by the Q-Plex I by dividing the relative VO_2 by 3.5.

Handrail Assisted StairMaster Ergometry (HA) - involved walking on the StairMaster while placing the hands on the handrail. Although no limitations were set to regulate gripping intensity, the subjects were instructed to use their hands only for balance and not to support their body.

Nonhandrail Assisted StairMaster Ergometry (NHA) - involved walking on the StairMaster with the arms positioned at the sides of the body in a normal walking fashion with no contact with the handrail.

Q-Plex I (Quinton Instruments; Seattle, Washington) - is a computer gas analyzer which utilizes an open-circuit method of analyzing the concentrations and volumes of expired gases. This machine was used to evaluate the various physiological parameters associated with StairMaster ergometry.

Ventilation (V_E) - was measured as the volume of expired air per minute. The pneumotach within the Q-Plex measured this volume in liters of air per minute ($l \cdot min^{-1}$ at BTPS).

Respiratory Exchange Ratio (R) - is equal to the volume of CO_2 produced divided by the volume of O_2 consumed. The ratio is an indicator of exercise intensity as an increase in intensity is reflected by an increase in the R value.

Caloric Expenditure (kcal) - is defined as the rate at which heat is liberated from the body. This value was determined by the Q-Plex I with the use of the R value and known oxygen equivalents for kcal.

Rating of Perceived Exertion (RPE) - is a scale, ranked 6-20, developed by Borg (1973) in which individuals rate their perception of exertion level while exercising.

Maximal Oxygen Consumption (VO_2max) - is defined as the maximal amount of oxygen one can take in, transport, and utilize during maximal exercise. During the study, VO_2 was measured by the Q-Plex I during submaximal and maximal stepping on the StairMaster Gauntlet.

CHAPTER II

REVIEW OF RELATED LITERATURE

Introduction

The recent rise in popularity of exercise has promoted the development of various new exercise modalities. When such new items are introduced, extensive research concerning the benefits, safety, and effects is warranted. Recent literature in regard to the StairMaster is quite limited, and therefore, more research is needed to evaluate its effectiveness as an exercise modality. According to Randal Sports Medical Products (1990), the distributor of the StairMaster, studies have been conducted to evaluate the training effectiveness of the StairMaster. Other studies have compared the physiological responses elicited on the StairMaster to those elicited on the treadmill. Although Cotes and Meade (1960) demonstrated that hand support influences physiological responses during treadmill running, limited research existed concerning the effect of handrail assistance during StairMaster ergometry. The following is a discussion of the related literature concerning the StairMaster and the effect of handrail assistance on physiological responses elicited during StairMaster exercise.

Handrail Assisted Versus Nonhandrail Assisted StairMaster Ergometry

Only one study (Barrett, 1939) examined the effect of different handrail assisted variations on physiological responses while exercising at various intensities on the StairMaster Gauntlet. Barrett examined the effect of no hand support, moderate hand support, and heavy hand support on oxygen consumption, ventilation, heart rate, respiratory exchange ratio, and rating of perceived exertion for a population of college-aged women. Results revealed that significant differences existed between methods in oxygen consumption values at all stages of the tests. Variables such as ventilation, respiratory exchange ratio, and rating of perceived exertion exhibited no significant differences between methods at the lower exercise intensities, but were significantly different at moderate to higher exercise intensities. Heart rates were found to not be significantly different between methods at any of the stages. This finding was consistent with Howley's (1989) finding which indicated no significant heart rate differences between handrail assisted and nonhandrail assisted StairMaster 4000 PT exercise.

Training

The StairMaster has been found to be an effective and useful training modality. Rosentsweig et al. (1986) found that a training period which incorporated three sessions a week for 12 weeks on the StairMaster 6000 PT elicited increases in VO_2max comparable to those increases elicited from training periods utilizing running and cycling. Another study (Verstraete & Ben-Ezra, 1987) examined the effectiveness of utilizing the StairMaster 4000 PT as an exercise modality for cardiac patients. They found that no significant differences existed in submaximal VO_2 and heart rates between the StairMaster climb and a treadmill run at similar intensities, and therefore, concluded that the StairMaster can be safely employed as an exercise modality for cardiac patients. The results of a similar study by Holland et al. (1988) supported these findings. On the basis of the above studies, it can be concluded that the StairMaster is an effective and useful training modality.

VO_2max

Only two studies have compared the difference in VO_2max values attained on the StairMaster and the treadmill in healthy individuals. Riddle and Orringer (1990) found that the StairMaster 4000 PT elicited VO_2max values that were significantly lower than those attained on the treadmill (no actual values were given). According to the researchers the reasons for this difference in VO_2max may have been the utilization of a smaller muscle mass due to limited arm movement on the StairMaster or possibly an earlier onset of anaerobic metabolism, which leads to earlier leg fatigue when exercising on the StairMaster as compared to the treadmill.

Another study examined the VO_2max differences between a "modified" StairMaster 6000 PT and the treadmill among firefighters (Ben-Ezra & Verstraete, 1988). Results showed that mean VO_2max values were significantly lower (7%) on the StairMaster (TM = 43.1 $ml \cdot kg^{-1} \cdot min^{-1}$ vs. SM = 40.1 $ml \cdot kg^{-1} \cdot min^{-1}$). These results may have been influenced by the fact that firefighters may be more efficient stair climbers than the general population because the activity is occupationally specific for firefighters. Therefore, the results of this study may not be representative of the population as a whole.

In contrast to these findings, Holland, Hoffman, Vincent, Mayers, and Caston (1990) reported no significant difference between VO_2max elicited on the StairMaster 6000 PT and the treadmill for cardiac patients. They did find, however, that comparative workloads on the StairMaster and the treadmill, as estimated by equated MET requirements for both stepping and running (American College of Sports Medicine, 1991), elicited VO_2 values that were significantly higher on the StairMaster than on the treadmill. The authors suggested that this difference may be due to error in the prediction equation that was used to equate MET level workloads between the two modes and/or a possible inherent difference in physiological response to StairMaster ergometry.

The conflicting findings of the previous studies result in the need for further analysis in regard to StairMaster ergometry. It is suggested by this researcher that hand placement during bouts of exercise on the StairMaster may have had an effect on oxygen consumption, and possibly, the previous research placed no restrictions on hand placement or gripping intensity when the subjects were being tested. In any event, further research in regard to variations involved in StairMaster exercise is clearly warranted.

