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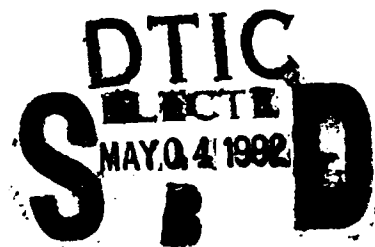
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PEPAB NORM DEVELOPMENT (PEPABNRM)

ANNUAL REPORT

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JANUARY 9, 1991



Supported by

U.S. ARMY MEDICAL RESEARCH AND DEVELOPMENT COMMAND
Fort Detrick, Frederick, Maryland 21702-5012

MIPR NO. 90MM0531

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92-11786



92 4 24 1992

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED			1b. RESTRICTIVE MARKINGS NONE		
2a. SECURITY CLASSIFICATION AUTHORITY N/A			3. DISTRIBUTION / AVAILABILITY OF REPORT Approved for public release; distribution unlimited		
2b. DECLASSIFICATION / DOWNGRADING SCHEDULE N/A					
4. PERFORMING ORGANIZATION REPORT NUMBER(S)			5. MONITORING ORGANIZATION REPORT NUMBER(S)		
6a. NAME OF PERFORMING ORGANIZATION Uniformed Services University of the Health Sciences		6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION U.S. Army Medical Research and Development Command		
6c. ADDRESS (City, State, and ZIP Code) USUHS - Dept. of Military Medicine 4301 Jones Bridge Road Bethesda, MD 20814-4799			7b. ADDRESS (City, State, and ZIP Code) ATTN: SGRD-PLF Fort Detrick Frederick, MD 21702-5012		
8a. NAME OF FUNDING / SPONSORING ORGANIZATION U.S. Army Medical Research & Development Command		8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER MIPR No. 90MM0531		
8c. ADDRESS (City, State, and ZIP Code) Fort Detrick Frederick, MD 21702-5012			10. SOURCE OF FUNDING NUMBERS		
			PROGRAM ELEMENT NO. 63002A	PROJECT NO. 3M6- 2300020995	TASK NO. BG
11. TITLE (Include Security Classification) PEPAB NORM DEVELOPMENT (PEPABNRM)					
12. PERSONAL AUTHOR(S) Montgomery, Leslie, Carol and Deuster, Patricia, Anne					
13a. TYPE OF REPORT Annual		13b. TIME COVERED FROM 89.11.1 TO 90.12.31		14. DATE OF REPORT (Year, Month, Day) 1991, January, 09	
15. PAGE COUNT 33					
16. SUPPLEMENTARY NOTATION					
17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)		
FIELD	GROUP	SUB-GROUP	Actigraph, aerobic, anaerobic, energy expenditure, RA 5 exercise, oxygen consumption, physical activity, questionnaire, submaximal, treadmill, VO2max, workload		
06	10				
06	04				
19. ABSTRACT (Continue on reverse if necessary and identify by block number) To evaluate physical performance under experimental or treatment conditions, exercise tests are routinely administered. We developed a tool for predicting the treadmill speed at which to run subjects in order to elicit a desired percentage of their maximal aerobic capacity. We generated, tested and refined a pair of regression equations: one for submaximal aerobic exercise, the other for high-intensity anaerobic exercise. Within the limitations of using linear equations to elicit physiologic responses that are sometimes curvilinear, the equations are useful to researchers. An Actigraph activity monitor was worn while performing a series of sedentary and physically challenging activities; heart rate and oxygen consumption ($\dot{V}O_2$) were also monitored. Actigraph counts were correlated with $\dot{V}O_2$ and heart rate for the physically challenging tasks ($r = 0.729$, $P < 0.001$; $r = 0.709$, $P < 0.001$, respectively). We suggest that the Actigraph could be used to grossly estimate energy expenditure because of the relation of oxygen consumption to expenditure (5 kilocalories are expended for each liter of oxygen consumed). Lastly, we developed a computerized physical activity questionnaire (PAQ) to quantify average daily energy expenditure. The PAQ quantifies work, sleep and leisure time-activities over a one-week and/or one-year period. Although dependent on the accuracy of subject recall, the PAQ has proven to be a useful tool for estimating energy expenditure in over 50 subjects. Used in conjunction with the Actigraph, fairly accurate estimations of physical activity and energy expenditure could be made outside of the laboratory.					
20. DISTRIBUTION / AVAILABILITY OF ABSTRACT ☐ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS			21. ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED		
22a. NAME OF RESPONSIBLE INDIVIDUAL Mary Frances Bostian			22b. TELEPHONE (Include Area Code) 301-619-7325		22c. OFFICE SYMBOL SGRD-RMI-S

FOREWORD

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PAD For the protection of human subjects, the investigator(s) have adhered to policies of applicable Federal Law 45CFR46.

In conducting research utilizing recombinant DNA technology, the investigator(s) adhered to current guidelines promulgated by the National Institute of Health.

Patricia A. Devoto

1/9/91

Principal Investigator's Signature Date

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Unannounced	☐
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Distribution/	
Availability Codes	
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I. REFINEMENT OF THE REGRESSION EQUATION FOR PREDICTING TREADMILL SPEED FOR SUBMAXIMAL EXERCISE TESTING

A. Introduction

To evaluate physical performance under a variety of treatment conditions, submaximal exercise tests often are administered. A submaximal test can simulate the work intensities of occupational or recreational activities and thus provide an accurate model for evaluating treatment effects. Furthermore, some metabolic and hormonal responses of interest to researchers are affected by exercise in an intensity-dependent manner. For these reasons, it is useful to have a tool whereby a workload can be selected that will elicit the desired intensity of submaximal effort. One tool would be a regression equation that would predict the treadmill speed necessary to obtain a desired level of effort. This level of effort is quantified as a percentage of the subject's maximal oxygen uptake ($\dot{V}O_{2max}$).

