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THE PHYSIOLOGICAL IMPACT OF ADDED UPPER-BODY MASS ON ROWING ERGOMETRY DURING INCREMENTED WORK LOADS

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By

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ABSTRACT

THE PHYSIOLOGICAL IMPACT OF ADDED UPPER-BODY MASS ON ROWING ERGOMETRY DURING INCREMENTED WORK LOADS

By

Keith C. Burley

The purpose of this study was to examine the steady-state effects of added upper-body mass on heart rate (HR) and oxygen consumption ($\dot{V}O_2$) while rowing on a rowing ergometer at three different intensities. Sixteen active subjects, 11 male 5 female, volunteered to perform three series of 6-minute intervals with and without a weighted vest condition containing 10% of the subject's body mass. At least 24 hours after the first mass condition, subjects performed the second set of three 6-minute intervals in the other weighted condition. Each interval was performed at 40, 55, and 70% of the subject's peak power obtained from a peak oxygen consumption assessment. Both the interval intensity and the mass condition were chosen at random. The results indicated no significant difference ($p<0.05$) between the weighted and the non-weighted condition for either HR or $\dot{V}O_2$ within each intensity level. The three intensity levels proved to be statistically dissimilar from each other according to both HR and $\dot{V}O_2$, increasing significantly ($p<0.05$) as workload increased. When gender was employed as a covariate, there was a significant difference between the mass conditions which indicates that the physiological impact of added upper-body mass during steady-state rowing may be gender specific. Future studies should focus on a kinematic interpretation of the effects of added mass and the differences observed with gender.

DEDICATION

This thesis is dedicated to Dianne and Gordon Burley, my two loving and very supportive parents who are best role models in the world.

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The author wishes to thank his thesis director, Dr. Randall Jensen for his support, inspiration, statistical knowhow, and most of all time; Dr. Phillip Watts for his insight and guidance; and Dr. Daryl Davis for his practical application suggestions and interpretations; Scott Burley & Jody Tervo for their assistance with data collection and subject recruitment; and all of the subjects who were willing to donate three hours of their precious summer hours to help me with my project. Without the help of these and others, this project could not have been completed.

This thesis follows the format of the manuscript submission to *The Journal of Strength and Conditioning Research*. (http://www.nsca-jscr.org/pt/re/jscr/authorinfo.htm)

PREFACE

The rowing ergometer used in this study was donated to the H.P.E.R. dept. by Mr. Daniel A. Kane, who applied his Excellence in Education grant funded by Northern Michigan University towards the most up-to-date Concept II indoor rowing machine. The cost of the research covered in this project including the weighted vest has been underwritten by Northern Michigan University via the Excellence in Education Award awarded to me during the summer of data collection. The results of this study do not constitute endorsement of any of the products used by the author or Northern Michigan University.

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SYMBOLS AND ABBREVATIONS

RE = Rowing Ergometer

VO2 = Oxygen consumption, $ml \cdot kg^{-1} \cdot min^{-1}$

HR = Heart rate, beats/min

BPM = Beats per minute

W = Watts

y = years of age

n = Sample size

r = Correlation coefficient

ReANOVA = Repeated measures analysis of variance

ReANCOVA = Repeated measures analysis of covariance

CHAPTER I: MANUSCRIPT

The Physiological Impact of Added Upper-Body Mass on Rowing Ergometry During Incremented Work Loads

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The Physiological Impact of Added Upper-Body Mass on Rowing Ergometry During Incremented Work Loads

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INTRODUCTION

The use of added upper body mass to increase the training workload of an athlete is by no means an innovation or a leap forward in theory. Although many sports, such as track, jogging, and football have adopted this unique and well-known training tool (6), it is relatively new territory for the sport of rowing and its substituent training platform, rowing ergometry.

Rowing, a sport usually performed on water, has been traditionally simulated using a dry-land simulator known as a rowing ergometer (RE). Many rowing clubs/teams, employ such a tool to facilitate training when on-water rowing is either not available (not enough members to fill a boat) or when the water condition is unfavorable. Due to the practical training purposes of the RE, many prior studies involving rowing have been conducted using this dry-land rowing trainer (3, 7, 24).

Rowing ergometers have been shown to adequately simulate the kinematics of a row stroke, especially in relation to the legs and trunk (21). Although Lamb et al. (21) did show slight variance of movement analysis in regard to the upper arm motion during the beginning and end of the drive phase, it was said to be "of minor importance because of the small contributions made by the arms at the catch (p.128)." Due to the similarities observed, an RE is easily ranked the number one tool used to study rowing indirectly and as such can be used to manipulate variables such as added mass (24).

With the increasing popularity, coaches and athletes are interested in workout designs with potential for improving the quality of training. One such design is the use of added body mass during rowing ergometry.

Research conducted by Mullis et al. (24) appears promising, showing that added upper body mass in the form of an attached backpack, weighing 10 % of the subject's body-mass, increases both heart rate (HR) and oxygen consumption ($\dot{V}O_2$) significantly as compared to a un-weighted control condition. However, because Mullis et al. did not utilize experienced rowers, the ability to determine the impact of added upper body mass could be compromised. In addition, the study used a subjective measure of work-rate, ratings of perceived exertion (RPE), and examined rowers at only one measure of this work rate.

The current project attempted to address the issues concerning the implementation a quantitative measurement for work-rate; that being a percentage of maximum power output during a peak $\dot{V}O_2$ test. This project additionally manipulated the work-rate at three distinct percentages of maximum power output while employing a weighted vest as the mass manipulation tool.

METHODS

Experimental Approach to the problem

Our hypothesis was that added upper body mass would increase the amount of internal work performed as indicated by changes in $\dot{V}O_2$ and HR. In order to determine the validity of our hypothesis, rowers of varied skill levels were employed to maintain a given workload during two treatment conditions. The two conditions included rowing ergometer work with and without added mass equivalent to 10% of the subject's body mass, separated by at least 24 hours. The added upper-body mass was simulated through use of a weighted vest (Ironwear short Uni-vest max-system, Pittsburgh Pennsylvania) containing a flexible mass called "flex-metal," allowing a form fitting natural feeling during dynamic movements such as rowing.

