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Measurement of Breathing Rate and Volume in Routinely Performed Daily Activities

CALIFORNIA ENVIRONMENTAL PROTECTION AGENCY

AIR RESOURCES BOARD
Research Division

MEASUREMENT OF BREATHING RATE AND VOLUME IN ROUTINELY PERFORMED DAILY ACTIVITIES

Final Report
Contract No. A033-205

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ABSTRACT

In order to evaluate more precisely the potential health risks from air pollution, it is critically important to have accurate estimates of the volume of air breathed (V_E) by exposed populations. There is a substantial amount of characteristic V_E data available in the literature, but values typically are representative of adult males during rest and in light to moderate activities. This is due in part to difficulties in the direct measurement of V_E in free-ranging people, which requires portable respirometers that can restrict normal performance of some common activities. Thus, V_E for free-ranging activity has usually been estimated from unobtrusive heart rate (HR) measurements in individuals whose V_E to HR relationship response to varied intensities of cycle ergometer or treadmill exercise had been established in the laboratory. However, it is not known how accurately V_E is predicted in the field when using this method. To resolve this problem, both V_E and HR must be measured simultaneously in the field across a wide range of free-ranging activities.

The primary purposes of this research were to 1) identify mean values and ranges of V_E for specific activities and populations, and 2) develop equations which would permit V_E predictions based on known activity and population characteristics. The subject population utilized in this study comprised 160 normally active individuals of both genders, and of varied age (6-77 years) and ethnicity. In addition, 40 children (6-12 years) were recruited for data validation and 12 young children (3-5 years) were identified as subjects for pilot testing purposes.

Subjects completed resting (lying, sitting and standing) and active (walking and running) laboratory protocols, and usually one or more field protocols (i.e., play, car driving/riding, car maintenance, yardwork, housework, mowing and/or woodworking). Collected laboratory data included steady-state measurements of V_E, HR, breathing frequency (f_B) and oxygen consumption (VO_2), while data collection in the field was limited to the continuous measurement of V_E, HR and f_B during each protocol.

Resting responses for the children's groups revealed no significant gender differences and those for the adult groups demonstrated minimal age-group differences; therefore, resting data were combined into children, adult female and adult male groups. Heart rate and V_E responses were poorly correlated in all resting postures for each group. However, f_B was a better predictor for V_E, with body surface area (BSA) being an important additive variable in multiple regression equations. Very similar observations were obtained from the cross-validation children's group.

Regression analysis revealed higher r values for walking and running protocols than for field protocols, which were higher than for resting protocols. Typically, HR was poorly correlated with V_E except during active laboratory protocols, whereas f_B and BSA were variables that better predicted V_E across all types of activities and population groups. The inclusion of all three variables (BSA, HR and f_B) in multiple regression equations, generally provided the most accurate

ACKNOWLEDGMENTS

Daniel J. McCann, Ph.D., worked collaboratively in all aspects of project organization and pilot work. He also assumed primary responsibility for the development and modification of both laboratory and field protocols, and in effecting essential elements of data reduction, storage and analysis. He personally conducted and supervised the early laboratory protocols and supervised the careful screening and training of personnel for conduct of subsequent laboratory protocols. He assumed primary responsibility for drafting a preliminary report of the children's group laboratory and field data that resulted in modification of protocols for the children's cross-validation group and for the young children's group.

Ms. Kathi Brookes Joye, Postgraduate Research Assistant, filled several essential roles that ensured successful completion of this project. She aided in recruiting subjects, especially for the young children and cross-validation children's groups. Upon Dr. McCann's relocation in July, 1992, she assumed primary responsibility for completion of the quality control assurance of the accuracy of the computerized database. She was primarily responsible for initial data analysis which, with the large number of subjects and age/gender groups, constituted a laborious, time consuming task. Finally, she was responsible for developing several sections of the first draft of this report. Her performance in all respects was extraordinary.

Alice Van Alstine, M.D., provided medical screening necessary for evaluation of subject acceptance to participate in this study, as well as medical supervision of laboratory exercise protocols for older subjects requiring this oversight. On some occasions, she was assisted in the latter role by James D. Shaffrath, M.D.

Richard E. Fadling, Electronics Technician and Manager, Human Performance Laboratory, provided expert technical expertise in the calibration of equipment and its upkeep to ensure reliable and valid measurements during the laboratory and field protocols. In addition to 25 years experience of highly successful completion of this vital staff support function, he brought omnipressant humor to our sometimes tedious efforts.

Susan D. Fox was the head field protocol technician, whose primary responsibities included organizing procedures for the recruitment of subjects and arrangement of scheduling for laboratory and field protocols, as well as developing an approved list of tasks to be accomplished by subjects during the various field protocols. In addition to conducting a large portion of the field protocols, she assumed primary responsibility for training a cadre of capable field protocol technicians.

Ron Hagen assumed numerous responsibilites in the conduct of the laboratory protocols. He worked directly with Dr. McCann in developing reliable and valid measurement procedures and also conducted a large portion of the laboratory protocols. He was responsible for training a cadre of capable laboratory protocol technicians. Upon Dr. McCann's relocation, he assumed

predictions of V_E across groups and activity types. The lower precision of prediction for active field protocols than for laboratory walking and running protocols was attributed primarily to the wide variety of individual activities and intensity of effort during field protocols.

Using the mean V_E values obtained for each population group and activity, field protocols were categorized into one of the following: sedentary activity, and light or moderate exercise. For the children's groups, spontaneous play protocols were identified as moderate exercise. Car driving/riding was classified as sedentary activity for both genders. Car maintenance for the male adult group was categorized as light exercise, while their V_E responses to woodworking, mowing and yardwork protocols were classified as moderate exercise. The adult female group was found to be performing light exercise while doing housework or yardwork.

It appears that V_E is best predicted in laboratory and field protocols when measurements of BSA, HR and f_B are all included. In addition, children's data should be analyzed separately from that of adults. Male and female adolescent and adult data require separate treatment across genders, but can be combined typically within a gender across age groups.

A consistent observation in this study was that V_E determined in active field protocols at a given HR was 10 to 20 percent lower than that observed in laboratory treadmill walking and running. This difference was ascribed to the greater HR to V_E relationship previously observed by others for arm work compared to leg work.

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responsibility for ensuring quality control assessment of the laboratory protocol data acquistion, data reduction and computer spreadsheet storage tasks.

Numerous U.C. Davis graduate and undergraduate students provided capable assistance in connection with this research. Those conducting laboratory protocols included Lynne Magliano, Liz Driver, Traci Moniz, and Roger Mathews. Those who conducted field protocols were: Bo Yule, Kerri Winters, Tara McKittrick, Mark Davidson, and Moira Jamati. Data reduction and computer spreadsheet entry were done by Josh Green, Dana Jones, and Kristie McWilliams. Julie Baugh provided substantial help in the preparation of the final report.