Hand Supported Versus Nonhand Supported Treadmill Ergometry

Because limited published research exists on the effect of hand support during StairMaster ergometry, it is important to analyze the research concerning the effects of hand support during treadmill running. Cotes and Meade (1960) was one of the earliest studies that reported energy expenditure is affected when arms are supported by guide rails during treadmill running. They stated that as one increased the amount of support by leaning on the rails, VO_2 was decreased compared to running without contact with the guide rails. Bruce and Hornsten (1969) reported that the duration of treadmill exercise may be extended by as much as 3 minutes if individuals were allowed to hold onto a handrail to gain support. These results were confirmed by Bruce (1971) who reinforced his earlier finding that treadmill time was extended by 3 minutes when hand support was allowed. Recently, Beadle, Holly, and Amsterdam (1990) reported that oxygen consumption values during handrail supported graded exercise tests were significantly lower than values obtained during nonhandrail supported graded exercise tests.

Ragg, Murray, Karbonit, and Jump (1980) also found significant decreases in both heart rate and oxygen consumption when handrail supported treadmill running was compared to nonhandrail supported treadmill running. In their textbook, Astrand and Rodahl (1986) suggested that oxygen consumption decreased by 10% when handrail support was allowed while jogging, and a 25% decrease in oxygen consumption when handrail support was allowed while walking.

In an attempt to demonstrate the effect of supporting body weight by leaning on the handrails, other researchers have examined the effect of handrail grip intensity on VO_2 during treadmill running. Zeimetz, McNeill, Hall, and Moss (1985) found no significant difference in VO_2 between nonhand supported treadmill running and resting the hands on the handrails while running, yet they found significant differences in VO_2 when subjects gripped, or leaned on the handrails at various intensities. As gripping intensity increased, VO_2 tended to decrease. These findings supported the earlier work of Bruce, Kusumi, and Hosmer (1973) and Workman and Armstrong (1963) who both reported hand support variations in reference to gripping intensities affected oxygen consumption during treadmill running. It appears that as a person increasingly supported their body weight by leaning on the handrails when treadmill running, a decrease in oxygen consumption resulted from a decreased oxygen demand by the working skeletal muscles of the legs. The establishment of the effect of hand support during treadmill running led this researcher to believe that hand support had an effect on oxygen consumption during StairMaster exercise.

StairMaster Validation

One method of oxygen consumption measurement involves the MET, or metabolic equivalent. One MET equals 3.5 $ml \cdot kg^{-1} \cdot min^{-1}$, which is the amount of oxygen used by the body at rest. Therefore, as oxygen consumption increases, MET expenditure increases proportionately. During exercise, the MET level is determined by dividing the value for relative VO_2 ($ml \cdot kg^{-1} \cdot min^{-1}$) by 3.5.

One study (Riddle & Orringer, 1990) examined the accuracy of the estimated MET levels attained during StairMaster 4000 PT ergometry. Results indicated that MET levels at all measured workloads were significantly less than estimated levels while exercising on the StairMaster 4000 PT. This difference increased incrementally as workloads increased. In reference to the StairMaster Gauntlet, Barrett (1989) discovered that the predicted MET levels significantly underestimated MET expenditure when hand support was allowed during bouts of exercise. According to Randal Sports Medical Products (1991), the

StairMaster Gauntlet's estimated MET level was derived from equations based on step height and stepping rate (American College of Sports Medicine, 1991). Given the fact that the 8 inch step height on the StairMaster Gauntlet is constant, the following equation was used to predict the MET level:

$$MET = 1 + (steps/minute * .1161)$$

Summary

The training effectiveness of the StairMaster has been shown to be comparable to the effectiveness of other training modes. The research concerning the physiological responses elicited during StairMaster work as compared to other modes, however, remained ambiguous at this point and research in this area was conflicting. The concept that hand support and gripping intensity affected oxygen consumption during treadmill running had been clearly established. This researcher believes that the variations in gripping intensity and handrail assistance may have been responsible for the conflicting results of the previous comparative studies involving the StairMaster and the treadmill.

CHAPTER III

METHODS

Introduction

The purpose of this study was to investigate and identify the differences in physiological response between handrail assisted and nonhandrail assisted exercise on the StairMaster Gauntlet. Additionally, a validation of the StairMaster Gauntlet's estimated MET levels was performed.

Subjects

Twenty male subjects from the University of Wisconsin-La Crosse volunteered to participate in the study. Volunteers were accepted with the assumption that they were in good health and that no cardiovascular problems existed.

Preparatory Procedures

Each subject was personally contacted and given a detailed description of the testing procedures, protocols, and the purpose of the study. Subjects were informed that two StairMaster VO_2 tests were to be administered. A coin flip was used to determine the order of the testing protocols. A coin toss of "heads" resulted in the handrail assisted StairMaster VO_2 test being administered first, followed by the nonhandrail assisted StairMaster VO_2 test; "tails" indicated the reverse order. The time span between the two tests was 7 to 14 days to allow for physiological recovery, yet not so long as to allow significant physiological changes to occur.

Subjects were requested to bring comfortable workout clothing and running shoes for the exercise testing sessions. Subjects were also requested to avoid strenuous exercise (i.e., exercise in excess of 85% of their perceived maximal capacity) at least 24 hours prior to their scheduled test time.

StairMaster Program

The StairMaster's computer was programmed with the specific practice session and actual testing protocols (workloads), interval times, and total times prior to its use.

Informed Consent

Upon arrival at the Human Performance Laboratory at the University of Wisconsin-La Crosse, subjects were presented with an Informed Consent form (see Appendix A). The Informed Consent form explained the procedures and risks involved with participation in the study. If any questions existed at this time, they were answered by the investigator.

StairMaster Familiarization

Prior to the actual StairMaster VO_2 testing, subjects were required to attend two practice sessions in which they familiarized themselves with exercising on the StairMaster. Subjects climbed on the StairMaster at estimated MET levels of 8, 11, and 14 utilizing both the handrail assisted and nonhandrail assisted positions. These levels were the workloads used for the actual testing. Subjects were also required to wear the headgear, mouthpiece, and noseclip to more accurately simulate the actual testing experience. Termination of the practice session occurred when both the investigator and the subject felt that adequate StairMaster competency was attained.