During the first testing day, the subjects arrived at the laboratory to have their anthropometric measurements assessed. Following initial measurements, peak $\dot{V}O_2$ was estimated on a RE which allowed for a calculation of their maximum power output to be graded on three intensity levels. During the next two testing days, the subjects rowed on a RE at the three randomized intensity levels, with or without the weighted vest (also randomized) to allow for comparison between the two conditions. Each rowing bout was six minutes in duration to attain steady state aerobic conditions (16). During the last two minutes of each rowing bout, HR and $\dot{V}O_2$ were measured in order to determine whether there was a difference while wearing the weighted vest as compared to not wearing the weighted vest. To allow for testing at another percentage of the subject's peak power during the same session, there were eight minutes of recovery following each interval to allow for a depression of their physiological parameters tested to their respective base line measurements. Prior to testing/data collection, the recovery was tested for validity during piloted testing where observation included both a drop in HR and $\dot{V}O_2$ to their respective baseline measurements within 6-8 minutes. Recovery was implemented via three minutes of active recovery through use of the rowing RE followed immediately by five minutes of passive recovery.

Subjects

The study examined 16 active university students (11 males, 5 females) who volunteered to participate in this study and did not receive any payment or compensation for their involvement in the study. Prior to all testing, the study was approved by the Human Subjects Research Review Committee of the university (Appendix B) and all subject signed an informed consent form along with a Physical Activity Readiness Questionnaire (8). The consent form presented details of the study and outlined any possible risks and/or benefits to them associated with the study. Demographic data were also recorded for each subject including age, height, mass, and experience level (Table 1).

Procedures

The first testing session consisted of an orientation session which included a formal introduction to the research study along with a presentation on safety issues involving the equipment. Peak $\dot{V}O_2$ was then assessed using a graded exercise test on a Concept II rowing ergometer (Concept II Inc., Morrisville, Vermont). Each subject was instructed to row at 75 watts for one minute and then to increase their power output 25 watts each additional minute (27, 29). Termination of the test was determined when the subject could not maintain the specific power output for three consecutive strokes. The power output at the termination of the test was considered the peak and was then used to calculate the three graded power output intensities at incremented work loads of 40, 55, and 70 percent of their peak.

Oxygen consumption was measured using a sterile mouth piece connected to a SensorMedics VMax29c (VIASYS Heathcare Inc., Yorba Linda, CA USA) breath-by-breath metabolic analysis system. Calibration of the VMax29c occurred prior to all collection assessments, where the mass flow sensor was calibrated with a three liter syringe and the VMaxc29c was calibrated with three distinct gas concentrations according to manufacturer's instructions.

Along with the air analysis system, a Polar HR monitor (Vintage XL., Polar Electro Inc., Finland) was utilized to measure HR throughout the testing procedure. Heart rate measures were recorded 20-seconds before the next stage of the graded exercise test.

During testing session two, the subjects performed three rowing ergometry trials in one of two upper-body mass conditions chosen randomly upon arrival (Table 2). To manipulate each subject's upper-body mass, the subjects were suited with a weighted vest containing: [1] 10% of the subject's body mass, or [2] no added mass. Each trial consisted of a six-minute rowing bout to obtain a steady-state aerobic rowing condition followed by a cool down recovery period, consisting of a three-minute active recovery on the RE at <35% maximum power output followed immediately by five minutes of passive recovery. During each trial, one of the three predetermined work-rates was applied in a randomized fashion. Subjects maintained the assigned specific work rate by using visual feedback of their power output from the Concept II PM3 Performance Monitor. The Concept II PM3 Performance Monitor was used to acquire the average power output through the entire event and researchers qualitatively observed that all subjects maintained the work-rate within 15 Watts to the requested intensity.

Through use of a paired t-tests it was determined that the vest and non-vest condition workloads were not significantly ($p>0.05$) different from each other within each intensity level. The lack of difference between the vest and non-vest conditions signified that both conditions were at approximately the same intensity level during each treatment, allowing power output to be held as a constant variable that reflects similar demands between the two conditions.

The PM3 Performance Monitor was also used to compile power output data during the row using the interval power average over the entire 6-minute interval. During the last two minutes of each interval, $\dot{V}O_2$, and HR data were collected in one-minute averages and then averaged over the two minutes for future analysis and interpretation. Table 2 represents dependent variables collected during each interval.

Statistical Analyses

Means and standard deviations were calculated for each dependent variable. Both HR & $\dot{V}O_2$ measures were tested using a 2 X 3 (vest X work rate) repeated measures analysis of variance (ReANOVA) to determine possible significant differences between the treatment conditions. All data were tested for significance with an alpha set *a priori* at the 0.05 level. A Bonferoni *post hoc* test was used if significant mean differences were observed. Statistical analyses were performed on SPSS for Windows statistical package (SPSS Inc., Chicago IL), version 15.0.

RESULTS

The main finding of the current study was that neither HR nor $\dot{V}O_2$ were significantly ($p>0.05$) different between the vest and non-vest treatments within each intensity level tested as seen in Figure 1 and 2. There were no interactions found among the vest condition and the intensity levels for either HR and $\dot{V}O_2$.

HR increased significantly ($p<0.05$) across intensities, increasing uniformly with workload. HR means for the 40, 55, 75% intensity levels in the no-vest condition were 138.7±15.0, 153.1±13.9, and 165.3±13.6 respectively while the vest condition for the 40, 55, 75% intensity levels were 144.5±16.4, 157.3±14.7, and 169.2±12.8 respectively (Figure 1).

Similar trends were also found with the $\dot{V}O_2$ data where $\dot{V}O_2$ means increased significantly ($p<0.05$) with increased workload, although did not differ when comparing vest and non-vest $\dot{V}O_2$ at the same intensity. $\dot{V}O_2$ ($ml \cdot kg^{-1} \cdot min^{-1}$) means from 40, 55, and 75%, included values of 22.9±4.3, 30.2±5.5 and 35.2±6.6 for the non-vest condition respectively. The vest condition at 40, 55, and 70% had mean values of 24.0±3.9, 29.5±4.8, and 35.7±5.4 respectively (Figure 2).

Although the treatment conditions were not significantly different from each other, upon further examination of the data, it was observed that gender may have played a role in the response to the weighted condition concerning both HR and $\dot{V}O_2$. A bivariate Spearman's correlation test was used to determine if gender did correlate to the results seen in both the dependent variables tested. This was completed by taking the difference between the vest and non-vest treatment condition data and testing this difference against the ordinal variable, gender. Because a significant ($p<0.05$) relationship existed concerning both HR and $\dot{V}O_2$ it was determined that a repeated measures analysis of covariance (ReANCOVA) should be conducted holding gender as the covariate.