Finally, the contribution of time and effort of the 212 individuals who served as subjects in both laboratory and field protocols is gratefully acknowledged.

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DISCLAIMER

The statements and conclusions in this report are those of the University and not necessarily those of the State Air Resources Board. The mention of commercial products, their source or their use in connection with material reported herein, is not to be construed as actual or implied endorsement of such products.

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SUMMARY AND CONCLUSIONS

The volume rate of air breathed (V_E) is a variable of primary importance in calculating the dose of an inhaled pollutant during a given period of time. The resultant rate of V_E can vary as a function of the type of physical activity, the intensity of activity, and population characteristics of individuals performing the activity (e.g., age and gender). Although the California Air Resources Board (ARB) has funded two recent studies that have identified typical activities that occupy the majority of time of various groups of individuals, little information is available regarding the resultant rates of V_E for these indoor/outdoor activities which are likely to result in exposure to air pollutants. Thus, it is critical to obtain realistic V_E data for these primary activities across all ages and genders (particularly those underrepresented in the literature) in order to refine dose estimates of air pollutants and reduce the uncertainty of risk assessment.

Direct measurement of V_E in free-ranging activities is difficult due to the restriction of normal patterns of activities with the use of portable respirometers. Thus, equations using heart rate (HR) as the predictive variable of V_E (derived from data gathered in laboratory protocols) have often been utilized to estimate V_E in the field. However, it is not known how accurately V_E is predicted in the field when using this method. To resolve this problem, both V_E and HR (and any other variable that might accurately predict V_E) must be measured simultaneously in the field across a wide range of activities using individuals of both genders and over a wide age range. The present study provides the first systematic investigation that simultaneously measures a variety of physiological variables that affect V_E in normally active individuals representative of the general population, with an equal emphasis on males, females, children, adolescents, adults, and seniors.

In this study, 160 subjects of both genders and varied age and ethnicity, performed laboratory and field protocols in an attempt to accomplish two major objectives: 1) identification of resultant V_E means and ranges for primary activities of children, adolescents, young/middle-aged adults and older adults, and 2) derivation of simple linear and multiple regression equations which predict V_E through other measured variables that could account for activity intensity and population characteristics, such as gender, age and body size. An additional purpose was to validate empirically derived equations for children engaged in selected field and laboratory activities. This was accomplished through the recruitment and testing of 40 additional children.

The laboratory resting protocols consisted of three 25 minute (min) phases of lying, sitting and standing, with data collection occurring in the last 5 min of each phase to ensure steady-state response. The active protocols comprised two phases (walking and running) which were performed on a treadmill over a progressive continuum of intensities ranging from light to moderately heavy exercise. To ensure steady-state response, data were collected for the last 3 min of 6-min bouts at each speed. Measurements during both laboratory protocols included V_E, HR, breathing frequency (f_B) and oxygen consumption (VO_2).

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groups . The differences in V_E response across populations could not be completely attributed to variance in body size; rather, they appeared to be the result of inherent physiological gender and

SUMMARY TABLE 1. Mean Minute Ventilation (V_E, L/min) by Group and Activity for Laboratory Protocols.

ACTIVITY		Young Children	Children	Adult Females	Adult Males
Lying		6.19	7.51	7.12	8.93
Sitting		6.48	7.28	7.72	9.30
Standing		6.76	8.49	8.36	10.65
Walking:	1.5 mph	10.25	DNP	DNP	DNP
	1.875 mph	10.53	DNP	DNP	DNP
	2.0 mph	DNP	14.13	DNP	DNP
	2.25 mph	11.68	DNP	DNP	DNP
	2.5 mph	DNP	15.58	20.32	24.13
	3.0 mph	DNP	17.79	24.20	DNP
	3.3 mph	DNP	DNP	DNP	27.90
	4.0 mph	DNP	DNP	DNP	36.53
Running:	3.5 mph	DNP	26.77	DNP	DNP
	4.0 mph	DNP	31.35	46.03*	DNP
	4.5 mph	DNP	37.22	47.86*	57.30
	5.0 mph	DNP	DNP	50.78*	58.45
	6.0 mph	DNP	DNP	DNP	65.66*

Young Children, male and female 3-5.9 yr olds; Children, male and female 6-12.9 yr olds; Adult Females, adolescent, young to middle-aged and older adult females; Adult Males, adolescent, young to middle-aged and older adult males; DNP, group did not perform this protocol or N was too small for appropriate mean comparisons; *, older adults not included in the mean value since they did not perform running protocol at particular speeds.

age differences, as well as possible mechanical efficiency differences (i.e., inefficiency of children walking and running compared to adults). Individual variations in V_E response within a

Protocols conducted outside the laboratory entailed normal activity patterns within specified activity classifications for subsets of the total subject population. All children completed spontaneous play protocols, while the older adolescent subjects (16-18 yrs) completed car driving and riding, car maintenance (males), and housework (females) protocols. Housework, yardwork and car driving and riding protocols were completed by all of the adult (19-60 yrs) and most of the senior (60-77 yrs) females, while adult and senior males completed car driving and riding, yardwork and mowing protocols. In addition, a subset of young/middle-aged adult males also completed car maintenance and woodworking protocols. Most protocols were 30 min long (driving and riding 20 min each) and were done twice. Heart rate, V_E and f_B were measured continuously during the field protocols using data acquisition techniques that minimized restrictions on free-ranging movement. Statistical analysis of all data included the use of t-tests and analysis of variance to determine group/gender differences, and simple linear and multiple regression analysis to determine the relationship between V_E and other measured variables.

Resting responses for the children's group revealed no significant gender differences and those for the adult groups demonstrated minimal age-group differences; therefore, resting data were combined into children, adult female and adult male groups (see Summary Table 1; also see body of report for ranges and standard deviations). The mean values obtained for each group were similar to those reported in the literature, though usually on more limited subject populations. The minimal age-group differences observed for the adult groups, as well as the gender differences between the adult male and female groups, were primarily due to differences in body size, particularly body surface area (BSA). V_E/BSA values were not significantly different between the adult groups. However, this was not true for comparisons between the children and adult groups. Despite the similar V_E values obtained for children and adult females, the much smaller BSA values for children resulted in proportionately greater V_E/BSA values than those obtained for the adult groups. This difference was ascribed primarily to the greater metabolic needs of children for growth. Interestingly, HR and V_E responses were poorly correlated in all resting postures for each group. In fact, f_B was a better predictor for V_E, with BSA being an important additive variable in multiple regression equations. Very similar observations were obtained from the cross-validation children's group.