Previously, we developed a comprehensive Performance Physiology Assessment Battery (PPAB) to quantify the following parameters: maximal aerobic power (MAP), submaximal aerobic endurance (SAE), anaerobic capacity (AC), and isokinetic muscle strength and endurance. The PPAB is described in detail in our Technical Report (12) and elsewhere (9,10,11). Briefly, MAP was assessed using a protocol refined at USARIEM (17); the SAE test involved 30-min of treadmill running at approximately 60% of $\dot{V}O_{2max}$. The AC test was an intermittent test: 30-sec of high-intensity treadmill running was alternated with 30-sec of rest (standing astride the treadmill). The target percentage of $\dot{V}O_{2max}$ was 90 when averaged over the 30-sec exercise interval. The determination of an optimal treadmill speed and grade for testing an individual's performance at various intensities was made using a regression equation ($R^2 = 0.948$, $r =$

0.973). This equation, generated using data collected from a previous study (6), was based on subjects' performance on the MAP test ($\dot{V}O_{2max}$ [L·min⁻¹], time on treadmill excluding the warm-up walk, and body weight [kg]). In addition, the pre-selected treadmill grade (5% for the SAE test and 10% for the AC test) and desired intensity (60 and 90 percent of $\dot{V}O_{2max}$, respectively, for the SAE and AC tests) were entered into the equation. (Please refer to the Technical Manual [12] for further details). This equation was then tested in our study of the effects of antihistamines on physical performance (10).

B. Test of the Original Regression Equation

1. Methods

All subjects were healthy active duty or active reserve military personnel who gave their consent to voluntarily participate in a study of the effects of antihistamines on physical performance. A complete description of the methodology is presented elsewhere (10). Twelve subjects (three females and nine males) performed the MAP, SAE and AC tests under each of three conditions: placebo, diphenhydramine (50 mg) or terfenadine (60 mg). Based on their results from the placebo MAP test, subjects were grouped by fitness level: high (HI) fit ($\dot{V}O_{2max} > 55$ ml·kg⁻¹·min⁻¹), moderately (MOD) fit ($\dot{V}O_{2max}$ 45-55 ml·kg⁻¹·min⁻¹) and low (LOW) fit ($\dot{V}O_{2max} < 45$ ml·kg⁻¹·min⁻¹). These group definitions were selected from the frequency distribution of $\dot{V}O_{2max}$ from the antihistamine study: HI and LOW fit groups were, respectively, the upper and lower quartiles ($N = 3$, each), and the MOD group was the middle half ($N = 6$). Characteristics of the subjects by fitness group are presented in Table 1.

The regression equation was applied as described previously with two modifications. First, if at the end of the first 5-min of the SAE test the percent of $\dot{V}O_{2max}$ ($\% \dot{V}O_{2max}$) was less than 45, the treadmill speed was increased slightly to achieve an intensity of effort closer to the target 60% of $\dot{V}O_{2max}$. Second, for the AC test, which consisted of intermittent rather than continuous running, a modification to the regression equation was required. Our preliminary studies had demonstrated that, because of the built-in rest periods, intermittent exercise could be tolerated at workloads (intensities) that approached or even exceeded the workload that could be tolerated if running continuously. In addition, there was a time-lag in the oxygen consumption ($\dot{V}O_2$) response to the onset of strenuous exercise. Therefore, in order that the obtained $\dot{V}O_2$ over the 30-sec exercise interval would average approximately 90% of $\dot{V}O_{2max}$, a work intensity higher than 90% of $\dot{V}O_{2max}$ was selected for entry into the regression equation: an intensity of 120%. The treadmill grade entered into the equation was 10%; in the study, however, subjects ran the first five bouts at a 5% grade in order to accommodate to the rigors of high-intensity intermittent treadmill running. The remaining bouts (6 to exhaustion) were performed on a 10% treadmill grade at the same speed as the initial bouts, as predicted by the regression equation.

The accuracy of the regression equation in predicting the appropriate treadmill speed for eliciting the desired $\% \dot{V}O_{2max}$ for each subject was gauged by examining the subjects' obtained $\% \dot{V}O_{2max}$, overall and by fitness group, for the SAE and AC tests. Differences between obtained

and targeted values were evaluated by general linear models analyses of variance with repeated measures using the SAS Statistical Package (16).

2. Results

Since there were no differences in performance by treatment condition or test order, subject data were averaged over the three test conditions. In general, the regression equation predicted a treadmill speed that was too slow for most of the subjects, particularly at the lower exercise intensity. For the SAE test the target $\% \dot{V}O_{2max}$ was 60%, yet the obtained value averaged over the first 5-min of exercise was only $44.5 \pm 2.8\%$. This value increased to $54.5 \pm 2.35\%$ of $\dot{V}O_{2max}$ by the end of the 30-min SAE test for reasons that are described below.

For the AC test, the average $\% \dot{V}O_{2max}$ of exercise bouts 3-5, while at a 5% treadmill grade, was $70.83 \pm 1.87\%$; the average of the subjects' last three bouts of exercise was $87.47 \pm 1.51\%$. Thus, at the time that the subjects ceased exercising their average oxygen consumption was near the target of 90% of their $\dot{V}O_{2max}$.

The regression equation was more accurate for those subjects who were highly fit but less accurate for all other subjects. Figure 1 provides a graphic comparison across fitness groups in the accuracy of the regression equation in predicting treadmill speeds to elicit the desired relative intensity ($\% \dot{V}O_{2max}$). These results are also presented in Table 2 along with the treadmill speeds used and other variables. Inter-group comparisons showed that the HI and LOW groups differed significantly in their obtained $\% \dot{V}O_{2max}$ and heart rate during the SAE test. During the first 5-min of the SAE test the equation grossly under-predicted treadmill speed for the LOW and MOD fitness groups. For

those subjects for whom the predicted treadmill speed did not elicit at least 45% of $\dot{V}O_{2max}$ by the end of the first 5-min, the treadmill speed was increased slightly. This increase in treadmill speed partially explains the increase in intensity ($\% \dot{V}O_{2max}$) over the duration of the 30-min test. However, by the end of the 30-min, $\% \dot{V}O_{2max}$ had also increased slightly in the HI fit group although there had been no increase in workload (treadmill speed) and all metabolic values (including post-test plasma lactate and respiratory exchange ratio values) indicated that the runners were in a steady state. Thus, the increase in $\dot{V}O_{2max}$ over the 30-min test was due to an increase in workload and/or an upward drift over time, as seen in the HI fit group.

The regression equation was more accurate in predicting treadmill speed for the high intensity anaerobic capacity test. As seen in Figure 1 and Table 2, the equation was very accurate for the LOW fitness group. Overall, at the end of the AC test, there were no statistically significant differences between targeted and obtained $\% \dot{V}O_{2max}$ values for any of the fitness groups. It is not known how these results might change if the LOW and MOD fitness groups had exercised at a higher intensity during the SAE test which immediately preceded the AC test. It could be that these groups would have achieved a different $\% \dot{V}O_{2max}$ on the AC test if they had been challenged more on the preceding SAE test.