The ReANCOVA revealed that both HR and $\dot{V}O_2$ were significantly ($p<0.05$) different between the mass conditions at all intensities tested. HR and $\dot{V}O_2$ were found to be significantly different between intensity levels; and via a pair-wise comparison, it was determined that mean differences of both dependent variables increased as the percentage of the subject's peak power increased. There was also an interaction with gender and the mass condition verifying that using gender as a covariate was valid.

DISCUSSION

The results found in the current study contrasted with research conducted by Mullis et al. that used similar methodology with the exception of how the upper-body mass was added (24). Regarding the current study, the use of a weighted vest containing 10% of the subject's body mass did prove to have significant HR and $\dot{V}O_2$ effects as well as a gender interaction when employing gender as a covariate, a finding not previously observed in past research. In contrast, Mullis et al. found significant ($p<0.05$) differences concerning these variables when adding upper body mass in the form of a backpack with 10% of the subject's body mass and no interactions between gender and the backpack condition (24).

Although the added mass was the same, the position of the mass could be an underlying factor that differentiated these two findings. The added mass could change the flexion and extension range of motion within the rowing stroke which would change the amount of external work being done. This increased work due to the increased range of motion could potentially lead to elevation of both HR, and $\dot{V}O_2$. However, without kinematic analyses to determine if the rowing stroke was altered by the added mass, it is unclear and thus such analyses are recommended. Current military research has also found that the closer the added mass is to the subject's center of mass while walking, the lower the energy cost place upon that subject, which is an important aspect to take note when addressing the effect of different modes of adding upper-body mass (20).

When comparing the two methods of adding upper body mass to the rower, the weighted vest fully surrounded the subject's center of mass which may reduce added mass movement or any excessive torsion effects. Future studies should focus on biomechanical analyses to determine if in fact the rowing stroke is affected and/or compromised by adding upper body mass and if it would contribute to a greater amount of external work being done.

The unexpected result of gender having an influence on physiological responses to the added mass is an interesting and noteworthy finding. Mean HR responses for the males when mass was added to their upper bodies was observed as a positive trend as seen in Figure 3.A and these results closely follow the responses observed by the females although having less magnitude (Figure 3.B).

In contrast $\dot{V}O_2$ in response to added mass increased in males, however, females responded in the opposite manner as seen in Figures 4.A and 4.B respectively. This gender response, is thought to be the reason why $\dot{V}O_2$ was not significantly different when comparing the vest and non-vest conditions at different intensity levels. We found this observation very intriguing especially when considering that all of the female subjects had lower $\dot{V}O_2$ rates during the weighted vest conditions as compared to rowing treatment conditions without the vest. Thus, HR may not be an appropriate indicator of $\dot{V}O_2$ for females while rowing.

To date no gender specific responses have been found in rowing research that have indicated similar deviations from the linear HR-$\dot{V}O_2$ relationship displayed in many aerobic sports. While studying rock climbers, Watts et al. observed that HR and $\dot{V}O_2$ were not linearly related, noting that HR increased as the intensity of the climb increased without comparable increases in $\dot{V}O_2$ (35). Dunk et al. in a gender specific chair ergonomics study found that there is indeed a gender difference in how males and females sit (10). They found that female university students tend to position their center of mass anterior to the chair's pivot point while males did the opposite and shifted their center of mass in the posterior direction (10). Although the findings of Dunk et al. do not match up precisely with the sitting done with rowing, it does point out that there could be differences in regard to how males and females distribute their body mass in different positions which may effect how they carry added upper-body mass. Future studies should engage the question of gender-specific rowing techniques and the effects of added upper body mass.

Furthermore, when taking into account the deviation of the typical linear HR-$\dot{V}O_2$ relationship, other investigations are needed to determine whether there is increased sympathetic nervous system activation due to the increased movement of the upper-body. Also, HR could have also increased un-proportionately with $\dot{V}O_2$ due to decreases in stroke volume, a side effect of a decreased venous filling that could have been caused by increased intrathoracic pressure. A review by Franklin et al. points out this HR-$\dot{V}O_2$ deviation in upper-body aerobic training programs and state that exercise prescriptions chosen based on a percentage of the patients maximal HR obtained through leg testing may be inappropriately high for arm training (13).

Although the aforementioned suggested explanations are within reason, without kinematic data analysis, inferences should be approached with caution as these suggestions were deduced through speculation and not scientific findings. Future studies should focus on the kinematic differences between males and females that may take place when upper body mass is added.

PRACTICAL APPLICATIONS

Our results indicate that rowers might see a benefit in terms of an overload effect for training when using a weighted vest while rowing on an indoor RE. Although, it could be speculated that females may see less of an effect than males when added mass is used to increase the internal work being done physiologically at a given power output. Furthermore, some subjects reported a feeling of "overheating" as well as a limited range of motion while wearing the weighted vest although this is to be expected with such a close-fitting garment. Therefore, the use of a weighted vest may be more of a personal decision in the rower's quest to implement a greater overload beyond just increasing rowing rate.

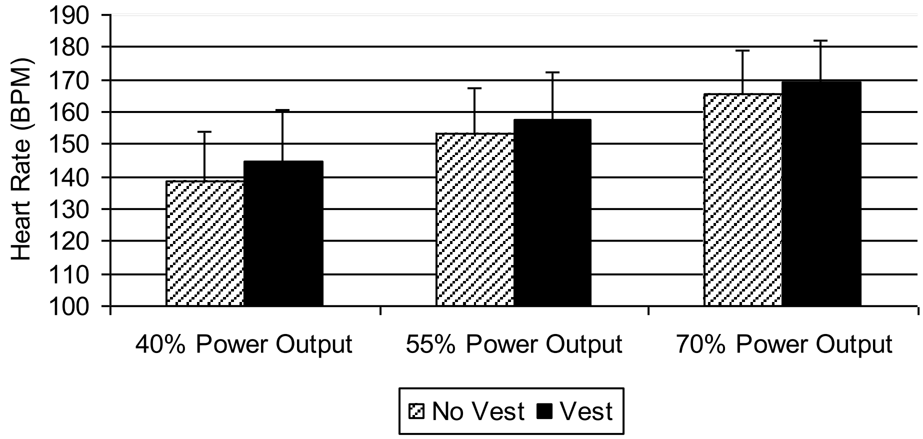

Figure 1. Rowing heart rate response comparison between the vest condition and the non-vest condition at three graded intensity levels.