Calibration Procedures

Expired gases during the StairMaster VO_2 tests were collected and analyzed with the use of the Quinton Q-Plex I (Quinton Instruments Company, 1989). The operation of the Q-Plex I is based on open-circuit spirometry which analyzed the concentrations of expired gases (O_2 & CO_2). A pneumotach within the Q-Plex I measured the volume of expired air. The measurements of inspired and expired O_2 and CO_2 fractions and gas volumes were used to calculate oxygen consumption values by the Q-Plex I. The calibration of the Q-Plex I involved entering ambient atmospheric conditions and calibrating of both the O_2 and CO_2 analyzers and the pneumotach. The first step in this process involved the determination of present atmospheric conditions. The atmospheric pressure was read from a standard wall mounted mercury barometer. The relative humidity was determined with the use of a sling psychrometer. The room temperature was read from the dry bulb thermometer on the sling psychrometer. These atmospheric conditions were then entered into the Q-Plex. The pneumotach was then calibrated with the injection of known volumes of air (3.002 L) with the use of a syringe pump. Next, the gas analyzers were calibrated with low and high O_2 and CO_2 concentrations, previously determined by the Scholander technique. Finally, the Q-Plex I was configured with the test time modes, test protocol, or event information.

Pretest Procedures

The subjects' weights were determined with the use of a scale in the Human Performance Laboratory. This information, along with other pertinent biographical information, was entered into the Q-Plex I's computer memory.

The subjects were fitted with the UNIQ-CIC Heartwatch (Computer Instruments Corporation, 1989). The UNIQ-CIC Heartwatch is a heart rate monitor which was strapped around the subject's chest, with the transmitter itself positioned just below the xiphoid process. The UNIQ-CIC Heartwatch contains a computer which detects the electrical impulses generated by the heart and transmits these impulses to the receiver on a wrist band. The wristband containing the receiver displayed the heart rate in beats per minute and was strapped onto the handrail of the StairMaster.

The result of the coin toss determined which exercise testing protocol would be utilized first. After the testing sequence was determined, the subjects were fitted with the mouthpiece and headgear. Directional membranes were utilized in the mouthpiece to ensure that all expired air was directed to the Q-Plex I via a plastic hose connecting the mouthpiece to the Q-Plex I.

StairMaster VO_2 Testing

Prior to the actual StairMaster VO_2 testing, the StairMaster's computer was programmed with the specific protocol that was to be utilized. Both the handrail assisted and nonhandrail assisted StairMaster tests utilized the same workload protocol (see Table 1). The protocol was discontinuous in that two minute rest periods were allotted between stages. Heart rates were read from the UNIQ-CIC Heartwatch and RPE's determined during the final fifteen seconds of each stage. The other physiological parameters (VO_2, R, V_E, METs, kcal) were measured each minute by the Q-Plex during the testing period. Values obtained for each variable during the fourth minute of each stage were used in the data analysis. The test was terminated when either the subject completed Stage 4 or was subject to volitional exhaustion.

Statistical Treatment

A two-way ANOVA with repeated measures was utilized to determine whether significant differences existed between the handrail assisted and nonhandrail assisted StairMaster tests for all variables (VO_2, heart rate, V_E, R, METs, kcal, and RPE). If a significant interaction was obtained, the Bonferroni method (Thomas & Nelson, 1990) was used to adjust alpha level and dependent t-tests were utilized to determine where significant differences occurred between handrail assisted and nonhandrail assisted StairMaster tests at each stage for all variables.

Table 1. Protocol stages for handrail assisted and nonhandrail assisted tests

Stage	Time (min)	Mets	Steps/Minute
warmup	1-5	6	41
1	6-9	8	56
rest	10-11		
2	12-15	11	80
rest	16-17		
3	18-21	14	103
rest	22-23		
4	24-27	17	127

CHAPTER IV

RESULTS AND DISCUSSION

Introduction

The purpose of this investigation was to compare the physiological responses between hand supported and nonhandrail assisted exercise on the StairMaster Gauntlet. Each subject initially completed two exercise orientation sessions on the StairMaster Gauntlet. Once StairMaster competency was attained, each subject completed two StairMaster tests: one with the use of handrail assistance and the other without the use of handrail assistance. Each test consisted of 4, 4 minute stages. The stages were representative of the StairMaster Gauntlet's estimated MET levels of 8, 11, 14, and 17. Variables examined during both tests included relative VO_2, absolute VO_2, ventilation, METs, respiratory exchange ratio, caloric expenditure, heart rate, and rating of perceived exertion. Stages 1 through Stages 3 were completed by all 20 subjects, while Stage 4 was completed by only 15 subjects. The discrepancy in the number completing the final stage was due to the fact that the final stage represented 17 METs or 59.5 $ml \cdot kg^{-1} \cdot min^{-1}$, which was greater than the maximal aerobic capacity of five subjects.

Subjects

Twenty males from the University of Wisconsin-La Crosse community were solicited as subjects. Average subject characteristics were: age 24.7 (2.63) years; weight 78.4 (12.39) kilograms; and height 178.3 (9.57) centimeters.

Results

A two-way ANOVA with repeated measures was utilized to determine whether significant differences existed between methods (handrail assisted versus nonhandrail assisted) and among stages (Stage 1 through Stage 4) for all variables. As expected, the results of the ANOVA revealed that overall a significant ($p < .05$) difference existed among all four stages ($4 > 3 > 2 > 1$) for all variables considered.

The ANOVA between the two methods revealed that the relative VO_2, absolute VO_2, V_E, METs, and kcal measurements were significantly ($p < .05$) higher for the nonhandrail assisted test than for the handrail assisted test. Those variables which displayed no significant ($p > .05$) difference between methods included the R value, heart rate, and rating of perceived exertion. Table 2 displays the overall variable means and standard deviations. Tables 3, 4, 5, and 6 display the means and standard deviations of each variable for each stage.

The ANOVA also indicated there was a significant ($p < .05$) interaction between method and stage. In an attempt to identify where differences existed for each variable between

Table 2. Overall means and standard deviations for all physiological variables ($\underline{N}$ = 20)

Variable	Handrail Assisted	Nonhandrail Assisted
VO_2 ($ml \cdot kg^{-1} \cdot min^{-1}$)	42.2[a] 1.68[b]	44.5* 1.86
VO_2 ($l \cdot min^{-1}$)	3.281 .509	3.447* .536
V_E ($l \cdot min^{-1}$)	84.7 19.04	94.2* 22.71
METs	12.0 .49	12.7* .62
R	0.93 .052	0.94 .056
kcal	16.4 2.58	17.3* 2.71
HR ($beats \cdot min^{-1}$)	155.2 15.17	157.9 15.75
RPE	12.7 2.37	13.4 2.06

a = mean
b = standard deviation
* significant at $p < .05$

Table 3. Means and standard deviations of physiological variables obtained for Stage 1 at 8 METs ($\underline{N}$ = 20)