For those in the HI fit group, it appears that they may not have been adequately challenged during the AC test since they averaged only 82.9% of $\dot{V}O_{2max}$. There is, however, the possibility that the workload was too high, rather than too low. Since the subjects were working at a very high workload, they may have been predominately utilizing anaerobic

metabolism; thus, their oxygen consumption could have been lower than if they were exercising more aerobically at a lower intensity. This possibility is supported by the finding that the plasma lactate of the HI fit group after the AC test was over 11 mM, even with the 30-sec rest intervals during which lactate could be removed.

3. Discussion

In conclusion, the regression equation we developed at the time that the PPAB was formulated was somewhat accurate in predicting the appropriate treadmill speed for eliciting a desired percentage of an individual's $\dot{V}O_{2max}$. For the HI fitness group, the equation was quite accurate at 60% and moderately accurate at 90%. However, there was obvious room for improvement in two areas: first, increasing the workload at the 60% level for the LOW and MOD fit groups; and second, developing a new equation for use with intermittent exercise. We determined that it was unacceptable to have an equation to predict a workload for eliciting 90% of $\dot{V}O_{2max}$ by entering 120% into the equation as the target intensity. In addition, the different nature of intermittent versus continuous exercise merited development of a separate equation. Therefore, the regression equation was revised and validated in another study, as described below.

C. Test of the Revised Regression Equations

Due to the mixed success of the original regression equation in our antihistamine study, we revised the equation in order to increase its accuracy. First, we increased the number of subjects in the data pool from 17 to 47 by adding subjects from the antihistamine study and three other studies conducted in our laboratory. All of these studies had continuous (15-min or

more) treadmill running across a range of intensities (60-85% of $\dot{V}O_{2max}$) and intermittent treadmill running at high intensities (90+% of $\dot{V}O_{2max}$) in common.

Because of the different demands of running continuously versus intermittently, we generated two separate equations: one for continuous running and another for intermittent running. A Pearson correlation coefficients matrix was generated using all performance measures ($\dot{V}O_{2max}$ in $ml \cdot kg^{-1} \cdot min^{-1}$ and $L \cdot min^{-1}$, time on treadmill, maximal heart rate) and subject physical characteristics (age, height, weight, percent body fat, body mass index, and lean body mass). Any variables that were significantly ($P < 0.05$) correlated with each other (e.g., percent body fat and $\dot{V}O_{2max}$) were not used together in subsequent regression analyses. An R-square analysis was used to identify the variables that were the strongest predictors of treadmill speed. Then, stepwise regression analysis was used to determine the actual variables in the regression equations; these variables were all independent of one another, as determined by the correlation matrix. The variables that had the highest R^2 value for continuous (0.9885, $r = 0.3942$) and intermittent running (0.9923, $r = 0.9961$) were: $\dot{V}O_{2max}$ in $ml \cdot kg^{-1} \cdot min^{-1}$, treadmill grade, and the target percent of $\dot{V}O_{2max}$. To determine the treadmill speed, the subject's own $\dot{V}O_{2max}$ was entered into the equation as well as the desired treadmill grade (e.g., 5% for the SAE test) and the target percent of $\dot{V}O_{2max}$ (e.g., 60% for the SAE test).

To test the revised equations a study was conducted which required subjects to perform treadmill running across a range of intensities: 30, 60, 75, and 90% of $\dot{V}O_{2max}$. Results were evaluated by comparing the obtained to the targeted percent of $\dot{V}O_{2max}$.

1. Methods

Fifteen subjects participated in the study after giving their informed consent. Subject characteristics are presented in Table 3. Subjects ran for three minutes on a 5% grade at intensities of 30, 60, and 75% of $\dot{V}O_{2max}$; then they ran at an intensity of 90% of $\dot{V}O_{2max}$ for 2-min on a 5% grade and then on a 10% grade for up to 4-min (if tolerated). The SAS Statistical Package (16) was used to conduct statistical analyses, which included t-tests for comparing obtained to targeted $\dot{V}O_2$ at each intensity, as well as group comparisons (males vs females and higher fit versus lower fit).

2. Results

Please refer to our FY 90 third quarter report (dated 12 July 1990) for an evaluation of the gender differences in the accuracy of the regression equation. In short, the equation was not at all accurate at any intensity for the females; this may be attributable to the fact that only 3 of 47 subjects in the sample population from which the regression equation was drawn were female. A comparison of the targeted and obtained percent of $\dot{V}O_{2max}$ for the males only is presented in Figure 2. At 30%, the obtained $\% \dot{V}O_{2max}$ was significantly higher than the target $\% \dot{V}O_{2max}$. At 60 and 75%, by the second half of the 3-min intervals, there were no significant differences between targeted and obtained $\% \dot{V}O_{2max}$. At 90%, there also was no significant difference, although it appears from the Figure that there would be; the high variability at this intensity may mask any statistical difference. If the subjects had continued running for longer than two minutes at 90% intensity (5%

grade) their $\dot{V}O_2$ may have plateaued. However, since after 2-min the treadmill grade was increased to 10%, a plateau did not occur.

Although data are not presented here by fitness level, the accuracy of the equation was similar for the higher and lower fit males, unlike the data from the antihistamine study.

3. Discussion

Overall, for the males the revised regression equations did a better job at predicting treadmill speed over a wide range of intensities than did the original regression equation. However, a few modifications were made to the equations to achieve this success. First, whereas inputting 30% and 60% into the regression equation for continuous running yielded treadmill speeds that were approximately 30 and 60% of $\dot{V}O_{2max}$, we had to input 90% into the regression equation to get the desired treadmill speed at 75%. Thus, it appears that the slope of the regression equation for continuous running is not great enough whereas the intercept is too high. In summary, the equations produced a speed that was too fast at the low end, and a speed that was too slow at the high end.

Second, the other equation, designed for intermittent and/or high-intensity exercise, yielded speeds that were too intense for the subjects to run continuously. It could be that if the subjects had exercised intermittently the equation may have been right on target. On the other hand, this equation was fairly accurate during the first 2-min of the 90% run when the treadmill grade was only 5%. Thus, the "intermittent" equation may be appropriate for high-intensity continuous running if the treadmill grade is halved once the predicted speed is calculated.

That is, the equation is used to determine treadmill speed based on a 10% grade, but subjects are run at a 5% grade; at a 10% grade the predicted speed would be too fast for continuous running.

D. Current Version of the Regression Equations

The regression equations were revised again by adding the subjects from the study just described, deleting from the sample population all females and all duplications (males who had participated in a number of studies for us), and eliminating a subject whose $\dot{V}O_{2max}$ value was identified statistically as being an outlier. The current sample population includes 47 males with their characteristics presented in Table 4.