The V_E responses obtained from male and female children during walking were not significantly different from each other; however, those obtained during running revealed a significant gender difference. In addition, there were significant age and gender differences within the adult populations for both walking and running. Summary Table 1 provides mean V_E treadmill walking and jog/running data for the following groups: young children, children, adult females and adult males (see body of report for individual population means, standard deviations and ranges). These values were found to be similar to those in the literature for previously studied population subject's fitness level, the intensity with which each person performed an activity, and the activity type.

The mean V_E for adults riding in a car was 5.4% greater than that obtained during laboratory sitting rest protocols for both males and females. While driving an automatic shift car, V_E was 15.2 and 15.6% higher than laboratory sitting rest V_E for females and males, respectively. Using mean values for population and activity type, field protocols were classified as follows: car driving and riding (males and females) as sedentary activity; car maintenance (males), housework (females), and yardwork (females) as light exercise; and mowing (males), woodworking (males), yardwork (males), and play (children) as moderate exercise. For a given mean V_E response, HR values in all active field protocols were about 10 percent higher than those obtained during walking. This suggests that different V_E-HR relationships exist for activities that comprise greater amounts of arm work relative to leg work.

Single best predictive variables for field V_E were the following: BSA, for spontaneous play, car maintenance, and housework; and f_B for cross-validation play, car driving/riding, yardwork (except older adult males), mowing and woodworking. Thus, HR was less well correlated with V_E during the field protocols than were BSA and/or f_B. In general, the r values obtained for all field protocols tended to be lower than those calculated for simple regression walking and running equations. Although the field r values increased when multiple regression equations with BSA, HR, and f_B were used to predict V_E, they were lower than those for walking and running in the laboratory. The lower precision of prediction for the field protocols was most likely due to the wide variety of individual activities and intensity of effort during these protocols.

From our results, and in consideration of others' observations, we conclude that:

1. Male and female children's responses to rest, walking and spontaneous play protocols were not significantly different and, thus, could be combined. However, significant gender differences existed between older subject groups. Significant age group differences were typically limited to comparisons between children's responses and those of combined adolescent and adult groups. While this study is the largest of its type conducted to date, the group sample sizes studied were not sufficiently large to be certain that future, larger studies might well find that some population groups (e.g., adolescents and adults of the same gender) are sufficiently different to warrant separate statistical analyses.

2. In this study, the most accurate predictions for V_E across all population groups and activity types were provided by the inclusion of BSA, HR and f_B in multiple regression equations. Despite extensive prior use of laboratory V_E-HR relationships in the field by other

population, though representative of a typical population, were due primarily to the wide variance in fitness level of the subjects. Higher correlation coefficients (r values) were obtained from regression analysis during walking and running due to the dramatic increases in metabolic demand, such that HR and V_E responses were more closely related than during resting protocols. Body surface area was better correlated with V_E in the children's groups than in the female and male adolescent and adult groups. In general, the highest r values for predicting V_E during walking or running occurred when BSA, HR and f_B were included in multiple regression equations.

SUMMARY TABLE 2. Mean Minute Ventilation (V_E, L/min) by Group and Activity for Field Protocols

ACTIVITY	Young Children	Children	Adult Females	Adult Males
Play	11.31	17.89	DNP	DNP
Car Driving	DNP	DNP	8.95	10.79
Car Riding	DNP	DNP	8.19	9.83
Yardwork	DNP	DNP	19.23+	26.07[a]/31.89[b]
Housework	DNP	DNP	17.38	DNP
Car Maintenance	DNP	DNP	DNP	23.21*
Mowing	DNP	DNP	DNP	36.55+
Woodworking	DNP	DNP	DNP	24.42+

Young Children, male and female 3-5.9 yr olds; Children, male and female 6-12.9 yr olds; Adult Females, adolescent, young to middle-aged and older adult females; Adult Males, adolescent, young to middle-aged and older adult males; DNP, group did not perform this protocol or N was too small for appropriate mean comparisons; *, older adults not included in mean value since they did not perform this activity; +, adolescents not included in mean value since they did not perform this activity; a, mean value for young to middle-aged adults only; b, mean value for older adults only.

Significant gender differences were not observed for spontaneous play protocols; thus, the data for male and female children were combined. Gender (but typically not age) differences were noted for all field protocols common to the female and male adult groups; therefore, they were analyzed separately. Mean V_E responses for each group and activity are included in Summary Table 2 (see body of report for standard deviations and ranges). These mean responses, though realistic population estimates, do not reflect the wide individual variations in values due to each

RECOMMENDATIONS

1. The observation in this study that f_B is a better predictor of V_E than HR during rest and in field protocols should be studied more comprehensively with better equipment, and should include the development and validation of a measurement technique that does not require a respirometer (e.g., an elastic belt with miniaturized transmitter worn over the diaphragm).

2. Since velocity increased the r values obtained during walking and running in this study, better techniques for measuring velocity could further improve V_E predictions in the laboratory and possibly in the field. Miniaturized electronic motion sensors (which can be attached to an arm and/or leg) have been shown to improve HR prediction of energy expenditure in various laboratory exercise protocols.

3. Mean HR responses in this study for active field protocols were consistently higher than those obtained for walking and running in the laboratory at a given V_E. Further investigation of free-ranging V_E-HR relationships should be conducted in the field and/or in laboratory simulations to monitor the influence of arm vs. leg work.

4. A body size component (probably BSA), in addition to HR and f_B, should be further investigated as predictors of V_E in various daily activities amongst people varying widely in size.

5. Further investigation of children's and young adolescents' actual V_E response during various daily activities should be done, since results of the present study suggest that they experience a greater V_E per m^2 of BSA at rest and during activities done at the same speed than do adults.

investigators, we found HR to be poorly correlated with V_E for all except laboratory active protocols.

3. Based on mean V_E responses of all population groups, the field protocols completed in this study were categorized as light or moderate exercise, with the exception of car driving/riding which was classified as sedentary activity.

4. Mean HR responses at a given V_E in this study for active field protocols completed by adolescent and adult subjects were consistently higher than those obtained for walking and running in the laboratory. This was attributed primarily to a greater HR that occurs at a given energy expenditure (and V_E) in activities requiring significant arm work than in those involving leg work.

5. Results of the present study suggest that children and young adolescents experience a greater V_E per m^2 of BSA at rest and during activities done at the same speed than do adults. This has important implications for air pollution risk assessment for these age groups.

extensive review of the related literature, Anderson et al. (1985), in a report prepared for the U.S. Environmental Protection Agency (EPA), were unable to identify equations that would enable the development of statistical distributions of V_E at all activity levels, especially during light or moderate activity for individuals under 18 years of age. Data on adult male and female populations, while more readily available, are severely limited in that the reported V_E values are not representative of the entire activity range (Anderson et al., 1985). Particularly of concern is the lack of established data relating V_E to light and moderate activities that fall into the primary classifications, identified above, that make up the majority of the individual's daily activity (Jenkins et al., 1991; Phillips et al., 1991).