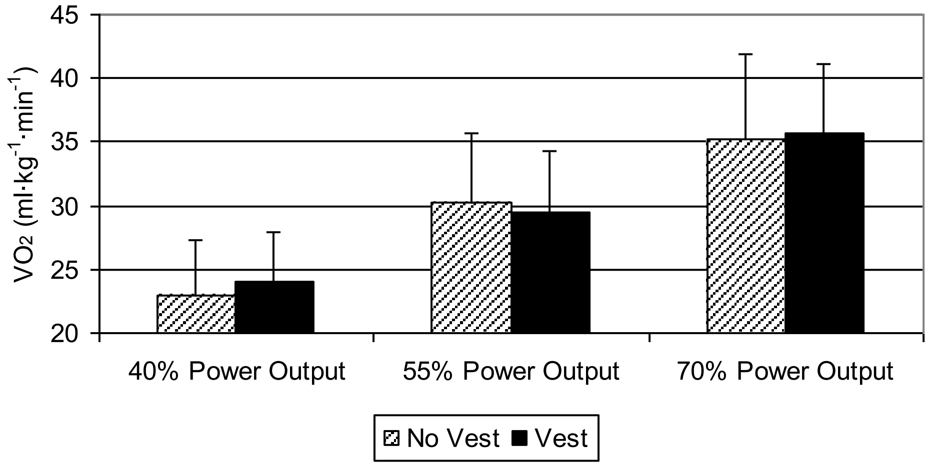

Figure 2. Rowing oxygen consumption response comparison between the vest condition and the non-vest condition at three graded intensity levels.

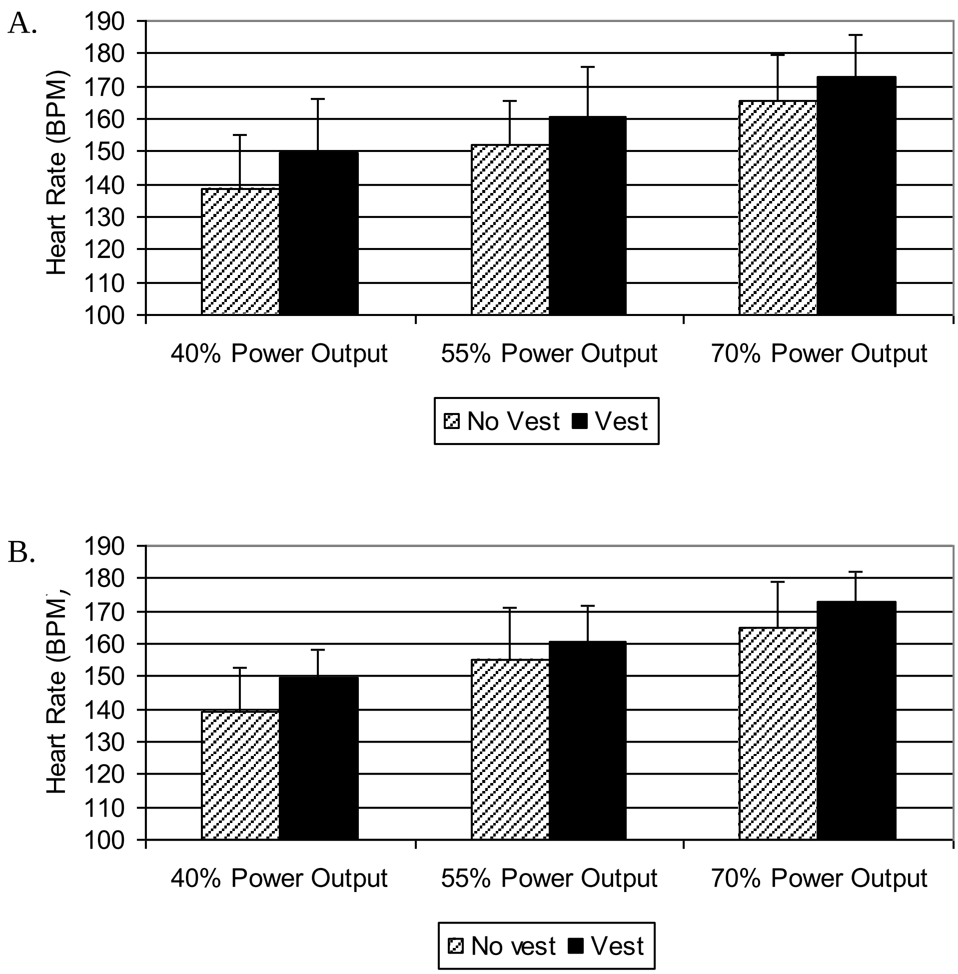

Figure 3. Male (A) and Female (B) rowing heart rate response comparison between the vest condition and the non-vest condition at three graded intensity levels.