A few dozen equations have been generated and tested on paper by back calculating to previous results (i.e., comparing the treadmill speeds predicted by different equations with the same input values). In general, the equations predict treadmill speeds that are within 0.4 miles per hour of each other at any given intensity regardless of whether the equation is for high fit or low fit individuals. Adding additional variables to the equation such as body mass index or age does not add significantly to the accuracy of the equation. Thus, only three variables are used in the equations shown below: PCTMAX (the target percent of $\dot{V}O_{2max}$), GRADE (the treadmill grade (e.g., 10 for a 10% grade), and the subject's $\dot{V}O_{2max}$ in $ml \cdot kg^{-1} \cdot min^{-1}$.

Continuous running ($R^2 = 0.9904$, $r = 0.9952$):

$$0.0577313 \cdot PCTMAX - 0.226657 \cdot GRADE + 0.05228267 \cdot \dot{V}O_{2max}$$

Intermittent/High Intensity Running ($R^2 = 0.9909$, $r = 0.9954$):

$$0.03941568 \cdot PCTMAX - 0.130829 \cdot GRADE + 0.11261356 \cdot \dot{V}O_{2max}$$

The results from back calculations show that these revised equations would have more accurately predicted treadmill speed in the antihistamine study. Figure 3 compares the current regression equation with the equation used in the antihistamine study using the same mean $\dot{V}O_{2max}$. Note how the weaknesses of the original formula (predicted speed too slow at the low intensities, a bit fast at the high intensities) appear to be compensated for by the revised equation. A comparison of predicted treadmill speeds by fitness group is presented in Figure 4 using data from the antihistamine study. Note how the revised equation greatly increases the treadmill speed for the LOW fit group and slightly increases the speed for the MOD fit group. In contrast, speed for the HI fit group would be decreased slightly, which is appropriate given that by the end of the 30-min run they were in excess of 60% of their $\dot{V}O_{2max}$. At high intensities, like the AC test, treadmill speed would be decreased slightly for all groups using the revised equation. This decrease may be appropriate since the MOD and LOW fit groups would be exercising at a higher intensity during the SAE test.

E. Conclusion

We have developed and refined a useful tool for predicting the treadmill speed at which to test subjects to elicit a desired percentage of their $\dot{V}O_{2max}$. This tool consists of two regression equations: one equation for continuous exercise at low intensities and another for continuous or intermittent exercise at high intensities. Although designed specifically for use with the Performance Physiology Assessment Battery, these equations may be of use to other researchers or clinicians. In FY 91 we will be testing additional subjects to validate the revised equations. Results from these tests will be added to the regression equation database and the equation will be revised

again. With each iteration the equation becomes more predictive (the r value increases).

As confident as we are in the general utility of the equations, we do foresee some limitations in the application of the equations. First, it appears that the slope of the linear equations may not match the slope of physiologic responses to increasing intensities of exercise. For example, if an equation is accurate at predicting treadmill speed for an exercise intensity of 30%, it will underpredict treadmill speed at 75% of $\dot{V}O_{2max}$. We circumvented this limitation by generating two equations with different slopes: one for low intensity continuous exercise and the other for high intensity exercise. A curvilinear model for the regression equations may be more accurate.

Second, because of the variation between subjects in their anaerobic thresholds, the transition point from using the "low" intensity equation to the "high" intensity equation is blurred. For some people, exercising at an intensity over 50-60% of their $\dot{V}O_{2max}$ requires substantial anaerobic metabolism and the exercise itself cannot be maintained for very long. For others, running at 80% of their $\dot{V}O_{2max}$ is steady-state exercise and well-tolerated. The individual's anaerobic threshold and capacity to tolerate anaerobic exercise are factors to be considered when selecting--and designing--regression equations. Our recommendation, given the current two equations, is to use the "low" intensity equation for continuous exercise up to 60% of $\dot{V}O_{2max}$. The "high" intensity equation could be used for all other exercise with the modification described in section I.C.3.: for continuous running, use a 10% grade in the equation, but run the subjects at a 5% grade. For intermittent running the high intensity equation could be used without modification.

One unanswered question of interest for applied use, is whether the equations would predict as well if $\dot{V}O_{2max}$ was not directly measured but was estimated. In field studies, $\dot{V}O_{2max}$ is often calculated based on the $\dot{V}O_2$ or heart rate data from a submaximal test (on a cycle ergometer, for example). There are also formulas in the literature for predicting $\dot{V}O_{2max}$ based on physical characteristics such as gender, age and weight. If these estimations of $\dot{V}O_{2max}$ could produce results in the regression equations similar to directly measured $\dot{V}O_{2max}$, then the necessity for testing maximal aerobic power would be obviated. This would reduce the potential risk to the subjects of maximal testing.

II. CORRELATIONS OF AN ACTIGRAPH ACTIVITY MONITOR WITH OXYGEN CONSUMPTION OVER A RANGE OF ACTIVITIES

A. Introduction

Concurrent with our test of the revised regression equation described above, we examined the correlation between activity "counts" (measures obtained from an Actigraph Activity Monitor) and oxygen consumption across a range of intensities of physical activity. The purpose of this study was to examine the sensitivity of the Actigraph to detect changes in activity and, furthermore, to detect changes in the intensity of a given activity. The Actigraph had been used in a study of post-myocardial infarction (post-MI) males to determine if angina occurred at times of increased physical activity (5). It was known that angina could be induced in post-MI subjects performing mental arithmetic under stress (5); in these cases heart rate increased, but physical activity was unchanged. Use of the Actigraph was seen as a reasonable way to gauge physical activity that was independent of physiologic arousal such as that caused by the non-physically demanding tasks of perform-

ing mental arithmetic or driving a car. We sought to determine if there were correlations among Actigraph activity counts and oxygen consumption measures, and if the Actigraph could discriminate between different intensities of the same activity. Heart rate values were also measured in order to correlate physical arousal with physical activity.