2. Pulmonary Ventilation.

Pulmonary ventilation is generally expressed as the minute volume of gas expired (V_E), corrected to body temperature, ambient pressure, saturated with water vapor (BTPS). Minute volume is the product of tidal volume (V_T)-the volume of gas expired with each breathing cycle- and frequency (f_B). Pulmonary ventilation and its components (V_T and f_B) can be assessed easily in the laboratory by a variety of techniques, ranging from state-of-the-art computerized systems to their classic predecessor consisting of the Douglas bag and an effective means of counting f_B. In either manner, V_E can be assessed in a single subject with repeated measurements during rest and steady-state submaximal exercise with a coefficient of variation (CV) of less than 5%.

Whether at rest or during exercise, the ultimate purpose of the pulmonary ventilation is to provide the body with the appropriate amount of ambient air to obtain adequate O_2 and to expire CO_2. During rest, this metabolic demand remains in a near steady-state over time, while during steady-state exercise, there is a rapid increase from rest over the first 1-2 min, followed by a plateau which reverts to rest as a function of a two-component curve following cessation of exercise (McArdle et al., 1991; p. 134). Since the onset and offset from steady-state exercise V_E is brief, the mean V_E for such an exercise bout can be effectively estimated by the steady-state value. However, if one's activity pattern encompasses numerous changes in activity from rest to various intensities of exertion, then V_E (or a closely correlated measure, e.g., f_B or HR) must be measured over the entire period for satisfactory precision.

Snyder et al. (1974), in the Report of the Task Group on Reference Man, cite means for liters of air breathed by the reference man (170 cm, 68.5 kg, BSA=1.77 m^2), the reference woman (160 cm, 54 kg, BSA=1.54 m^2), and a 10 yr.-old boy (140 cm, 36.5 kg, BSA=1.18 m^2) as 7.5, 6.0, and 4.8 l/min for rest, and 20, 19, and 13 l/min for light activity. The daily activities were assumed to consist of 8 hours (h) rest and 16 h of light activities, including 8 h of light occupational work activity. When these data are expressed as liters of air breathed for the 24-h day, the total is very nearly proportional to the reference man, woman, and child's BSA in m^2. Indeed, Johnson (1989), of PEI Associates, has used the assumption that V_E and BSA vary to-

BODY OF REPORT

INTRODUCTION

1. Research Rationale.

In order to estimate the dose of an inhaled pollutant, one must know the concentration of the pollutant, the duration of exposure, and the pulmonary ventilation rate (V_E), i.e., the amount of air containing that concentration of pollutant which has been inhaled during the given time period. As a person performs physical activity, whether indoors, in an occupational task, or simply as recreational activity/exercise, his/her V_E increases with increasing work rate. As V_E increases, it follows that the pollution dose will increase, thus enhancing its effects. Hence, in order to evaluate more precisely the potential health risks from air pollutants, it is critically important to have accurate estimates of the V_E experienced by exposed populations.

The Air Resources Board (ARB) is required to assess the general population's exposure in indoor environments as well as in ambient (outdoor) air in evaluating the level of potential exposure to toxic air contaminants (California Health and Safety Code Section 39660.5). The ARB is also required to identify the relative contribution of indoor concentrations to total exposure. Estimation of exposure, or inhaled dose, for a given pollutant requires knowledge of the air concentration of that pollutant in different microenvironments, the length of time people spend in each microenvironment, and the amount of air typically inhaled during major activities that commonly occur in each microenvironment. However, little information is available regarding breathing rates and volumes during typical activities and during some activities likely to result in exposure to air pollutants.

One of the critical information needs for exposure assessment is detailed data on human activity patterns, since they can determine the duration, frequency, and intensity of exposure (Jenkins et al., 1991). Because information of this type obtained by previous national and California activity studies were deemed unsatisfactory, the California Air Resources Board (ARB) recently funded two statewide surveys of Californians' activity patterns (Jenkins et al., 1991; Phillips et al., 1991). The results of these two studies identified a number of primary activities that occupy the majority of an individual's time. This information, in conjunction with knowledge of the physiological intensity and resultant rate of V_E that occurs in these activities, is necessary if a significant reduction in the uncertainty of risk assessment to various toxic air pollutants is to be achieved.

Incorporation of quantitative assessments of the intensity of daily activities and resultant V_E into risk assessment models must include population estimates of both the mean and standard variance values for a given activity. Unfortunately, such data are not currently available for many of the primary activites discussed above, especially for children, women, and the elderly. After

4. Statement of the Problem.

Clearly a need exists for identification of the intensity and the resultant V_E for the primary activities of children, adolescents and adults that have been recently identified (Jenkins et al., 1991; Phillips et al., 1991). All three of these populations participate in several common activities that entail different postures (i.e., lying, sitting, and standing) and light activity involved in walking, personal care, and transportation. Also, since many individuals in each of these populations participate in some form of recreation, likely recreational activities that have the potential to induce high levels of V_E, should be investigated. These activities include: brisk walking, running, bicycle riding, aerobics and/or team activities (Jenkins et al., 1991; Phillips et al., 1991).

Population specific activities should also be considered, especially where the duration of the activity and the proximity to pollutant sources warrant special attention. These type of activities, also identified in the activity assessments provided to ARB (Jenkins et al., 1991; Phillips et al., 1991), include: classroom type activities for individuals 19 years of age and younger; auto repair and or cleaning, woodworking, and gardening for males over the age of 19 years; and office work, meal preparation, housework (including vacuuming and scrubbing the bathroom) and gardening for females over the age of 19 years.

This information, in conjunction with knowledge of the physiological intensity and resultant rate of V_E that occurs in these activities, is necessary if a significant reduction in the uncertainty of risk assessment to various toxic air pollutants is to be achieved. However, knowledge of the V_E associated with most primary activities of concern is lacking, especially for specific populations such as children, adolescent and adult females, and the elderly.

Direct measurement of V_E in free-ranging people requires portable respirometers that can restrict normal performance of some common activities done in the home, workplace, or in recreation. Thus, in previous studies, V_E for free-ranging activity has been estimated from unobtrusive HR measurement in individuals whose V_E-HR relationship response to varied intensities of cycle ergometer or treadmill exercise had been established in the laboratory (Raizenne and Spengler, 1989; Shamoo et al., 1991). However, the relationship of energy expenditure (and, thus, V_E) and HR varies considerably in individuals engaged in normal daily activity (especially in the light activity range). At this low range of HR, the slope of the HR/oxygen uptake (and V_E) association is not uniformly linear (Washburn and Montoye, 1986). In addition, many factors besides physical activity, such as temperature, type of muscle contraction (e.g., static vs. dynamic), and emotional stress are known to affect HR (Haskell et al., 1992).