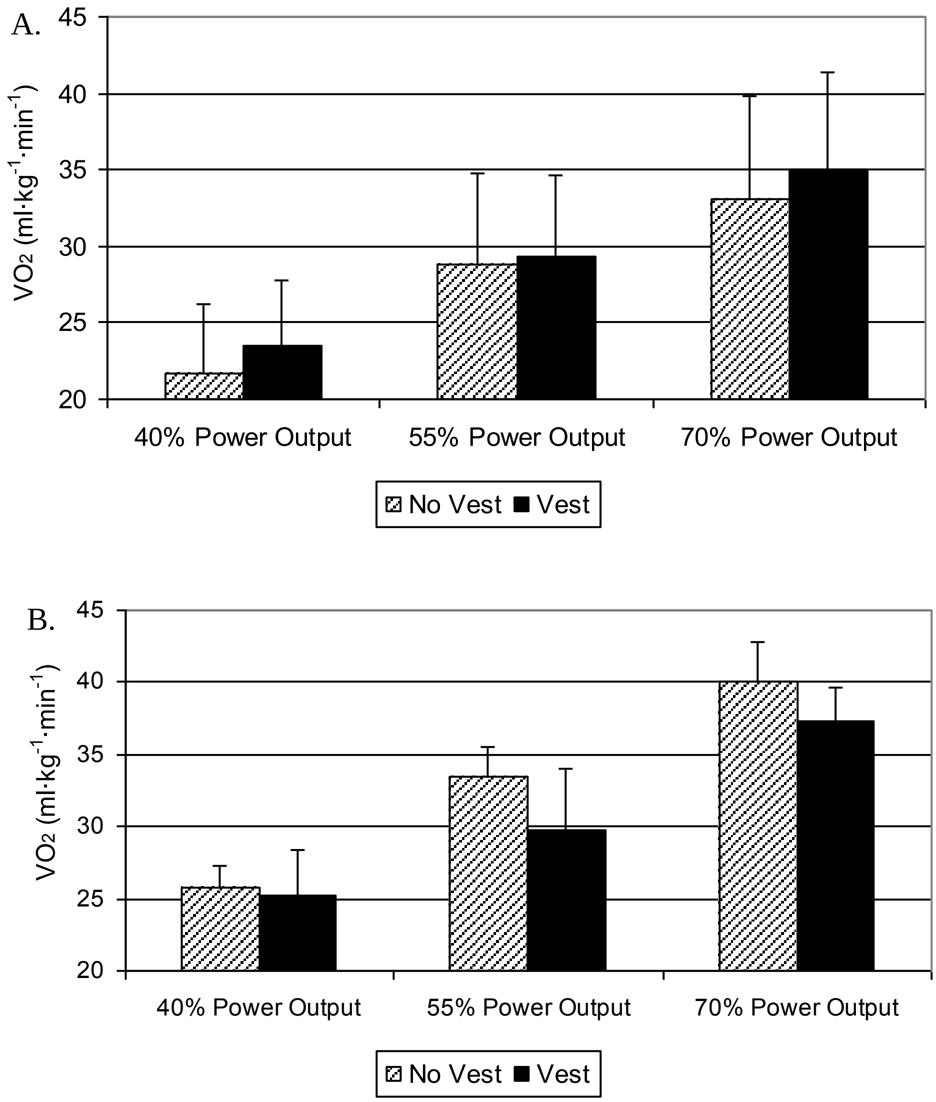

Figure 4. Male (A) and Female (B) rowing oxygen consumption response comparison between the vest condition and the non-vest condition at three graded intensity levels.

Table 1. Mean ± SD for Subject Descriptive Characteristics.

	Males (n=11)	Females (n=5)
Age (y)	24.6 ± 2.5	23.4 ± 2.6
Mass (kg)	76.8 ± 8.4	63.2 ± 3.7
Height (cm)	171.9 ± 4.7	166.4 ± 7.3
BMI (kg/m^2)	26.03 ± 3.14	22.9 ± 1.6
Peak Power (W)	224.3 ± 39.4	199.4 ± 12.0

Table 2: Sample Protocol for Subject x with the Two Conditions Randomized

	CONTROL			10% of BW Added		
	40%	55%	70%	40%	55%	70%
Subject_x	HR, VO2, Avg-Power	HR, VO2, Avg-Power	HR, VO2, Avg-Power	HR, VO2, Avg-Power	HR, VO2, Avg-Power	HR, VO2, Avg-Power

CHAPTER II: LITERATURE REVIEW

Rowing is a whole-body sport that recruits a large portion of the rower's skeletal muscle for event durations of six to eight minutes, covering approximately 2000 meters within each event (31). It has been estimated that a successful rower, during a 2000 meter race, will row in a cyclic repetitive motion approximately 220 to 240 times while evoking a huge aerobic response from the estimated 70-85% of slow-twitch fibers along with fast-twitch fibers possessing increased oxidative enzyme activity (30, 33). Forces generated during each stroke have been shown to be highest during relatively low velocities of 0.3 to 0.4 meters/second which answers why more successful rowers train 70-90% at intensities below their lactic acid threshold (30, 33). Carey et al. has shown that the use of a dry-land rowing trainer (rowing ergometer) elicits a greater $\dot{V}O_2$ response during maximal work as compared to treadmill running with a mean $\dot{V}O_2max$ of 5.32 L/min ± 0.11 in trained university club rower's (5). Furthermore, di Prampero et al. even go as far as to say that absolute rowing power is certainly higher in rowers as compared to athletes performing other aerobic exercises. (9)

Although rowing has been shown to be heavily correlated to $\dot{V}O_2max$ and maximum power output (1), researchers such as Yoshiga et al. (36) have found rowing performance to be correlated with both body mass and body height. This study suggests that individuals with larger body sizes and aerobic power enjoy a somewhat advantage during a 2000m rowing bout (36).

Rowing Ergometry

The highly technical rowing stroke is a combination of both timely force production and aerobic power (21). Due to the aerobic component of rowing, training requires a significant amount of sport-specific training hours which presents logistical issues concerning water, climate, boat, and crew member circumstances. To avoid these issues, a dry-land trainer known as a rowing ergometer (RE) is used by most crew clubs as a training, and assessment tool. The attractiveness of this rowing alternative has led many rowing investigators to study rowing via an RE as well as contrast it with on-water rowing. The RE has been shown to possess the same kinematic variables throughout the drive phase as compared to on-water rowing, especially when examining the trunk and lower body (21). Lamb et al. did, however, find differences between upper arm and forearm kinetics attributed to minor contributions made by the arms at the catch and suggested this is of minor importance to researchers. Their findings using vector loop analysis also provided important information regarding significant trunk contributions made during the drive phase, being a greater contributor as compared to legs in both the on-water and RE conditions.

It has also been shown that interconversion of segmental energy pertaining to both the on-water and RE conditions was not significantly different, decreasing the difference between the two forms of rowing further (23). In support of these findings, the use of an RE would be a suitable on-water rowing simulator and likely result in relatively similar physiological responses.

Power Responses During Rowing Ergometery

The power measurement option found on many REs manufactured today has become a valid and practical training tool to help modulate the athlete's intensity levels during rowing. Concept II rowing ergometers have been shown to produce reliable intra-sample power measurements although, Boyas et al. have demonstrated that its estimates are consistently underestimated by approximately 25 watts when compared to the measurements provided by mechanical sensors (4). This underestimation was found to be independent of power production, yet dependant on changes in intensity and pace.

According to Sprague et al., maximum power output of collegiate varsity crew members tested was found to be at a rate of 40 strokes/min, which is similar to that of Olympic rowers during competition (36-41 strokes/min) (32). Sprague et al. utilized a six-stroke maximum power output assessment initiated by a verbal command (32) which according to Hartmann et al. will allow the rower enough strokes to attain peak power output (18). Hartmann et al. also showed that peak power may be obtained during strokes four through six of both a five and ten stroke maximum power output assessment (18).