B. Methods

Fifteen subjects completed a battery of tests which included sedentary and physically challenging tasks. In order of administration, subjects performed the following sedentary activities: mental arithmetic, reading, typing, and playing a video game. Actigraph counts, oxygen consumption, and heart rate were measured for each activity except during the mental arithmetic task which required the subject to vocalize (no oxygen consumption measured). Following these sedentary activities, the subjects performed physically challenging activities on and off the treadmill. Non-treadmill activities included two 2-min sets of knee bends (at 28 and 48 bpm) and step climbs (at 20 and 36 bpm). The knee bends were performed with the hands on the hips and the subjects bent their knees about half way (shallow, not deep, bends). The step climb involved stepping up onto and then down from an 8-inch high step. The treadmill activities involved running at four different intensities (30, 60, 75 and 90% of the individual's $\dot{V}O_{2max}$) as described in section I.C.1. above. Administration of the physical activities was randomized such that sometimes treadmill running occurred first, and sometimes step climbing preceded knee bends. In no case did treadmill running occur between the knee bend and step climb activities.

An Actigraph activity monitor was worn on the non-dominant wrist. In between the sedentary activities, the non-dominant wrist was held still in

order to demarcate activities from one another. Data were analyzed using the SAS Statistical Package (16) by performing Pearson's correlations among variables of activity counts, oxygen consumption and heart rate.

C. Results

None of the four sedentary activities' Actigraph counts were significantly correlated with heart rate or $\dot{V}O_2$ when examined separately. However, when all sedentary activities were averaged, Actigraph counts were significantly correlated with heart rate ($r = 0.348$, $P < 0.001$) and $\dot{V}O_2$ ($r = 0.464$, $P < 0.001$).

Actigraph counts from the non-treadmill physically challenging tasks also showed a significant correlation with heart rate ($r = 0.599$, $P < 0.001$) and $\dot{V}O_2$ ($r = 0.628$, $P < 0.001$). When all physically challenging tasks were examined together, the strength of the correlation was increased: Actigraph counts and heart rate $r = 0.709$, $P < 0.0001$) and Actigraph counts and $\dot{V}O_2$ $r = 0.729$ ($P < 0.0001$). Interestingly, the Actigraph discriminated well among the different treadmill speeds, but when only an increase in treadmill grade occurred, such as during the maximal treadmill tolerance test or submaximally at the 90% level, the Actigraph could not discriminate the change in activity despite an increase in heart rate and $\dot{V}O_2$. However, only a few subjects ran for more than two minutes at 90%, so a statistical analysis of this finding cannot be applied.

In order to determine the reliability of the Actigraph counts, four subjects repeated the entire test protocol. The test-retest correlation for all activities was very high ($r > 0.98$, $P < 0.0001$).

C. Discussion

The strength of the correlations of Actigraph counts with heart rate and oxygen consumption suggests that oxygen consumption could be fairly well predicted using a combination of Actigraph counts and heart rate measurements. Thus, during light to heavy physical activity, these two non-invasive measures may provide sufficient information to estimate oxygen consumption and may be a useful tool for estimating the oxygen consumed when performing a wide range of activities in the field. Furthermore, since oxygen consumption values are directly related to caloric expenditure (5 kcal expended per liter of oxygen consumed), the Actigraph and heart rate measures could also provide a gross estimate of the energy cost of various physical activities.

III. DEVELOPMENT OF A COMPUTERIZED PHYSICAL ACTIVITY QUESTIONNAIRE

Epidemiologic data indicate that physical activity--exercise, work-related activity, and/or leisure time activity--is inversely related to cardiovascular mortality in men (3); however, the relation of physical fitness and cardiovascular health is less clear (1,4). Many researchers distinguish between physical activity and fitness: i.e., an individual may be highly active without necessarily being highly fit (7,8). Specifically, a spectrum of physical activity has been proposed (7): cardiovascular fitness on the Y-axis and physical activity level on the X-axis. A sedentary person would be at the low end of both axes. At the high end of the activity level axis are those who are on the low (e.g. active workers), moderate (e.g., recreation athletes) or high (e.g., competitive athletes) end of the cardiovascular fitness axis. For example, a postal carrier whose job requires nearly constant activity but who engages in no vigorous activity would be on the high end of activity but the low end of cardiovascular fitness.

The benefits of physical activity and fitness are blurred because they are both inversely associated with other risk factors, such as cholesterol level, body fatness, resting heart rate, and blood pressure. Establishing either physical activity or cardiovascular fitness as independent factors in the reduction of heart attack or coronary heart disease risk is therefore difficult. However, recalling the spectrum of physical activity mentioned above, one comprehensive review of the epidemiologic data concluded that scoring high only on the activity axis may be more strongly associated with a reduced risk of heart attack than scoring high on both the activity and fitness axes (7). Thus fitness--i.e., cardiovascular fitness usually defined as maximal work capacity and/or $\dot{V}O_{2max}$ --may play a role different from that of physical activity in the reduction of cardiovascular risk and mortality.

Numerous longitudinal studies have demonstrated that expending a certain number of calories per week (usually 2000 kcal) or engaging in physical activities for a certain number of hours per week is independently associated with decreased heart attack risk and/or incidence of hypertension (2,4,13,14). It matters not what the source of that caloric expenditure is--aerobic or anaerobic exercise, gardening or running--what does matter is that some threshold of physical activity is exceeded.

In our laboratory, we routinely test maximal work capacity-- $\dot{V}O_{2max}$ --and use that measurement to classify individuals into fitness groups. What we had not considered, beyond a cursory inquiry as to the subjects' fitness training regimen, was the physical activity status of the subjects. Does their job require them to be physically active? Are they active in their leisure time in addition to their exercise regimen? We did not have a mechanism for estimating daily activity/energy expenditure.

Therefore, we developed a computerized questionnaire for quantifying an individual's physical activity patterns. The Physical Activity Questionnaire (PAQ), as described in previous reports, gathers general descriptive data on sleep and work habits and more specific data on the number of hours spent performing various leisure-time recreational and sports activities. Over 60 activities are listed, ranging in physical intensity from handiwork (e.g, knitting) to swimming competitively. Many of the activities are further subdivided by intensity (usually pace or distance). The activity's intensity code and the subject's body weight (kg) are multiplied together; the resulting value is an estimate of the number of calories expended per minute during performance of that activity. Data from all activities are summed, by week and/or by year, and added to the descriptive data (sleep and job-related activity). The end result is a report which provides a gross estimate of the number of calories expended per day, on average, and also a breakdown of caloric expenditure by activity.

One of the distinguishing characteristics of the PAQ is its provision of various intensity levels for many of the activities; other questionnaires do not estimate intensity or duration (3,15). In the PAQ, each activity's intensity code was derived from an extensive review of the literature; the intensities of some activities were determined by extrapolating between two known intensity codes, if necessary. The more intense (energy demanding) the activity, the higher the intensity code. For example, reading and handiwork have the lowest intensity code (0.022) and performing the crawl swim stroke during a race has the highest intensity code (0.286). Thus over a 20-min period, a 70 kg person would expend 30.8 kcal knitting and 400.4 kcal swimming.