Variable	Handrail Assisted	Nonhandrail Assisted
VO_2 ($ml \cdot kg^{-1} \cdot min^{-1}$)	28.0[a] 1.07[b]	29.2* 1.36
VO_2 ($l \cdot min^{-1}$)	2.200 .349	2.291* .379
V_E ($l \cdot min^{-1}$)	48.9 8.51	51.5 10.25
METs	8.0 .31	8.3*[c] .39
R	0.85 .033	0.85 .047
kcal	10.8 1.70	11.2* 1.83
HR ($beats \cdot min^{-1}$)	124.9 16.28	126.2 16.86
RPE	9.4 1.81	9.7 1.72

* significant at $p < .01$
a = mean
b = standard deviation
c = significantly higher than estimated MET level of 8.00

Table 4. Means and standard deviations of physiological variables obtained for Stage 2 at 11 METs ($\underline{N}$ = 20)

Variable	Handrail Assisted	Nonhandrail Assisted
VO_2 ($ml \cdot kg^{-1} \cdot min^{-1}$)	37.0[a] 1.44[b]	38.3* 1.44
VO_2 ($l \cdot min^{-1}$)	2.909 .454	3.005* .469
V_E ($l \cdot min^{-1}$)	67.8 14.27	70.9 16.39
METs	10.6[c] .41	11.0* .41
R	0.90 .046	0.90 .047
kcal	14.4 2.27	14.8* 2.37
HR ($beats \cdot min^{-1}$)	146.4 17.11	148.2 17.83
RPE	11.6 2.28	12.1 1.98

* significant at $p < .01$
a = mean
b = standard deviation
c = significantly lower than estimated MET level of 11.00

Table 5. Means and standard deviations of physiological variables obtained for Stage 3 at 14 METs ($\underline{N}$ = 20)

Variable	Handrail Assisted	Nonhandrail Assisted
VO_2 ($ml \cdot kg^{-1} \cdot min^{-1}$)	46.7[a] 1.69[b]	49.4* 1.66
VO_2 ($l \cdot min^{-1}$)	3.675 .604	3.877* .659
V_E ($l \cdot min^{-1}$)	94.3 21.61	108.0* 32.84
METs	13.3[c] .50	14.1* .85
R	0.96 .064	0.98 .076
kcal	18.4 3.11	19.5* 3.45
HR ($beats \cdot min^{-1}$)	169.0 15.11	172.4 15.89
RPE	13.9 2.69	14.6* 2.52

* significant at $p < .01$
a = mean
b = standard deviation
c = significantly lower than estimated MET level of 14.00

Table 6. Means and standard deviations of physiological variables obtained for Stage 4 at 17 METs (n = 15)

Variable	Handrail Assisted	Nonhandrail Assisted
VO_2 ($ml \cdot kg^{-1} \cdot min^{-1}$)	57.0[a] 2.52[b]	61.0* 2.97
VO_2 ($l \cdot min^{-1}$)	4.341 .629	4.615* .635
V_E ($l \cdot min^{-1}$)	127.7 31.75	146.4* 31.73
METs	16.3[c] .72	17.4* .85
R	1.01 .065	1.04* .052
kcal	22.0 3.22	23.6* 3.19
HR ($beats \cdot min^{-1}$)	180.5 12.17	184.8 12.42
RPE	15.7 2.69	17.2* 2.01

* significant at $p < .01$
a = mean
b = standard deviation
c = significantly lower than estimated MET level of 17.00

methods, a paired t-test was performed on each variable at all four stages. The Bonferroni method of adjusting alpha significance ($p < .01$) was used to determine significance level.

The paired t-tests revealed that all the variables based on oxygen consumption (relative VO_2, absolute VO_2, METs, and kcal) were significantly ($p < .01$) lower for the handrail assisted condition than the nonhandrail condition at all four stages. Values for V_E were found to be significantly ($p < .01$) lower with handrail assistance for Stages 3 and 4, but not for Stages 1 and 2. No significant ($p > .01$) differences existed in R values between the two methods for Stages 1 through 3, however, significantly ($p < .01$) higher R values were obtained during Stage 4 for the nonhandrail assisted test. Heart rate comparison revealed that no significant ($p > .01$) differences existed between methods at any of the four stages. Ratings of perceived exertion were found to be significantly ($p < .01$) higher when handrail assistance was used during Stages 3 and 4, but no significant ($p > .01$) differences were found at Stages 1 and 2.

Comparison of actual MET levels during the handrail assisted trials and predicted MET levels revealed that the predicted MET levels significantly ($p < .01$) overestimated MET expenditure in Stages 2 through 4 when compared to handrail assisted StairMaster exercise. Comparison of predicted MET levels and nonhandrail assisted MET levels revealed that no significant difference ($p < .01$) existed in Stages 2 through Stage 4, but in Stage 1, the predicted MET level significantly underestimated actual MET expenditure.

Discussion

The finding of oxygen consumption differences existing between handrail assisted and nonhandrail assisted StairMaster Gauntlet exercise agrees with the data of Barrett (1989) who found that oxygen consumption values were significantly different at all stages of testing between nonhand supported and "moderate" supported StairMaster Gauntlet exercise. Barrett's stages consisted of predicted MET levels of 7.0, 8.5, 10.0, 11.5, 13.1, 14.5, 16.1, 17.5, and 19.4. The gearing of the StairMaster Gauntlet was altered in order to attain these predicted MET levels. The results also agree with the studies that have found that the oxygen consumption measurements were lower for handrail assisted versus nonhandrail assisted treadmill exercise (Astrand & Rodahl, 1986; Beadle et al., 1990; Cotes & Meade, 1960; Ragg et al., 1980; Ziemetz et al., 1985). It appears that as the stages progressed (i.e., the intensity of exercise increased) the difference in oxygen consumption between the handrail assisted and nonhandrail assisted conditions increased incrementally, with handrail assisted costs being reduced. A possible reason for this lower cost for handrail assisted exercise is the utilization of a larger muscle mass involved in the nonhandrail assisted condition due to the increased oxygen demand by the muscles of the arms and upper extremities. As intensity increased, it appeared that arm swing increased proportionately, which, in effect, may have led to an increased oxygen demand.

The difference in kcal values between the handrail assisted and nonhandrail assisted conditions is an interesting point to consider in terms of potential weight loss. If one exercises on the StairMaster Gauntlet without handrail assistance, he/she may burn more calories than they would with handrail assistance. For example, mean caloric expenditure at 14 METs without handrail support equalled 19.52 kcal/min. Mean caloric expenditure with the use of handrail assistance equalled 18.57 kcal/min, with the difference between the two conditions equalling 1.15 kcal/min. This difference projected over a 60 minute workout session would increase to 69.0 kcal/hour. This would result in result in a significant weight loss over a period of months if one was to utilize the StairMaster Gauntlet without the use of handrail assistance.