During a six-minute maximal RE test (6MMT), it has been shown that peak force decreases significantly by the fifth stroke accounting for a 30% drop in total force (18). Peak velocity during a 6MMT has shown the opposite effect, with lower initial stroke forces followed by an exponential increase to maximum by the fifth stroke. After 12 seconds of a 6MMT, peak force, velocity and also power have a steady decrease. Peak velocity and peak power were both in the range of 84-90% of their measured maximums followed by a curvilinear decline through the remaining six minutes. It was estimated that average power output was reduced to approximately 62% of maximum after the 2nd

minute of the 6MMT followed by values of 59% after the 5th and 6th minute (18). This data highlights the decreased power output range during a typical six to eight minute 2000m rowing event.

Peak power has been seen by many rowing scientists as one of the key performance determinants for a 2000m rowing bout on a RE (1, 19, 14) along with $\dot{V}O_2$ max (7, 28). It should be noted, however, that although sports such as rowing, running and cycling are similarly influenced by movement efficiency and $\dot{V}O_2$max and the predictive values for both running and cycling are relative to performances sustained below the power output seen at $\dot{V}O_2$max. In contrast, Bourdin et al. found that RE work elicits power outputs of 13% higher than power output observed at the rower's maximal aerobic capacity (1).

Maximum Oxygen Consumption /Aerobic Power

Maximum oxygen consumption ($\dot{V}O_2$max) is defined as the ability to uptake and utilize oxygen at a specific maximal rate. Therefore, $\dot{V}O_2$max is the single best indicator of cardiovascular fitness, which is limited by the cardiorespiratory system's ability to obtain and deliver oxygen to working muscles (1). $\dot{V}O_2$max increases observed as a result of training are attributed to the increases of maximal cardiac output, especially the stroke volume component (1).

Athletes, while rowing on an RE, have been shown to have much higher $\dot{V}O_2$max values as compared to the standard treadmill running protocol to obtain $\dot{V}O_2$max (37). Yoshiga et al. attributes this common phenomenon to an activation of more skeletal muscle and the rower's body position as it affects both ventilation and venous return which results in higher $\dot{V}O_2max$ values and smaller maximum heart measurements (37).

There are many ways in which researchers have gone about obtaining $\dot{V}O_2max$ values for rowers, one of which includes increasing the work rate incrementally every minute through modification of the rower's 500m split time (7, 28). Testing would then be terminated upon exhaustion or when the subject is unable to maintain the prescribed split time during three consecutive strokes. Another method commonly used is to increase the power output, observed from the ergometer monitor, 25 watts every minute from an initial workload of 100 watts (25, 29).

Modification of Mass Applied to Rowing

Elite and serious athletes are constantly trying to find better and more efficient ways to train to get an extra edge on their competition. Sports such as running have been modified and then examined very carefully to understand how to stress the athlete's cardiovascular and musculoskeletal loads effectively. Research has shown that nearly 74% of the energy cost in running is attributed to the support of the body's mass alone (14, 34). Therefore, if one were to modulate this huge percentage of energy cost it could lead to a significant added stress on metabolism and skeletal muscle itself. Adding mass could also lead to altered locomotion biomechanics leading to even higher energy costs due to corrections and adjustments as well as increase the downward forces thereby increasing the amount of work at a given distance(11).

Adding mass to a subject may have many effects that could be utilized to increase the stress load in hopes of enhancing that particular effect. Carrying mass in the subject's hands while doing dynamic work has been shown to increase oxygen uptake, heart rate, and pulmonary ventilation linearly (2). Borghols et al. even goes further to say that increases in increments of mass would be relatively independent of the dynamic work being done. Military research has also found that the closer the added mass is to the subject's center of mass while walking, the lower the energy cost placed upon that subject, which is an important aspect to take note of especially in long-duration walking that military members do daily (9). Short-term added mass has also been shown to increase postural muscles to help stabilize body segments which could be the effects of the CNS to anticipate torsion and inertial effects during dynamic activity (22).

Cardiovascular and skeletal loads have been found to be increased during a hypergravity situation (15, 26). Groppo et al. observed that subjects under hypergravity conditions had significantly elevated oxygen consumption rates, as well as ground reaction forces in both competitive and non-competitive subjects (15).

A weighted vest is one of the most frequently used ways of modifying upper body mass and is used by countless coaches in many sports such as football and track (6,12). Its mass is close to the center of mass of the athlete allowing for a relatively uninhibited experience as far as range of motion is concerned. Coaches utilize a weighted vest to apply a greater energy demand upon the athlete as well as recruit more muscle fibers and thus increase neural activation (12). The enhanced neural activation theory has led some researchers to find dramatic speed increases along with other power assessments (12,17,25). Long-term effects of weighted vest performance are minimal at best however, some authors mention that it most likely develops maximal velocity and not maximum acceleration during running (25). Although adding mass to athletes during training has been used for decades to elicit a training overload, most of the knowledge surrounding its effectiveness during the specific sport is mostly anecdotal as there is limited research for this training tool used by many on a daily basis. It has been found, however, that the use of a weighted vest containing 2% of the athlete's body mass during a dynamic warm up activity enhances acute vertical jumping performance by almost 12% (12). Faigenbaum et al. believe this significant enhancement in high school female athletes is due to an enhancement of neuromuscular function known as postactivation potentiation (PAP). PAP appears to have the greatest effects on fast twitch muscle fibers (17) and thus is more likely to affect such power activities as jumping sprinting and throwing. Furthermore, running specific studies have shown that running with a weighted vest of approximately 7 to 13% of body mass improves vertical jumping performance as well. In addition, training with a weighted vest for running has been shown to increase "mechanical output, peak oxygen deficit, running time to exhaustion, vertical velocity when running upstairs, and oxygen consumption." (15).

Little research has been done to determine if modulating upper body mass of rowers would have any effect. Mullis et al. utilized a backpack containing a mass comprised of 10% of the subjects body mass, finding that $\dot{V}O_2$, HR, and a rating of perceived exertion increased due to the effects of the added mass (24). These physiological and psychological elevated measures could be due to a number of reasons such as an increased energy cost of inertial effects during the cyclic rowing cycles. Other possible explanations include the effects of increased activation of muscle fibers to support the load, the increased recruitment of postural muscles to stabilize body segments, and/or the energy cost required to rectify any deviations of typical rowing locomotion biomechanics.