Approximately 50 subjects have completed the PAQ thus far, and most find the information useful and fairly accurate. Unfortunately, the PAQ can be tedious to complete if one partakes in many leisure time activities or if the data are for the whole year rather than for the current week. In addition, some subjects have difficulty in translating their workouts into minutes per week, as opposed to miles per week as with running. Still, the PAQ is a useful tool both for quantifying level of physical activity and for estimating daily energy expenditure.

Lastly, investigating the use of the PAQ in conjunction with the Actigraph would be worthwhile. Daily recall of physical activity could be compared to daily activity counts from the Actigraph to obtain sufficient information for estimating both oxygen consumption and energy expenditure. With the addition of a portable heart rate monitor, these estimations would be even more accurate. This approach to field estimations of energy expenditure merits additional study.

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Table 1. Characteristics (mean $\pm$ SEM) of subjects in the antihistamine study by fitness group (data from the placebo maximal aerobic power test).

	FITNESS GROUP		
	HI	MOD	LOW
Age (yr)	29.33 $\pm$ 3.33	32.00 $\pm$ 1.81	34.67 $\pm$ 1.76
Height (cm)	177.00 $\pm$ 3.51	175.25 $\pm$ 3.04	169.00 $\pm$ 6.66
Weight (kg)	73.63 $\pm$ 2.35	77.35 $\pm$ 4.99	65.20 $\pm$ 8.19
Body fat (%)	12.83 $\pm$ 3.65 [†]	17.07 $\pm$ 2.21	21.25 $\pm$ 1.18
$\dot{V}O_{2\max}$ (L $\cdot$ min ⁻¹)	4.68 $\pm$ 0.44	3.92 $\pm$ 0.30	2.61 $\pm$ 0.51*
$\dot{V}O_{2\max}$ (ml $\cdot$ kg ⁻¹ $\cdot$ min ⁻¹)	62.60 $\pm$ 4.77*	50.47 $\pm$ 1.25*	38.97 $\pm$ 3.01*
Maximal heart rate (bpm)	186.00 $\pm$ 1.15	191.60 $\pm$ 0.98*	182.00 $\pm$ 3.61
Treadmill time (min)	12.36 $\pm$ 1.10*	9.47 $\pm$ 0.30*	5.86 $\pm$ 0.82*
Post Plasma Lactate (mM)	13.72 $\pm$ 1.62	14.29 $\pm$ 1.11	10.63 $\pm$ 1.93

* Significantly different from other groups ($P < 0.05$).

[†] Significantly different from LOW group ($P < 0.05$)

Table 2. Comparison of percent of $\dot{V}O_{2max}$, treadmill speed used and selected variables by fitness groups in the Antihistamine Study.

	FITNESS GROUP		
	HI	MOD	LOW
SUBMAXIMAL ENDURANCE TEST			
First 5-min ($\% \dot{V}O_{2max}$)	55.89 $\pm$ 1.54 [†]	44.00 $\pm$ 1.74	34.63 $\pm$ 1.18
Treadmill Speed (mph)	5.73 $\pm$ 0.31*	4.20 $\pm$ 0.07*	3.00 $\pm$ 0.07*
Last 5-min ($\% \dot{V}O_{2max}$)	61.00 $\pm$ 1.25 [†]	54.89 $\pm$ 2.05	47.13 $\pm$ 2.33
Treadmill Speed (mph)	5.73 $\pm$ 0.31*	4.40 $\pm$ 0.10	3.76 $\pm$ 0.08
Plasma Lactate (mmol·L ⁻¹)	1.23 $\pm$ 0.14	1.42 $\pm$ 0.14	1.20 $\pm$ 0.12
Heart Rate (bpm)	152.00 $\pm$ 3.47 [†]	141.94 $\pm$ 4.64	121.78 $\pm$ 2.57
ANAEROBIC CAPACITY TEST			
Bouts 3-5 ($\% \dot{V}O_{2max}$)	67.25 $\pm$ 1.26	68.83 $\pm$ 1.46	78.88 $\pm$ 2.88*
Last 3 Bouts ($\% \dot{V}O_{2max}$)	82.88 $\pm$ 2.34 [†]	87.83 $\pm$ 1.33	91.75 $\pm$ 2.52
Treadmill Speed (mph)	9.40 $\pm$ 0.17*	8.10 $\pm$ 0.07*	6.94 $\pm$ 0.08*
Number of Bouts of			
Intermittent Exercise	13.67 $\pm$ 0.94	22.22 $\pm$ 1.65*	14.00 $\pm$ 2.29
Plasma Lactate (mmol·L ⁻¹)	11.10 $\pm$ 0.47	10.58 $\pm$ 0.63	9.22 $\pm$ 0.57
Heart Rate (last 3 bouts)	169.57 $\pm$ 1.53	177.96 $\pm$ 1.82	170.96 $\pm$ 2.25
Peak Heart Rate	178.57 $\pm$ 1.40	184.31 $\pm$ 1.76	175.56 $\pm$ 2.34

* Significantly different ($P < 0.05$) from other fitness groups.

[†] Significantly different ($P < 0.05$) from low fitness group.

Table 3. Characteristics of subjects in the study of the revised regression equations ($N = 15$; 5 females, 10 males).

	MEAN $\pm$ SEM	RANGE
Age (yr)	29.33 $\pm$ 1.26	22 - 38
Height (cm)	175.42 $\pm$ 2.76	152 - 192
Weight (kg)	68.73 $\pm$ 3.07	48.0 - 87.5
Body Mass Index	22.26 $\pm$ 0.67	17.1 - 27.7
$\dot{V}O_{2max}$ (L $\cdot$ min $^{-1}$)	3.15 $\pm$ 0.25	1.8 - 4.8
$\dot{V}O_{2max}$ (ml $\cdot$ kg $^{-1}\cdot$ min $^{-1}$)	45.27 $\pm$ 2.40	34.7 - 63.0
Maximal heart rate (bpm)	194.00 $\pm$ 1.99	179 - 205
Treadmill time (min)*	9.71 $\pm$ 0.74	3.9 - 14.5

Table 4. Characteristics of the male subjects in the current regression equation's data pool ($N = 47$, unless otherwise noted).