Results from the analysis of ventilation were in agreement with Barrett's (1989) study which found no significant differences in ventilation at lower exercise intensities. At higher intensities, however, Barrett found that nonhandrail assisted exercise had higher ventilation rates than did the handrail assisted condition. A possible explanation for this finding was that the lower intensities were not as physiologically demanding because the arm swing involvement was minimal. During the latter stages, however, arm swing involvement increased, and possibly increased the rate at which the proprioreceptors located in the arms sent impulses to the respiratory center in the medulla to increase the respiration rate, thus causing an increase in ventilation (Hole, 1990). In addition, the increased metabolic rate associated with the higher work intensities under the nonhandrail assisted condition, which may have had accompanied with it an increased concentration of blood CO_2, may have stimulated the increase in ventilation during the latter stages of testing. Also, the fact that 15 of the 20 subjects completed Stage 4 of the test, which represented a VO_2 of 59.5 $ml \cdot kg^{-1} \cdot min^{-1}$ showed that a relatively highly fit sample participated in this study (American Heart Association, 1972). This fact may have contributed to the lack of significant differences existing at the lower intensities as these stages may not have been physiologically demanding enough to elicit a significant difference in terms of ventilation response.

Results from the analysis of RPE revealed that the handrail assisted were significantly lower than the nonhandrail assisted values in the latter stages, but not in the preliminary stages. This finding is also consistent with Barrett's (1989) findings that handrail assisted RPEs were significantly lower only at higher exercise intensities. When analyzed together with ventilation, it appeared that as the ventilation differences increased, the perception of effort increased accordingly. In effect, the increase in ventilation may have greatly influenced the perception of effort.

The finding that handrail assisted respiratory exchange ratios were significantly lower than the nonhandrail assisted values only during Stage 4 is also consistent with Barrett's (1989) results which found significant differences only during the latter stages of testing. It appeared that the incorporation of an increased arm swing that accompanied the higher intensities and the increased physiological demand resulted in significant differences appearing only in the higher intensity stages. Perhaps the high fitness level of the subjects tested accounted for the significant differences appearing only during the final stage of testing. An important factor to consider is the excessive CO_2 "blow-off" that accompanied the higher exercise intensities, which may have altered the respiratory exchange ratio slightly, thus lending ambiguity to the analysis of the respiratory exchange ratio differences between the two methods.

Heart rates, which did not differ between methods for any of the stages, were in agreement with Barrett's (1989) and Howley's (1989) studies which both found no significant differences in heart rates between nonhandrail assisted and "light to moderate" handrail assisted StairMaster exercise. The fact that oxygen consumption values differed significantly and heart rate values did not leads this researcher to believe that the sample examined, which was relatively highly fit, may have compensated for the increased oxygen demand by altering stroke volume without a significant increase in heart rate. Another explanation could possibly be that the highly trained subjects had an increased oxygen carrying capacity and capillary density, and also had a greater ability to extract available oxygen from the blood which may have enabled them to supply more oxygen to the working muscles, thus resulting in minimal heart rate increases.

Results of the validation of the StairMaster Gauntlet's predicted MET values provided by the company revealed that the actual values obtained during the handrail assisted tests were significantly lower than predicted, while the nonhandrail assisted condition produced values that more closely approximated the predicted levels. Barrett (1989) also found that the predicted METs significantly overestimated oxygen consumption when compared to handrail assisted exercise. This finding, in effect, possibly resulted from the fact that the predicted METs were calculated from equations that are based essentially on stepping without the use of handrail assistance. Therefore, when handrail assistance was utilized, the oxygen requirement was significantly reduced. Randal Sports Medical Products (1991), in an effort to compensate for the inaccuracy of their computer, has recently produced new computers which more closely approximate actual MET expenditure.

Some limitations existed in regard to this study. The fact that the amount of handrail assistance allowed was not quantifiable may have led to some problems in terms of test control. It was stressed to the subjects that minimal support was allowed, and that they use just enough handrail assistance to retain balance. Also, the StairMaster Gauntlet's maximal speed, representative of 17 METs, was limiting in that 75% of the subjects tested completed this stage. It was possible that if higher speeds were available, maximal data could have been obtained for all of the subjects.

Summary

The finding that overall mean oxygen consumption (absolute VO_2, relative VO_2, METs, and kcal) and ventilation values differed significantly between handrail assisted and nonhandrail assisted StairMaster Gauntlet exercise, with handrail assisted values being lower, led to the rejection of the null hypotheses that there would be no significant difference between methods for these physiological variables. The fact that the other physiological variables (heart rate, respiratory exchange ratio, and rating of perceived exertion) exhibited no significant difference between methods in terms of overall means led to the acceptance of the null hypotheses for these variables.

CHAPTER V

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

This study was designed to determine if significant differences existed in physiological response variables (absolute VO_2, relative VO_2, V_E, METs, R, kcal, HR, and RPE) between handrail assisted and nonhandrail assisted StairMaster Gauntlet exercise. Twenty healthy males, ages 21-30, performed exercise tests for each of the handrail assistance conditions at predicted MET levels of 8, 11, 14, and 17. Variables were monitored throughout the tests, with the fourth minute, end-stage values being used in the data analysis. Individual ANOVAs performed on each variable revealed significant ($p < .05$) differences between overall method means for values representing oxygen consumption (absolute VO_2, relative VO_2, METs, and kcal) and ventilation, with handrail assisted values being lower than nonhandrail assisted values. Variables not exhibiting significant ($p > .05$) differences between overall method means included heart rate, respiratory exchange ratio, and rating of perceived exertion.

In order to locate where significant differences occurred between methods because of significant interaction, individual t-tests were performed on each variable at each stage of testing. Results revealed that values obtained for oxygen consumption were significantly ($p < .01$) higher under the nonhandrail assisted condition at all four stages of testing. Nonhandrail assisted ventilation and rating of perceived values were found to be significantly ($p < .01$) higher during Stages 3 and 4, but no significant ($p > .01$) differences were observed for Stages 1 and 2. Values representing the respiratory exchange were significantly ($p < .01$) higher under the nonhandrail assisted condition for Stage 4, but no significant ($p > .01$) differences between methods were observed for Stages 1 through 3. No significant ($p > .01$) differences were observed between methods at any of the stages for heart rate.