Directions for Future Research

Studies examining the physiological effects of added upper body mass on rowing ergometry are very limited and have not addressed the effects at different work-rates. Studies such as Mullis et al. appear promising, showing that added upper body mass in the form of an attached backpack, weighing 10% of the subject's body mass, increase both heart rate and oxygen consumption significantly as compared to a controlled condition. Because Mullis et al. used a subjective measure of work rate, a modified Borg scale (RPE), and examined rowers at only one measure of this work rate these measurements could be compromised (24). Furthermore, it is possible that the use of the backpack may not adequately address the effects of a balanced and true upper-body load.

Hence, future studies should try to address the issues concerning mode of mass addition and implement a quantitative measurement for work-rate such as a percentage of maximum power output. Future studies should also try to manipulate the work rate during the added mass condition as to investigate the possibility of physiological trends and effects due to incremented intensities. Also, the use of a better mode of added mass to decrease any effects seen as added mass moves away from the center of mass, such as in the research produced by Knapik et al. (9).

CHAPTER III: CONCLUSIONS AND RECOMMENDATIONS

This investigation tested 16 Northern Michigan University students (11 male, 5 female) with a mean age of 24.6 ± 2.5 years. Students came into the laboratory on three different occasions to allow for an initial rowing assessment assessing peak power and then two additional treatment days where subjects were randomly assigned a mass condition to row with. A weighted vest containing 10% of the subject body mass was used to add upper-body mass whereas the control was rowing without the vest. Rowing was modulated with a Concept II Rowing Ergometer fitted with a PM3 monitor allowing for data acquisition and subject visual feedback concerning work-rate. Each treatment day consisted of three 6-minute intervals where subjects rowed at 40, 55, and 70% of their peak power, which was acquired during the first day. The three intervals had 8-minute recovery sessions between each consisting of 3-minutes of active recovery and then followed by 5-mintes of passive recovery. Heart rate (HR) and oxygen consumption ($\dot{V}O_2$) data were collected during the last two minutes of each interval for future analysis.

A repeated measures analysis of covariance used to test for significance between both treatment conditions as well as intensity differences. Results indicated that there was a significant ($p<0.05$) difference of both HR and $\dot{V}O_2$ between the weighted and the non-weighted treatment at all intensity levels. Results also indicated that there was an interaction between gender and the mass treatment, suggesting that males and females may react to the added upper-body mass differently. Statistical measures also indicated that HR and $\dot{V}O_2$ at the intensity levels were significantly ($p<0.05$) different from each other, increasing significantly as intensity increased.

Mullis et al. also researched the effects of added upper-body mass on the rowing ergometer and found similar result with the exception of the gender and mass treatment interaction found in the current study (24). Although similar methodology was used, Mullis et al. added upper body-mass through the use of a weighted back-pack. These contrasting results may be explained by the methods used for increasing upper-body mass as the mass in the backpack could have changed the flexion and extension range of motion aspects. To further understand why there was a gender difference, future studies should focus on kinematic analysis to compare gender and the vest condition which would allow a comparison of the differences within the rowing stroke as upper-body mass is added.

Due to HR and $\dot{V}O_2$ being the only two dependent variables analyzed, it is difficult to interpret what truly is occurring between both genders. Males with added upper-body mass expedited the hypothesized effect of an elevation of both HR and $\dot{V}O_2$. Females, on the contrary, exhibited a slight positive elevation of HR in the weighted treatment with $\dot{V}O_2$ data depressed as compared to the non-vest condition.

Without kinematic data analysis, inferences should be approached with caution as these suggestions were deduced through speculation and not scientific findings. Future studies should focus on the kinematic differences between males and females that may take place when upper body mass is added.

Overall, rowers might benefit in terms of an overload effect for training when using a weighted vest while rowing on an indoor rowing erg. Although it could be speculated that females may see less of an effect than males when added mass is used to increase the internal work being done physiologically. Additionally, due to the tight fitting vest, some rowers mentioned that they felt very hot during their row and that range of motion may be reduced. Therefore, the use of a weighted vest may be more of a personal decision in the rower's quest to implement a greater overload beyond just increasing rowing rate.

Overall, future research should be directed toward both biomechanical and physiological analysis of gender differences that occur during rowing and the supplemental effects of gender-specific adaptations to an added upper-body mass condition. Researchers should test a balanced number of males and females and used gender as an independent variable, allowing for direct comparisons. Furthermore, non-experienced and experienced rowers should be included in the sample to test for experience level effects. Kinematic analysis would allow researchers to observe how the rowing stroke is affected by added upper-body mass as well as a comparison between gender-specific differences. It is suggested that the stroke rate of the rowers be held constant to avoid any changes in momentum that may prevent adequate comparison between subjects and rowing bouts.

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APPENDIX A

HUMAN SUBJECTS INFORMED CONSENT FORM

Department Exercise Science Laboratory Services
Department of Physical Education and Recreation
Approve by HSRRC: #HS08-163

CONSENT TO ACT AS A HUMAN SUBJECT

Subject Name (print):__________________________ Date: __________

1. I hereby volunteer to participate as a subject in exercise testing. I understand that this testing is part of a study entitled: "The Physiological Impact of Added Upper-body Mass on Rowing Ergometry During Incremented Work Loads." The purpose of the study is to investigate the physiological impact surrounding a modification of upper body weight on rowers while rowing on an ergometer at a range of graded work loads.

   I hereby authorize Keith C. Burley and/or assistants as may be selected by him to perform on me the following procedures:

   (a) A VO2max test along with an assessment of maximal power output during the preliminary testing day, which is to be completed prior to the remaining two testing days.

   (b) Two days of ventilation, heart rate, and video data collection while I row for approximately 18 minutes of intermitted rowing bouts, all performed at less than or equal to 70% of maximum power output. All rowing will be completed on the Concept II Rowing Ergometer.

   (c) I understand that I will be breathing through a mask covering my nose and mouth during all testing. I also am aware that I will be suited with a backpack containing either 10% of my body weight or no weight at all.

2. The procedure outlined in paragraph 1 has been explained to me.

3. I understand that the procedures described in paragraph I (above) involve the following risks and discomforts: short-term muscle pain/soreness, elevated heart rate beyond resting levels which could lead to increased risks of high blood pressure, arrhythmia, or even a heart attack. Although I acknowledge these risks, I also understand that I may terminate the testing at any time should I deem necessary. Furthermore, I should halt any test where I experience abnormalities such as vertigo, light-headedness, and/or shortness of breath, etc.