With regard to the type of exercise effect on the V_E-HR relationship, HR at a given oxygen consumption (VO_2)--and, presumably, V_E--is higher in predominantly arm work than in leg work (McArdle et al., 1991; p. 339). Samet et al. (1991) have utilized laboratory simulated activity gether in such a way that their quotient (i.e., V_E/BSA, which he called the equivalent liters per minute, or ELPM) is nearly constant at a given level of exertion for populations and individuals who vary significantly in body size.

3. Pulmonary Ventilation During Rest and Physical Activity.

Over an entire day, all but the few individuals who engage in heavy physical labor or in prolonged athletic training, will experience the majority of their metabolic (and thus, V_E) demand as a result of basal metabolism. Further, there is clear evidence that most of our population constitute an effective demonstration of an evolving species, *homo sedentarius* (Astrand, 1986), in which most individuals' daily activities are characterized by prolonged periods of very light activity. Indeed, Waterlow (1986) reports a mean daily energy expenditure (i.e., metabolic demand) for both adult females and males that is only 1.78 times that necessitated for basal metabolism alone. However, there are notable individual exceptions in which metabolic demand and V_E are significantly elevated for prolonged periods, and sometimes in the presence of significant air pollution (Adams, 1987).

Anderson et al. (1985) has reviewed the literature relative to V_E reported for physical activity levels beyond light work. They found very few observations for both male and female children and for young adults in physical activities categorized as either light or moderate, especially for females. There was also a paucity of similar data for the elderly, again especially for females. Though there was a comparative abundance of V_E data for maximal work for all ages above 6 yrs for both genders, it is of minimal importance relative to the total V_E per day because such workloads can only be sustained for 5 to 20 minutes (min), and are normally not repeated during a single day.

There have been numerous classification systems advanced to categorize the workload/physical demands of activities, particularly for tasks entailed in various occupations. Although many are based on workload assessment and measurement of physiological response of the workers, the various levels identified remain rather arbitrary. For example, the EPA identified the collapsed range of activities accepted in the EPA Environmental Criteria and Assessment Office for the ozone criteria document, as follows:

1. Light exercise ($V_E \leq 23$ L/min)
2. Moderate exercise ($V_E = 24$ to 43 L/min)
3. Heavy exercise ($V_E = 44$ to 63 L/min)
4. Very heavy exercise ($V_E \geq 64$ L/min)

While these values are appropriate for a 70 kg. "reference man", they are not suitable for use with children, adult females, or for the elderly. This is due in large part to the close association between BSA and V_E at any given work intensity (Johnson, 1989).

DESIGN & METHODS

1. Subject Selection, Recruitment, and Orientation.

Subject Selection. The primary subject population in this study comprised 160 individuals, selected according to age, gender, and ethnicity. There were four age dependent groups: 1) children 6 to 12.9 yrs., 2) adolescents between 13 and 18.9 yrs., 3) adults between 19 and 59.9 yrs. of age, and 4) seniors, > 60 yrs. Within each age group category, which was subdivided by gender into males and females, the range of age representation was widely distributed. Further, in an attempt to closely approximate the primary ethnic group representation in the 1990 U.S. census for California-i.e., 55% Caucasian, 27% Hispanic, 9% Asian, and 8% Black-each of our 8 subject population groups of 20 included 11 Caucasians, 5 Hispanics, and 2 each Asians and Black subjects. While very few of our subjects could be properly described as "couch potatoes", none were training for athletic competition; thus, our subjects spanned most of the range of normally active individuals.

Subject Recruitment. Initially, we considered utilizing mass communication appeals, such as advertising in local newspapers, contacting local schools, service clubs etc. However, since we anticipated that this would involve significant administrative effort, we first elected to utilize our previously successful restricted subject recruitment procedure of appealing to UC Davis students, faculty, and staff. This included announcements in large lecture classes for young adult subjects (accenting the need for ethnic minority individuals), preparing an informational flyer for distribution to University staff, and personal phone contact with faculty known to members of the research team. We also were successful in obtaining a significant number of middle-aged adult subjects (though without full ethnicity representation) from individuals who had participated as subjects in previous Human Performance Laboratory studies. From these efforts, "word-of-mouth" suggestions from subjects, having completed the study, of other individuals who might be willing to participate in the study provided us with most of our remaining subject population.

However, several "special" recruitment efforts were necessary to uncover adequate numbers of subjects for certain age and ethnicity representation. These included development of an informational flyer for recruiting children at a local elementary school that resulted in over a dozen subjects, about equally boys and girls. A teacher at another elementary school with an unusually large ethnic minority representation provided a list of ten families with one or more children, which resulted in the identification of more than a dozen subjects. Another contact with a women's P. E. teacher/coach at an intermediate school (6th-8th grades) in Dixon, with a significant Hispanic student representation, resulted in identification of all of the Hispanic subjects needed within this age range, i.e., older children (11-12 yrs.) and young adolescents (13-14 yrs.). Following the recruitment of several seniors of both genders, who completed testing and recommended others of involving lifting and vacuuming, which more closely parallels activities performed by free ranging individuals in their normal daily activity, to establish a V_E-HR relationship. However, V_E and HR have not been measured simultaneously in the field while subjects actually perform activities typical of their normal daily routine.

There is substantial evidence that body size affects the V_E-HR relationship. However, other factors including gender, age, and one's fitness level, also appear to influence the V_E-HR relationship (Åstrand & Rodahl, 1977; pp. 344-355). Thus, further investigation is necessary to determine whether a single equation which accounts for these factors can be created for use in V_E estimation for the general population, or whether separate equations must be created for specific population groups such as the elderly, children, males or females, etc.

5. Statement of Research Objectives.

There were two primary objectives that this research was designed to achieve. The first was to identify, through laboratory and field study, measures of the average values and ranges of V_E associated with specific activities and populations identified by the ARB. The second was to derive through statisical analysis, simple empirical equations that predict levels of V_E achieved during these and other similar activities, based on knowledge of the major independent variables of body size, age, gender, mode and intensity of activity. While variables such as body size, age, gender and mode of activity are easily obtained, quantification of the intensity of activity is not. Therefore a secondary purpose of this research was to identify the relationship between the physiologic indicators of activity intensity (HR and f_B) with V_E for each of these populations and activities. It was also our intent to determine if the V_E-HR relationship for laboratory resting and activity protocols was the same as that observed during the field protocols. Finally, since there are so little V_E data for children under 13 years-old, another secondary purpose of this research was to provide cross-validation of the empirically derived equations for breathing rate and volume for children engaged in selected field and laboratory activities. In this procedure, a second group of children of similar age and body size is studied in the same manner as the original group. If similar predictive accuracy is obtained in the second (i.e., cross-validation) group when utilizing equations developed on the original group, it would indicate a high degree of external validity of these equations.