Conclusions

Handrail assisted StairMaster Gauntlet exercise resulted in lower oxygen consumption (absolute VO_2, relative VO_2, METs, and kcal) and ventilation when compared to the nonhandrail assisted condition. These differences became greater as the intensity of the exercise increased. Respiratory exchange ratios and ratings of perceived exertion were not found to be significantly different between handrail assisted and nonhandrail assisted StairMaster Gauntlet exercise. However, post-hoc analysis revealed that, at higher exercise intensities, values representative of these variables were significantly higher under the nonhandrail assisted condition. No significant differences were observed for heart rate between handrail assisted and nonhandrail supported StairMaster Gauntlet exercise. The StairMaster Gauntlet's programmed MET levels significantly overestimated the actual MET level when compared to the handrail assisted condition. The nonhandrail assisted condition more accurately simulated the predicted MET levels.

The practical applications of the results of this study are two-fold. One, exercise specialists and technologists who utilize or advocate the use of the StairMaster Gauntlet as an exercise modality or testing apparatus must realize that handrail assistance variations affect the physiological response of the user in terms of oxygen consumption and ventilation. Second, health club employees and members must realize that excessive handrail assistance while training on the StairMaster Gauntlet significantly reduces the actual amount of work completed in terms of oxygen cost.

Another important aspect to consider when analyzing the effects of handrail assistance during StairMaster Gauntlet exercise is the applicability of the present research to the StairMaster 4000 PT. Due mainly to its lower cost and safety benefits, the 4000 PT is more predominately used in the health club and rehabilitative setting than the Gauntlet. Analysis of the mechanics involved when exercising on the 4000 PT, which is the pedal-type of StairMaster, leads this researcher to speculate that the physiological response differences between handrail assisted and nonhandrail assisted exercise would be greater than those observed with the Gauntlet. A possible reason for this greater difference may be a higher energy expenditure associated with balance on the two pedals while exercising without handrail assistance, as opposed to stepping on the steps as they revolve on the Gauntlet. However, the practicality of exercising on the StairMaster 4000 PT without handrail support must be considered.

Excessive leaning on the handrails during both StairMaster Gauntlet and 4000 PT exercise is also interesting to consider. One need not to observe StairMaster users very long to identify individuals who excessively lean on the handrails or computer module in an effort to decrease the work actually being performed. Therefore, it is very important for those health care providers and instructors who advocate StairMaster utilization, either the Gauntlet or the 4000 PT, to be aware of both the effects of handrail assistance and excessive leaning while exercising on the various types of StairMasters.

Recommendations

Based on the conclusions, the following recommendations for future studies were made:

1. Examine the effect of handrail assistance at maximal levels on the StairMaster Gauntlet.

2. Incorporate a larger, more heterogeneous sample.
3. Examine the effect of handrail assistance on blood pressure.
4. Examine the difference between sexes in terms of the effects of handrail assistance.
5. Examine the effect of handrail assistance with a quantifiable gauge to measure the amount of assistance.
6. Further analyze the effect of handrail assistance on heart rate.
7. Publicize the effect of handrail assistance to those individuals utilizing the StairMaster Gauntlet as an exercise modality.
8. Examine differences between fitness levels in terms of the effects of handrail assistance.
9. Examine training programs incorporating the StairMaster into leg strengthening programs.
10. Examine the biomechanics involved in exercising on the various types of StairMasters.
11. Compare physiological responses between the steptreadmill and pedal types of StairMaster.

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APPENDIX A

INFORMED CONSENT

INFORMED CONSENT
FOR STAIRMASTER STUDY

I, _________________ , volunteer to be a subject in a study to determine what effect hand support has on various physiological parameters (VO_2, heart rate, etc.) during exercise on the StairMaster Gauntlet, which is a steptreadmill ergometer. I understand that participation in this study requires that I complete two maximal VO_2 tests on the StairMaster Gauntlet, one test without the use of handsupport and the other with hand support. The time span between the two tests will be four to eight days.

Prior to the actual tests, I will be required to attend two practice sessions in an attempt to familiarize myself with StairMaster exercise. When I am able to demonstrate competency in StairMaster exercise, the practice sessions will be terminated. I also understand that these practice sessions will be scheduled at my convenience.

The StairMaster maximal VO_2 tests will consist of an initial warm-up for five minutes at a relatively low climbing speed. Four stages will follow the warm-up. Each stage, consisting of four minutes, will increase in climbing speed. The test will last approximately 30 minutes. During the test my exhaled air will be collected and heart rate monitored. I understand that I can stop the test at any time. I also understand that there exists the possibility that adverse changes (extreme shortness of breath, chest pain, dizziness) may occur during the tests. If any abnormal situations arise, the test will be immediately terminated.

I consider myself in good health and do not have any physically limited condition or disability, especially in regard to my cardiorespiratory system, that would preclude my participation in the study.

I have read the foregoing and completely understand what is expected of me. Any questions that may have occurred to me have been answered to my complete satisfaction. I have been fully advised of the nature of the study and the possible risks which may be involved. I, therefore, voluntarily consent to participate as a subject in the study. I also may withdraw from the study at any time.

Signed:________________________________ Date:___________

Witnessed:_____________________________ Date:___________

APPENDIX B

RAW DATA

Table 7. Handrail assisted relative VO_2 values for all subjects

Subject	8 METs	11 METS	14 METs	17 METs
01	28.3	37.0	48.0	59.2
02	30.0	38.2	46.9	54.1
03	27.5	37.1	49.5	57.9
04	29.4	36.8	47.8	58.6
05	26.6	35.4	42.9	55.3
06	26.0	34.8	45.0	54.1
07	27.4	36.2	47.0	58.4
08	26.7	36.8	48.3	59.0
09	27.1	35.0	44.7	56.7
10	27.0	35.7	45.2	53.5
11	28.4	38.2	48.0	59.0
12	28.6	37.4	45.9	
13	27.6	37.1	47.1	56.7
14	27.9	36.8	46.0	
15	29.9	39.2	49.7	
16	29.0	40.8	46.9	60.0
17	27.8	35.9	46.8	
18	28.0	38.2	47.4	59.3
19	28.4	36.2	44.7	
20	29.0	37.0	46.0	54.9