4. I have been advised that the following benefits will be derived from my participation in this study: aside from the educational benefit of learning about aerobic testing or about my fitness level, there are no direct benefits to me.

5. I understand that Keith C. Burley and/or appropriate assistants as may be selected by him will answer any inquires that I may have at anytime concerning these procedures and/or investigations.

6. I understand that all data, concerning myself will be kept confidential and available only upon my written request. I further understand that in the event of publication, no association will be made between the reported data and myself.

7. I understand that in the event of physical injury directly resulting from participation, compensation cannot be provided.

8. I understand that I may terminate participation in this study at anytime without prejudice to future care or any possible reimbursement of expenses, compensation, or employment status.

9. I understand that if I have any further questions regarding my rights as a participant in a research project may I contact Dean Cynthia Prosen of the Human Subjects Research Review Committee of Northern Michigan University (906-227-2300). Any questions I have regarding the nature of this research project will be answered by Keith C. Burley <keburley@nmu.edu> or Randall Jensen <rajensen@nmu.edu>

Subject's Signature: ______________________________ Date: ___________

Witness: ____ Date: ___________

Appendix B: HSRRC Letter of Approval

Northern Michigan University

Continuing Education & Sponsored Programs
1401 Presque Isle Avenue
Marquette, MI 49855-5325

March 21, 2008

TO: Keith Burley
HPER

FROM: Cynthia A. Prosen, Ph.D.
Dean of Graduate Studies & Research CR

RE: Human Subjects Proposal #HS08-163
"The Physiological Impact of Added Upper-body Mass on Rowing Ergometry During Incremented Work Loads"

The Human Subjects Research Review Committee has reviewed your proposal and has given it final approval. To maintain permission from the Federal government to use human subjects in research, certain reporting processes are required. As the principal investigator, you are required to:

A. Include the statement "Approved by HSRRC: Project # (listed above) on all research materials you distribute, as well as on any correspondence concerning this project.

B. Provide the Human Subjects Research Committee letters from the agency(ies) where the research will take place within 14 days of the receipt of this letter. Letters from agencies should be submitted if the research is being done in (a) a hospital, in which case you will need a letter from the hospital administrator; (b) a school district, in which case you will need a letter from the superintendent, as well as the principal of the school where the research will be done; or (c) a facility that has its own Institutional Review Board, in which case you will need a letter from the chair of that board.

C. Report to the Human Subjects Research Review Committee any deviations from the methods and procedures outlined in your original protocol. If you find that modifications of methods or procedures are necessary, please report these to the Human Subjects Research Review Committee before proceeding with data collection.

D. Submit progress reports on your project every 12 months. You should report how many subjects have participated in the project and verify that you are following the methods and procedures outlined in your approved protocol.

E. Report to the Human Subjects Research Review Committee that your project has been completed. You are required to provide a short progress report to the Human Subjects Research Review Committee in which you provide information about your subjects, procedures to ensure confidentiality/anonymity of subjects, and the final disposition of records obtained as part of the research (see Section II.C.7.c).

F. Submit renewal of your project to the Human Subjects Research Review Committee if the project extends beyond three years from the date of approval.

It is your responsibility to seek renewal if you wish to continue with a three-year permit. At that time, you will complete (D) or (E), depending on the status of your project.

kjm

Telephone: 906 227-2102 ■ FAX: 906 227-2108
E-mail: conteduc@nmu.edu ■ Web site: www.nmu.edu/ce

Appendix C

RAW DATA FROM INTERVAL TRIALS

SUB_ID	GENDER*	NV.40.VO2	NV.55.VO2	NV.70.VO2	VE.40.VO2	VE.55.VO2	VE.70.VO2	EXP_level
1	0	24.5	32.7	38.3	25.8	32.9	38.8	3+
2	0	21.85	27.3	34.75	24.85	31.7	36.95	3+
3	0	23.5	29.3	34.15	24.1	31.4	34.35	<0.5
4	0	15.4	19.2	23.9	18.2	22.7	24.85	<0.5
5	1	23.95	30.65	36.85	28.5	24.6	34.9	<0.5
6	0	24.15	33.3	37.9	27.9	31.15	38.4	<0.5
7	0	26.5	34.35	37.8	26.75	32.45	39.5	<0.5
8	0	18.75	23.15	27.25	18.05	23.35	28.9	<0.5
9	0	11.6	18.55	21.85	16.35	20	25.45	<0.5
10	0	25.75	34.25	42.05	28	37.2	45.3	3+
11	1	26.5	34.6	43.55	24.6	31.7	40.05	<0.5
12	0	21.90	33.50	27.65	21.8	27.9	34.05	<0.5
13	0	24.10	31.10	38.00	26.6	32.05	38.65	<0.5
14	1	24.25	32	37.7	20.7	26	34.5	<0.5
15	1	26.65	34.65	40.40	24.8	32.5	37.9	3+
16	1	27.4	35.35	41.8	27.7	34.25	38.85	<0.5

SUB_ID	GENDER*	NV.40.HR	NV.55.HR	NV.70.HR	VE.40.HR	VE.55.HR	VE.70.HR	EXP_level
1	0	137	153.5	180.5	146	156.5	183.5	3+
2	0	156	161	183	181	191	191.5	3+
3	0	171.5	182.5	191.5	173.5	187	193.5	<0.5
4	0	139	146	157	145	159.5	168.5	<0.5
5	1	118.5	130	143	127.5	141	150	<0.5
6	0	141	160.5	165.5	158.5	163	179	<0.5
7	0	146.5	151	167.5	155	157.5	171	<0.5
8	0	125.5	152.5	160.5	135	155.5	164	<0.5
9	0	123.5	143	158.5	137	148.5	166.5	<0.5
10	0	116	137	148	130.5	147	159	3+
11	1	132.5	147	162.5	123.5	140	157	<0.5
12	0	145	155.5	159	153.5	158	170	<0.5
13	0	123	132.5	147	130	142	152.5	<0.5
14	1	148.5	168.5	178.5	144	164.5	174.5	<0.5
15	1	148	163.5	171.5	141	160	167	3+
16	1	148	166	170.5	131.5	145	159.5	<0.5

*Gender (0) = Male, (1) = Female
NV = No Vest Condition
VE = Vest Condition
HR = Heart Rate
VO2 = Oxygen Consumption