It was anticipated that results from this study would simplify the task of predicting the average values of V_E for a given activity. Having this capability would eliminate the need for cataloging mean V_E measures on each and every combination of the variables that can affect V_E. It would also identify those factors which are most important in determining V_E for each of the populations. Quantification of these relationships will produce simple empirically derived equations which, when used correctly, will enhance the predictability of levels of V_E achieved by Californians during normal daily activities.

The subject's height and body weight were measured, as was skinfold thickness at three sites for determining their percentage of body fat (Jackson and Pollock, 1978; Jackson et al., 1980; Lohman, 1986). Body surface area was calculated from measured height and weight using the formula of DuBois and DuBois (1916), where $BSA(cm^2) = Ht.(cm)^{0.725} \times Wt.(kg)^{0.425} \times 71.84$. The orientation session concluded with the subject's participation in 5 different activities, each lasting several minutes. These activities included: 1) lying quietly, 2) sitting quietly, 3) standing, 4) walking on a treadmill at 3 speeds ranging from slow to moderately fast, and 5) if able, jog/run at 3 speeds ranging from slow to moderately fast. During the performance of these activities, they were asked to wear a noseclip and a small rubber mouthpiece attached to a light-weight, low resistance respiratory valve. Their HR was monitored via a chest band with miniature transmitter and a wrist watch telemetered receiver. An attempt was made to provide adequate time to relieve any anxiety the subject might experience during this initial performance of these activities while wearing the data collection devices.

2. Experimental Design.

Laboratory Protocol Activities. Each subject was studied twice in the laboratory under quiet, relaxed and thermoneutral temperature conditions; the first session consisted of a resting protocol, and the second an active protocol. The resting protocol consisted of three phases: 1) lying, 2) sitting, and 3) standing. The lying phase was 25 min in length to ensure that a quiet steady-state resting level was achieved before collecting data during the last 5 min. Utilizing only the final 5 min for data collection attenuated any carry-over effects of previous activity, and was considered to represent the best estimate of the true V_E "required" for this activity The sitting and standing phases of the resting protocol were conducted in the same manner. During the protocol, subjects were permitted to read, listen to quiet music, or to draw while sitting and standing (only a few children did the latter).

The active protocol consisted of two phases: 1) walking, and 2) jog/running. Both were performed on a treadmill at a continuum of intensities, since the wide range of pulmonary ventilations associated with these activities is significantly affected by intensity. Each of the two phases entailed an incremental progression of work rate. Subjects first walked for 6 min each at 3 speeds ranging from slow to moderately fast. Following a short break of 5 to 10 min, subjects jogged/ran for 6 min each at 3 speeds, ranging from slow to moderately fast. The ranges of speed utilized for any particular subject were dependent on their age, body size and fitness. However, an attempt was made to utilize at least one and, if possible two, speed(s) common to all subjects of all groups. This was possible for the walking phase, but it was not feasible to achieve an overlapping speed range for jog/running for all subjects in all groups. In fact, less than one-quarter of the senior females could jog at even one speed (between 3.8-4.5 mph), while less than their age as possible participants, it became clear that a more effective method than "word-of-mouth" for identifying an adequate subject pool in this age group was needed. Hence, we distributed an informational flyer to a seniors group working with the UCD Medical Center Department of Community Health and to staff members at both the Davis and Woodland Senior Citizen Centers. This resulted in procurement of all remaining senior subjects except for those of Hispanic ethnicity. The latter group, who are underrepresented in Davis, was eventually completed primarily by consistently requesting names of older Hispanic adults (male and female) from adult subjects completing the study and diligently following up on these recommendations. In summary, while most of our subjects were UC Davis students or residents of Davis, about 25% resided in Dixon, Woodland, or in the Sacramento area.

Subject Orientation. Once individuals were contacted (as described above) and indicated interest in participating as a subject in this study, they were provided with a Campus approved human subjects informed consent form (which described the laboratory and specific field protocols and methods to be used, as well as the estimated time required of the subject) and a health history form. They were asked to read the consent form and to complete and return the health history form (a parent, or legal guardian did both for subjects under 18) as soon as possible. Each health history form was screened initially by a member of the research team according to procedures approved by the project physician consultant. Specifically, those individuals who had a case history (or major symptoms) of cardiovascular, pulmonary, or metabolic disease, or who had any musculoskeletal impairment sufficient to restrict performance of the activities to be studied, were not permitted to serve as subjects. Those chosen for the physician's personal review were directed to her for follow-up and approval for participation in both the laboratory and field protocols. If an individual was rejected on the basis of information provided on the health history form, the physician personally advised him/her of this fact (This occurred in 7 cases out of 65 persons over age 45 who were solicited as subjects.).

Upon arriving at the laboratory, each subject brought their human subject consent form, which was signed during this orientation session. (NOTE that minor children were accompanied on this occasion by a parent/legal guardian, except in a few cases when they had previously signed the form indicating approval for their child to participate as a subject.) The subject was first asked if he/she had any questions concerning the content of the consent form. They were then shown the equipment to be used in the subsequent laboratory and studies. This also included familiarization with equipment and the experimental procedures to be used, including the portable, light-weight (1.1 kg) breathing and HR measurement assembly used in the field studies. The research team member then asked the subject if he/she had any questions before they signed the informed consent form indicating their intention to participate in the study.

also followed for activities identified by ARB as being of special interest due to the heightened possibility of exposure to particular toxic air pollutants. These included lawn mowing with a gas-powered push mower, woodworking, and car maintenance/repair, for which some subjects might not have facilities and/or equipment at their home to perform. Thus, these protocols were carried out either at the subject's home or at another location where facilities to perform these tasks were available. In the latter case, a microenvironmental locale was identified, including an enclosed garage where tools and other necessary materials were available for those adult males who had experience in woodworking, but did not have these facilities available at their residence. Similarly, about a half-dozen lawn mowing protocols were done on a grass plot adjacent to the Human Performance Laboratory that required at least 30 min using the UC Davis Athletic Department gas-powered push mower.