Table 8. Nonhandrail assisted relative VO_2 values for all subjects

Subject	8 METs	11 METS	14 METs	17 METs
01	27.8	37.4	48.0	62.1
02	28.9	37.2	48.1	53.1
03	28.5	38.0	49.0	62.3
04	33.1	40.7	50.7	64.3
05	29.3	39.3	50.1	63.7
06	27.2	37.0	46.2	57.8
07	28.2	37.9	49.5	58.6
08	29.1	38.9	49.8	60.5
09	27.8	37.3	48.2	60.5
10	29.6	37.8	49.2	60.3
11	28.4	37.7	48.1	61.9
12	29.5	38.6	49.2	
13	29.7	40.0	53.0	64.0
14	28.0	36.3	47.6	
15	29.4	39.6	51.8	
16	30.8	40.4	50.9	63.4
17	30.5	37.3	51.1	
18	28.5	36.7	48.1	59.5
19	29.0	37.3	48.0	
20	30.9	41.3	50.7	63.2

Table 9. Handrail assisted absolute VO_2 values for all subjects

Subject	8 METs	11 METS	14 METs	17 METs
01	2.223	2.906	3.765	4.646
02	2.422	3.082	3.785	4.170
03	1.581	2.140	2.852	3.335
04	2.095	2.620	3.405	4.174
05	2.072	2.778	3.595	4.320
06	2.582	3.418	4.438	5.513
07	2.529	3.489	4.582	5.592
08	2.114	2.810	3.405	4.391
09	1.966	2.537	3.244	4.112
10	2.080	2.755	3.482	4.129
11	1.865	2.511	3.154	3.881
12	2.299	3.004	3.687	
13	2.451	3.299	4.190	5.038
14	2.919	3.855	4.823	
15	2.086	2.740	3.470	
16	1.980	2.889	3.317	4.246
17	2.911	3.761	4.906	
18	1.754	2.390	2.964	3.714
19	2.034	2.594	3.203	
20	2.037	2.602	3.235	3.859

Table 10. Nonhandrail assisted absolute VO_2 values for all subjects

Subject	8 METs	11 METS	14 METs	17 METs
01	2.182	2.937	3.765	4.871
02	2.310	3.003	3.882	4.285
03	1.641	2.191	2.823	3.588
04	2.359	2.895	3.613	4.581
05	2.160	2.934	3.670	4.587
06	2.674	3.589	4.696	5.551
07	2.744	3.672	4.695	5.705
08	2.338	3.133	3.999	5.301
09	2.007	2.690	3.473	4.366
10	2.267	2.900	3.769	4.625
11	1.870	2.477	3.160	4.072
12	2.299	3.004	3.687	
13	2.561	3.450	4.566	5.516
14	2.892	3.749	4.921	
15	2.025	2.730	3.576	
16	2.194	2.873	3.626	4.513
17	3.196	3.912	5.357	
18	1.784	2.296	3.008	3.723
19	2.107	2.709	3.485	
20	2.129	2.845	3.495	4.355

Table 11. Handrail assisted V_E values for all subjects

Subject	8 METs	11 METS	14 METs	17 METs
01	51.0	66.0	89.2	129.6
02	49.2	68.7	103.7	127.0
03	37.9	50.3	67.6	86.1
04	45.3	62.6	88.9	138.4
05	43.2	54.6	67.5	88.8
06	47.8	65.3	90.3	124.8
07	63.5	84.9	124.7	195.6
08	57.7	77.8	111.4	167.4
09	39.5	49.8	64.6	83.5
10	44.0	65.9	94.3	139.4
11	39.2	55.9	90.8	130.4
12	43.8	61.5	90.0	
13	56.3	71.5	97.3	131.9
14	62.1	89.2	109.7	
15	46.4	67.6	102.1	
16	55.1	93.1	98.1	163.1
17	65.0	97.9	156.4	
18	37.3	48.4	64.5	96.3
19	45.5	61.9	89.8	
20	48.3	63.1	85.7	113.4

Table 12. Nonhandrail assisted V_E values for all subjects

Subject	8 METs	11 METS	14 METs	17 METs
01	47.4	62.2	93.3	141.8
02	46.8	65.7	100.2	125.8
03	38.9	49.2	66.2	93.4
04	54.2	68.9	106.7	169.5
05	44.9	59.4	79.2	114.4
06	47.5	67.4	99.1	144.6
07	64.8	96.4	147.4	198.5
08	61.1	85.4	123.8	181.4
09	44.4	55.6	76.1	117.1
10	47.4	66.7	100.6	159.8
11	41.9	55.6	90.9	147.6
12	49.6	71.1	108.6	
13	57.1	78.1	117.0	177.9
14	61.5	98.3	150.8	
15	45.1	65.1	105.0	
16	66.6	88.4	124.8	179.2
17	78.1	107.7	210.3	
18	40.5	50.1	72.7	99.2
19	45.5	62.5	98.5	
20	46.2	64.8	88.4	145.6

Table 13. Handrail assisted MET values for all subjects

Subject	8 METs	11 METS	14 METs	17 METs
01	8.10	10.58	13.71	16.92
02	8.57	10.91	13.40	14.76
03	7.84	10.61	13.56	16.54
04	8.41	10.52	13.67	16.75
05	7.61	10.12	12.26	15.81
06	7.42	9.94	12.87	15.46
07	7.82	10.35	13.44	16.70
08	7.62	10.32	13.81	16.86
09	7.74	9.99	12.77	16.19
10	7.71	10.21	12.90	15.30
11	8.10	10.91	13.70	16.86
12	8.18	10.69	13.12	
13	7.88	10.60	13.47	16.19
14	7.96	10.51	13.15	
15	8.54	11.21	14.19	15.18
16	8.00	11.67	13.40	17.15
17	7.94	10.26	13.38	
18	8.01	10.91	13.53	16.95
19	8.11	10.34	12.77	
20	8.28	10.58	13.15	15.68

Table 14. Nonhandrail assisted MET values for all subjects

Subject	8 METs	11 METS	14 METs	17 METs
01	7.95	10.69	13.71	17.74
02	8.18	10.63	13.74	15.17
03	8.14	10.87	14.00	17.80
04	9.47	11.62	14.50	18.38
05	8.37	11.21	14.31	18.21
06	7.78	10.56	13.21	16.51
07	8.06	10.82	14.16	16.75
08	8.31	11.12	14.22	17.28
09	7.95	10.66	13.16	17.30
10	8.45	10.81	14.05	17.24
11	8.13	10.76	13.73	17.69
12	8.43	11.02	14.05	
13	8.49	11.44	15.14	18.29
14	7.99	10.36	13.60	
15	8.39	11.32	14.80	
16	8.80	11.53	14.55	18.11
17	8.72	10.67	14.61	
18	8.14	10.48	13.73	17.00
19	8.30	10.67	13.72	
20	8.81	11.79	14.49	18.05