	MEAN $\pm$ SEM	RANGE
Age (yr)	29.13 $\pm$ 0.76	21 - 40
Height (cm)	178.62 $\pm$ 0.97	165 - 192
Weight (kg)	77.55 $\pm$ 1.14	64.4 - 91.0
Body Mass Index	24.34 $\pm$ 0.36	19.5 - 30.1
Percent Body Fat ($N = 37$)	12.82 $\pm$ 0.77	4.6 - 23.5
$\dot{V}O_{2\max}$ (L $\cdot$ min $^{-1}$)	4.16 $\pm$ 0.09	2.5 - 5.9
$\dot{V}O_{2\max}$ (ml $\cdot$ kg $^{-1}\cdot$ min $^{-1}$)	53.74 $\pm$ 1.03	34.8 - 71.0
Maximal heart rate (bpm)	189.72 $\pm$ 1.18	168 - 205
Treadmill time (min)*	10.91 $\pm$ 0.26	7.5 - 14.5

FIGURE 1. OBTAINED PERCENT OF VO2MAX BY FITNESS LEVEL
IN TEST OF ORIGINAL REGRESSION EQUATION

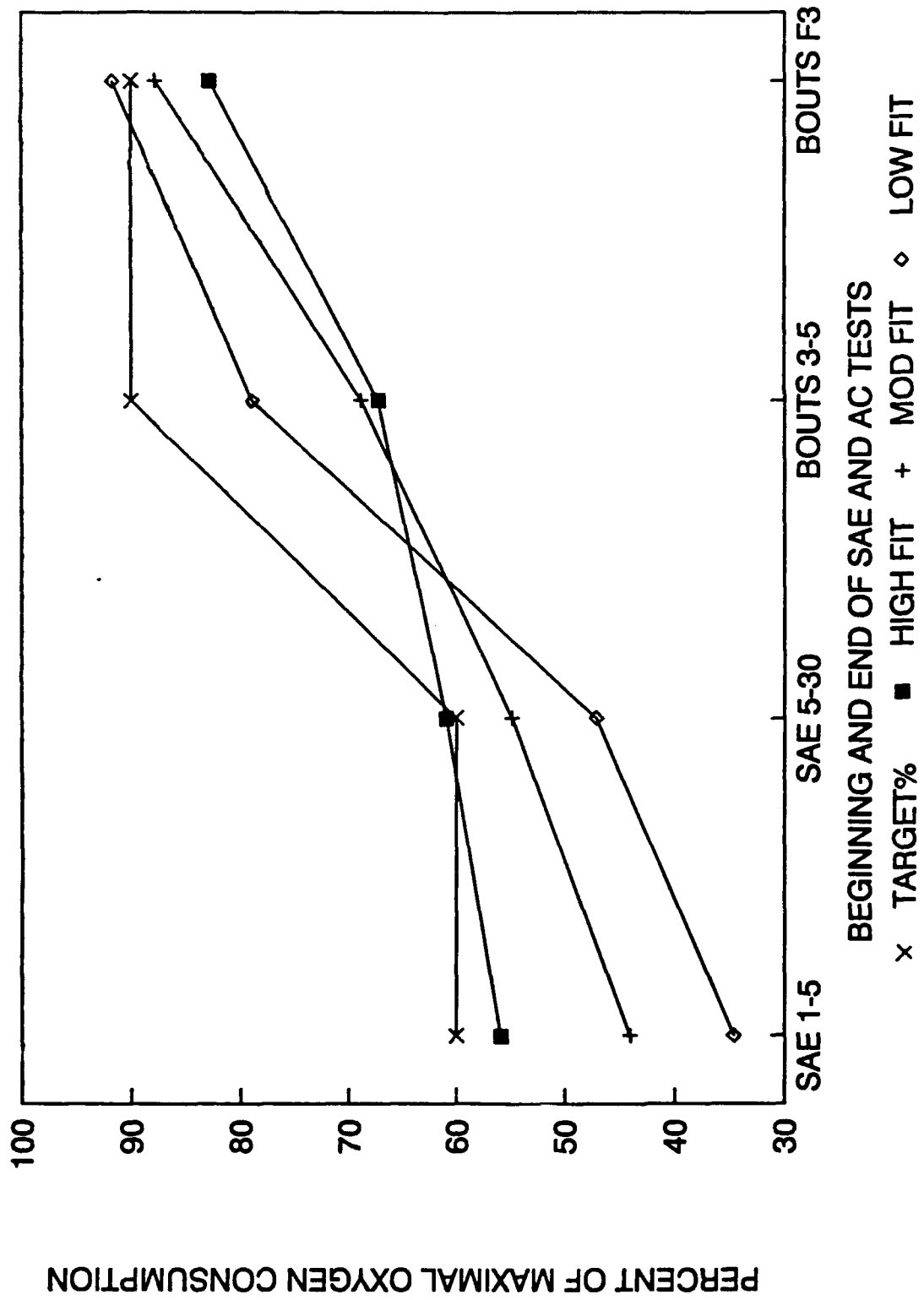


FIGURE 2. COMPARISON OF PREDICTED TO OBTAINED
PERCENT OF VO₂MAX (MALES ONLY, N=10)