Activities suggested by ARB staff as suitable within the above field protocol classifications included the following:

1. **Yardwork**-hoeing, raking, pruning, watering, digging with shovel, sweeping, weeding, and spading with hand trowel
2. **Housework**-vacuuming*, scrubbing* floor/sink/shower, meal preparation, mopping, washing dishes, dusting, and polishing
3. **Mowing**-lawn with gas-powered push mower and emptying clippings
4. **Woodworking**-sawing (by hand), hammering, painting, sanding
5. **Car repair/maintenance**-change tire, check under hood (oil & other fluid levels, sparkplugs, etc., change oil, wash, dry, and wax

* vacuuming and scrubbing were requested in all housework protocols

Drive/ride field protocols, which required licensed drivers 16 yrs. or older, were conducted in cars (usually the subject's personal vehicle, but occasionally one rented from the University garage) equipped with automatic transmission. Subjects were usually paired, such that one drove while the other rode in the back seat, then reversing roles (thus necessitating two lab technicians, each utilizing a separate set of data collection apparatus). Subjects performed the driving and riding tasks in essentially random order, with time of each reduced to 20 min, since no notable variation in ventilation volume or heart rate values over time were observed in pilot testing of 30 min length. Testing of almost all subjects took place on a single occasion. All testing protocols included a route that included near equal portions of "in-town", two-lane county road, and freeway driving.

Children's spontaneous play protocols were conducted both indoors and outdoors, sometimes in or adjacent to Hickey Gymnasium. A near similar number were conducted at a playground nearby the subject's home, with a few at the subject's home. Children were asked to play as usual but, in some cases, because of apparent timidity, they were encouraged to increase half of the senior males were able to jog at one or more speeds (ranging from 3.8-5.5 mph). Some of the children, especially those 8 yrs, or younger, were also unable to jog/run at more than one or two speeds. Almost all individuals in the adolescent and adult groups, including subjects of both genders, ages 13-59 years, were able to walk at three speeds and to jog at one or more speeds.

Field Protocol Activities. Protocols conducted outside the laboratory (i.e., in the field), entailed study of normal activity patterns in several activity classifications by specific population categories (see Table 1). All field activity protocols were carried out at a freely chosen pace deter-

TABLE 1. Summary of Field Activity Classification by Population Category.

Population	Field Activity
children (boys & girls)	- spontaneous play
adolescents (males age 16-19)	- car maintenance and repair - driving and riding in a car
adolescents (females age 16-19)	- housework - driving and riding in a car
adult males	- yardwork - driving and riding in a car - mowing (gas powered mower) - car maintenance and repair - woodworking
adult females	- housework - yardwork - driving and riding in a car
seniors (males)	- yardwork - driving and riding in a car - mowing (gas powered mower)
seniors (females)	- housework - yardwork - driving and riding in a car

mined by the individual. However, standardization of the methods of instruction and data collection were maintained within and between populations. For adult subjects, most field protocols (except for car drive/ride) were conducted at their home. For these activities, the subject was instructed to carry on the activity at their usual pace, being sure to include all of the individual tasks that were typical of their normal activity pattern. The time spent during each task was proportional to the relative contribution of the time it normally took the subject to complete the task when compared to the total time usually spent in the activity. For example, if an individual usually worked at four different tasks while performing 60 min of yardwork, they were asked to spend half as much time doing each task during the 30 min data collection period. This procedure was through the same rubber mouthpiece and Hans Rudolph two-way breathing valve assembly (with noseclip) used in the resting protocol, which was mounted on a light-weight plexiglass helmet liner positioned on the subject's head. During the 18 min of continuous walking, the subject breathed continuously through the respiratory valve. Heart rate was monitored during each of the last 5 min of each 6-min measurement period, utilizing a UNIQ CIC Heart Watch Monitor™ system, with f_B determined in the same manner as that used during the resting protocol during each of the last 3 min of each 6-min period.

Pulmonary minute ventilation and standard respiratory metabolism parameters were continuously monitored, with 1-min average values printed out from an on-line computerized data acquisition system every 15 seconds (s). Data acquisition instruments interfaced to the DEC LSI 11/2 microcomputer included a Parkinson-Cowan (PC) Type CD4 high-speed gas meter, an Applied Electrochemistry S-3A O_2 analyzer, a Beckman LB-2 CO_2 analyzer, and a temperature thermistor located in the expired gas line. While V_E and VO_2 data were collected continuously, only the data taken during the last 3 min of each 6-min level was used for analysis, as this period represented the best estimate of steady-state responses following the initial ~3 min cardiorespiratory lag at each work level.

Following a short break of 5 to 10 min, subjects jogged/ran for 6 min each at from 1 to 3 speeds, dependent on their age, body size and fitness. Methods and procedures for obtaining V_E, f_B, HR, and VO_2 data were identical to those used for the walking phase, except that some subjects stopped for several minutes between one or more of the 6-min jog/run bouts.

4. Field Protocol Measurements.

Heart rate, V_E, and f_B were measured during field protocols. Since the activities monitored consisted of a variety of tasks requiring extensive freedom of movement, data acquisition techniques with a minimum of restriction to free-ranging movement were employed. Heart rate was monitored on a minute-by-minute basis by using the programmable data averaging and storage mode of the UNIQ CIC Heart Watch Monitor™ also employed in the laboratory protocols. Pulmonary minute ventilation and f_B were measured via a Harvard™ portable respiratory air monitor (model 50-8226) with attached Medishield Wright flow transducer and mouthpiece. The attached expired gas temperature measurement system employed a thermocouple digital thermometer (Cole-Parmer, model 8500-40), while an AIWA stereo tape cassette was used to record the continuous pulse signal during the expiratory phase of each breath cycle. Adolescent and adult/senior subjects performed their field protocols wearing a noseclip and with a rubber mouthpiece and light-weight respiratory valve (with 53 ml dead air space) assembly, which had a wired connection to the Harvard respirometer module and attachments that were carried in a cloth carpenter's apron secured around the waist of the field research technician.

their intensity of play in order to ensure a more representative range of ventilation volumes and heart rates.

3. Laboratory Protocol Measurements.

Resting Protocol. Resting physiological measures taken for each posture (lying, sitting, and standing) included: 1) V_E, 2) f_B, 3) HR, and 4) oxygen consumption (VO_2). An expired air sample of 5 minutes duration for each posture was collected in a Tissot respirometer according to the procedure of Consolazio et al. (1963, pp. 12-16). The rubber mouthpiece and Hans Rudolph two-way breathing valve (Model 2700) had a dead-air space of 114 ml. Heart rate was monitored during each minute of the 5 min measurement period for each posture, utilizing a UNIQ CIC Heart Watch Monitor™ system, which included an adjustable chest band with a clipped-on miniature transmitter and a wrist watch telemetered receiver..

Following 15 min lying quietly, the subject placed the mouthpiece in their mouth and positioned the noseclip to obviate nasal breathing. During the next 5 min, the subject's expired air directed into the Tissot tank was flushed on two occasions to remove residual room air gas concentrations from the system. The subject continued to breathe through the respiratory valve for another 5 min while expired air was collected for ventilation volume measurement. During this period, HR was monitored each minute, while f_B was measured during each of the last 3 min by stopwatch determination of the elapsed time for 10 expirations, and extrapolation to breaths per minute (br/min). Immediately following the 5 min collection period, expired air temperature in the Tissot tank was recorded and barometric pressure was noted. Duplicate samples of expired air were then analyzed for O_2 and CO_2 concentration using an Applied Electrochemistry S-3A O_2 analyzer and a Beckman LB-2 CO_2 analyzer. Both analyzers were calibrated with standard gases immediately prior to analyzing the samples. Ventilation volume and VO_2 calculations were done according to the equations of Consolazio et al. (1963, pp. 5-9).