Table 15. Handrail assisted R values for all subjects

Subject	8 METs	11 METS	14 METs	17 METs
01	.91	.91	.97	1.05
02	.84	.90	1.05	1.01
03	.84	.85	.87	.96
04	.80	.86	.93	1.06
05	.84	.85	.87	.90
06	.90	.92	.97	1.07
07	.85	.89	.97	1.07
08	.83	.84	.87	.94
09	.87	.89	.92	.98
10	.91	.97	1.06	1.08
11	.84	.89	1.02	1.06
12	.79	.84	.95	
13	.86	.90	.93	1.03
14	.84	.91	.95	
15	.87	.94	1.02	
16	.88	.97	.98	1.06
17	.85	.97	1.05	
18	.82	.84	.87	.95
19	.88	.97	1.04	
20	.86	.88	.94	1.00

Table 16. Nonhandrail assisted R values for all subjects

Subject	8 METs	11 METS	14 METs	17 METs
01	.86	.89	.97	1.08
02	.87	.92	1.04	1.06
03	.80	.81	.85	.94
04	.79	.85	.99	1.11
05	.78	.82	.87	.98
06	.84	.91	1.01	1.08
07	.87	.92	1.02	1.07
08	.78	.83	.89	.98
09	.90	.90	.93	1.01
10	.86	.92	1.04	1.10
11	.87	.91	1.01	1.08
12	.86	.94	1.05	
13	.84	.89	.94	1.03
14	.84	.95	1.07	
15	.82	.88	.89	
16	.98	.94	1.01	1.10
17	.84	.95	1.10	
18	.83	.84	.92	1.01
19	.89	.97	1.09	
20	.81	.85	.91	1.03

Table 17. Handrail assisted kcal values for all subjects

Subject	8 METs	11 METS	14 METs	17 METs
01	11.00	14.37	18.86	23.72
02	11.80	15.20	19.30	21.08
03	7.70	10.44	13.45	16.69
04	10.10	12.83	16.93	21.36
05	10.31	13.70	16.69	21.66
06	10.23	13.78	18.02	22.12
07	12.62	16.83	22.23	28.28
08	12.29	16.98	22.48	27.87
09	9.64	12.50	16.09	20.68
10	10.29	13.81	17.79	21.20
11	9.07	12.36	15.98	19.86
12	11.08	14.64	18.42	
13	11.98	16.27	20.83	25.62
14	14.23	19.05	24.09	
15	10.23	13.64	17.59	
16	9.74	14.49	16.66	21.70
17	14.21	18.85	25.05	
18	8.49	11.63	14.54	18.54
19	10.00	12.99	16.29	
20	9.97	12.79	16.12	19.47

Table 18. Nonhandrail assisted kcal values for all subjects

Subject	8 METs	11 METS	14 METs	17 METs
01	10.66	14.46	18.89	25.00
02	11.32	14.89	19.78	21.90
03	7.92	10.59	13.77	17.89
04	11.35	14.14	18.21	23.65
05	11.24	15.17	19.60	25.57
06	10.53	14.51	18.58	23.57
07	13.10	17.80	23.78	28.21
08	13.19	17.85	23.12	28.67
09	9.91	13.27	17.24	22.10
10	11.10	14.38	19.17	23.86
11	9.17	12.26	15.99	20.89
12	11.64	15.50	20.24	
13	12.46	17.00	22.76	28.01
14	14.08	18.70	25.20	
15	9.83	13.42	17.98	
16	11.02	14.31	18.36	23.29
17	15.56	19.54	27.64	
18	8.66	11.18	14.91	18.85
19	10.37	13.57	17.94	
20	10.28	13.88	17.29	22.15

Table 19. Handrail assisted HR values for all subjects

Subject	8 METs	11 METS	14 METs	17 METs
01	120	138	168	180
02	137	163	191	203
03	107	127	156	171
04	109	129	162	181
05	106	118	130	149
06	119	144	168	192
07	120	146	164	179
08	119	140	168	188
09	103	122	147	173
10	140	168	179	188
11	117	143	166	178
12	137	164	185	
13	106	133	159	176
14	160	179	192	
15	150	169	184	
16	114	136	165	184
17	144	159	182	
18	137	158	178	191
19	132	154	175	
20	120	137	160	175

Table 20. Nonhandrail assisted HR values for all subjects

Subject	8 METs	11 METS	14 METs	17 METs
01	112	134	160	179
02	146	171	196	208
03	105	127	152	171
04	109	133	163	187
05	110	125	144	163
06	124	150	187	205
07	112	142	168	180
08	123	140	170	188
09	101	116	141	166
10	147	166	180	185
11	113	136	163	182
12	149	180	193	
13	120	145	167	186
14	157	173	193	
15	139	167	183	
16	139	155	180	193
17	134	155	189	
18	118	137	171	190
19	145	165	180	
20	121	147	168	189

Table 21. Handrail assisted RPE values for all subjects

Subject	8 METs	11 METS	14 METs	17 METs
01	12	14	16	18
02	10	12	15	18
03	9	11	13	16
04	9	9	12	16
05	9	10	12	15
06	9	12	13	16
07	12	14	15	17
08	8	12	13	15
09	8	10	12	14
10	8	13	15	18
11	6	6	6	9
12	10	12	15	
13	7	11	14	17
14	10	12	16	
15	9	12	15	
16	11	12	15	17
17	11	15	17	
18	9	10	13	15
19	13	16	18	
20	7	9	13	16

Table 22. Nonhandrail assisted RPE values for all subjects

Subject	8 METs	11 METS	14 METs	17 METs
01	11	13	15	19
02	9	13	15	19
03	9	10	13	16
04	9	12	12	18
05	9	11	13	17
06	9	12	15	19
07	12	14	16	19
08	10	12	14	16
09	8	10	13	14
10	9	12	15	18
11	6	6	7	13
12	10	12	15	
13	10	12	15	19
14	11	13	17	
15	12	15	17	
16	11	12	15	19
17	12	15	19	
18	7	11	13	15
19	12	14	18	
20	8	12	14	17

Table 23. Subject characteristics

Subject	Age	Height (cm)	Weight (kg)
01	24	180.3	78.3
02	24	180.3	80.5
03	28	167.6	57.5
04	24	175.3	71.0
05	24	177.8	79.6
06	26	172.7	79.2
07	24	200.7	94.1
08	23	191.0	94.1
09	22	172.7	71.9
10	22	182.9	76.5
11	30	175.3	65.6
12	22	175.3	80.1
13	23	195.6	88.7
14	28	182.9	103.2
15	25	170.2	69.7
16	24	165.1	71.0
17	31	185.4	104.5
18	23	167.6	62.4
19	22	167.6	71.5
20	25	180.3	68.8