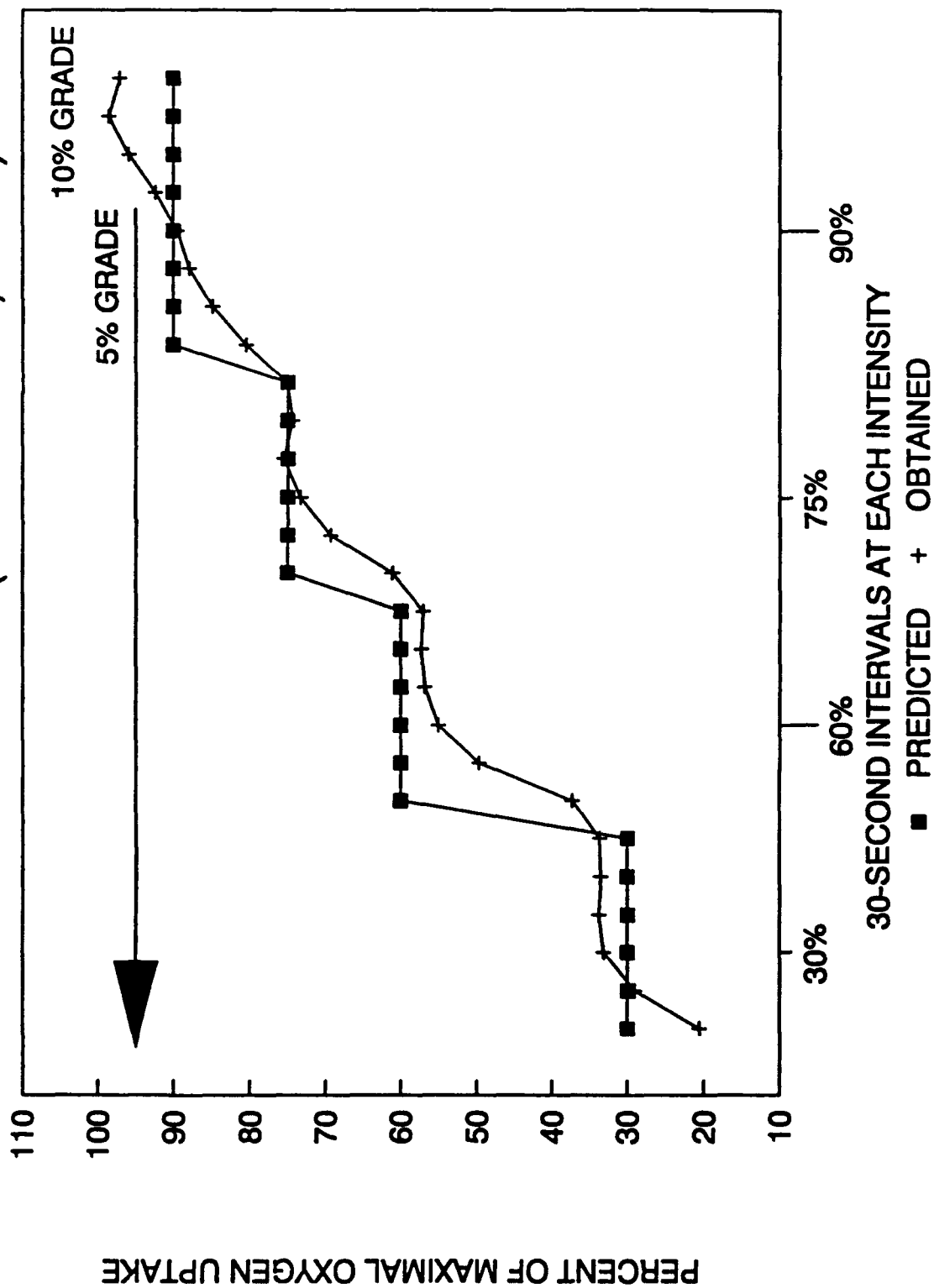


FIGURE 3. REVISED & ORIGINAL EQUATIONS
BASED ON THE SAME MEAN VO₂MAX VALUE

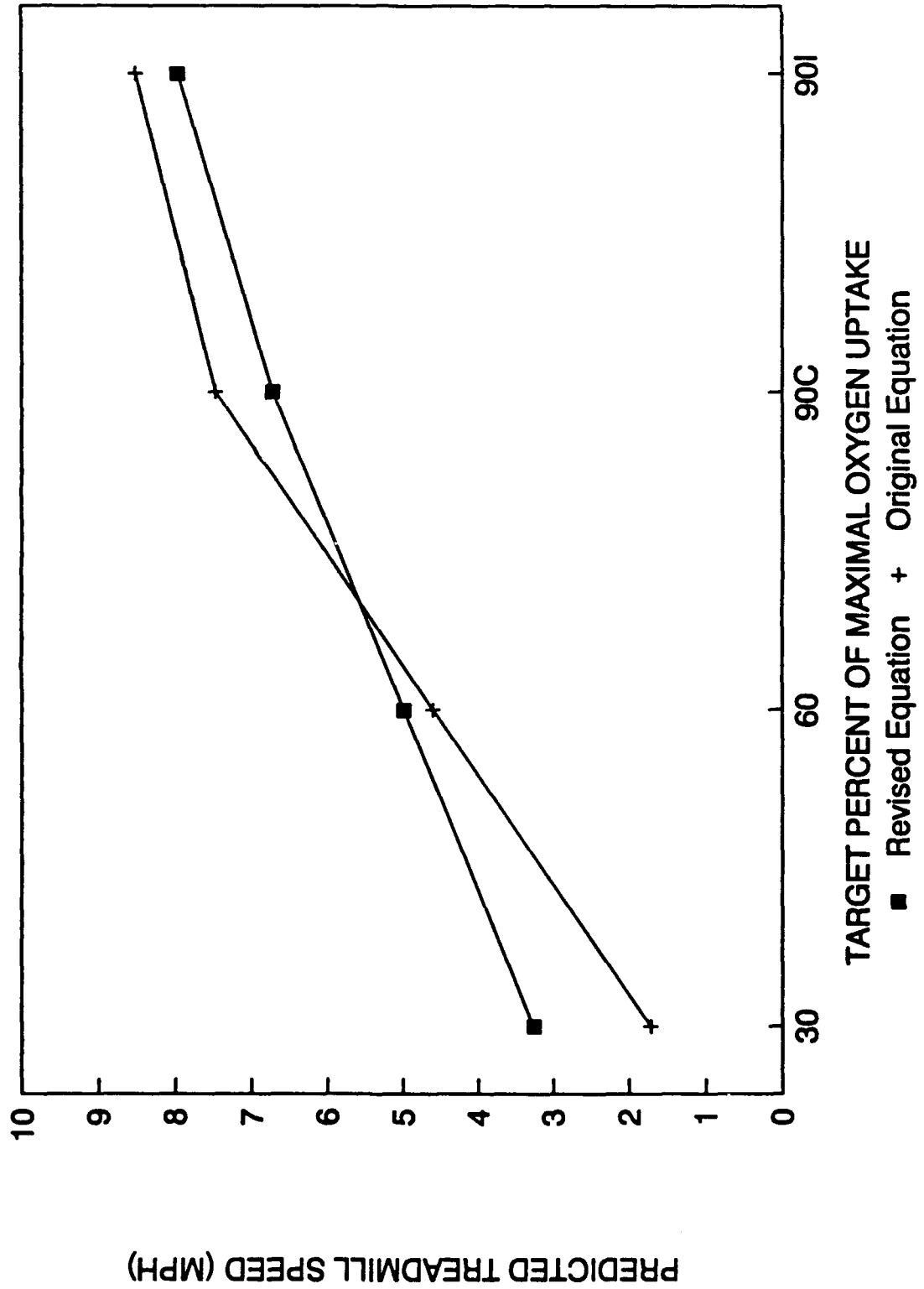


FIGURE 4. COMPARISON OF ORIGINAL AND REVISED EQUATIONS
BY FITNESS GROUPS