Following completing the lying measurement phase, the subject immediately assumed a comfortable sitting position that was maintained for the next 25 min. Similarly, after completing the sitting measurement phase, the subject stood erect and maintained a comfortable non-rigid standing posture for the next 25 min. The methods and procedures utilized for both the sitting and standing measurement phases were the same as those used for the lying measurement phase.

Active Protocol. Physiological measurements obtained during the active protocol were the same as for the resting protocol, viz., 1) V_E , 2) f_B, 3) HR, and 4) VO_2. For most subjects, there were two phases--walking and jog/running, each entailing an incremental progression of work rate designed to effect a range of intensity extending from slow to moderately fast. Since both the walking and jog/running phases were initiated at a low intensity, warm-up was "built in" to the first 6-min bout. To obtain expired air volume and gas concentrations, the subject breathed

It was anticipated that this would result in a better understanding of the predictability of the original study population's response, as well as the opportunity to refine the data base.

To accompish the latter, statistical analysis was performed to determine if the group mean values for the cross-validation sample were significantly different from those of the original study children's group. Also, statistical comparisons were made in order to evaluate the accuracy of our prediction equations on this second population sample. It was anticipated that any significant differences between the groups would identify specific areas of uncertainty in generalizing from the original group's data. Conversely, similarities between the two populations would justify pooling the data, thus resulting in an improvement in subsequent predictability during application of the analytical results.

With two notable exceptions, the experimental protocols and techniques for data collection in the cross-validation study were identical to those utilized on the original 40 children of this age group (see above). A preliminary analysis of the original children's population V_E and HR responses during the resting protocol, showed that there were no significant differences between the lying and sitting conditions. Because of this observation and, since sitting is more often a posture experienced during activities (except for sleep which our protocol was not designed to assess) both in and out of the home, we proposed and received approval from ARB staff to eliminate the lying condition from the cross-validation study. We also received approval to reduce the play field protocol from two 30-min sessions to one of 35 min length in the cross-validation study, since our preliminary analysis of the original children's population V_E and HR responses showed significantly lower values for the first 5 min than for any other 5 min period (which remained near constant) in both sessions (which did not differ significantly from each other).

6. Special Population Pilot Study (Children, 3-5 yrs).

Because of our anticipation of special difficulty in obtaining and successfully testing a full complement of children less than 6 yrs. of age, we proposed only to complete the laboratory and field protocols specified above for this age range as a pilot study on a limited number of individuals (N=12). Hence, the data obtained in this pilot work were not analyzed statistically according to procedures used for the original study population. However, it was anticipated that group means and ranges for the same physiological responses during both laboratory and field protocols, as were obtained on the older original study population, would provide useful- and near unique- information of use to ARB pollutant exposure risk assessment objectives.

The experimental protocols and techniques for data collection in this pilot study were similar to those utilized with the original study's population of 40 children, ages ranging from 6 to 12.9 yrs. (see above). Each of these young children completed the orientation session and the resting V_E and HR measurement protocol, though the length was reduced from 25 to 15-20 min

Each field protocol required that the subject become familiar with the requirements of the protocol and performance of the activities while wearing the HR monitoring device and having the noseclip and light-weight mouthpiece/respiratory valve assembly in place. After reviewing these requisites with the subject, the field research technician signaled the subject to begin the protocol as he/she started the HR and V_E/f_B measurement devices. Cumulative ventilation volume readings on the Harvard digital display, along with expired air temperature readings from the portable telethermometer, were recorded by the technician at 1 min intervals. Following completion of the protocol, the cassette tape was rewound in preparation for subsequent downloading on a Hewlett-Packard strip chart recorder (model 7402A) from which f_B could be counted manually. Gas temperature values were averaged and converted to a volume correction factor for V_E values. Minute-by-minute average HR was recorded on the subject's data sheet by downloading from the Heart Watch storage mode.

Due to the active and unpredictable nature of children's spontaneous play activities, the "tethered" method for recording field data used with adolescent and adult/senior subjects was deemed to be too restrictive for children. An alternative method was developed in which the entire equipment assembly (consisting of the Harvard respirometer, portable telethermometer, and cassette taperecorder, weighing 1.9 kg.) was secured on the subject via a backpack with 3 pockets on the outside for each piece of measuring equipment. The pockets contained a window to allow reading the measurement values directly off the subject's back. The backpack was secured on the subject by a chest and waist strap. This effectively "unleashed" the subject to play as he or she wished. While HR was measured every minute as described above, minute-by-minute V_E measurement recording was not feasible. Thus, cumulative V_E value at 5 min intervals were utilized to permit the children to play more spontaneously. (Note: Although data were collected every minute during the adolescent and adult/senior field protocols, these data were averaged into 5 minute periods for further analysis.)

5. Cross-Validation Study.

Since children between the ages of 6 and 12 yrs show a rather large range of body size and activity patterns, and there is a dearth of information concerning the physiological responses during normal activity for this population, a cross-validation study of the empirical equations derived for this population from the original study population described above, was conducted. In this study, laboratory protocols (resting and walk/jogging) and field (spontaneous play activities) protocols on an additional 40 subjects (20 boys and 20 girls) not included in the original analysis, were performed. To reduce the potentially confounding effect of body size on the physiological responses of interest, an attempt was made to match each group's mean body height and weight.

volume correction factor (CF) was found to be 0.97, while that for Harvard respirometer #2 was 0.98.

In order to appropriately correct ventilation volumes when using the Harvard respirometer, it is necessary to measure the temperature of expired gas. Because this feature is not provided on this instrument, we devised an expired gas temperature measurement system using a thermocouple digital thermometer. A small thermocouple was taped in the mouthpiece so that expired air temperature values could be recorded every minute to determine the appropriate volume correction factor for V_E values read from the Harvard digital display.

The Harvard respirometer provides a continuous pulse signal during the expiratory phase of each breath cycle, but does not automatically display, record, or store this information. Thus, we developed a means of measuring and recording breathing frequency from the expiration pulse signals. This was achieved by utilizing a small tape cassette to record each expiratory pulse signal from the Harvard respirometer.

c. Data management. Data management for this project consisted of three phases. The first phase, data acquisition, took place during each experimental protocol. The second phase, data reduction, which, depending on the type of exercise protocol, involved several discrete tasks. In general, data reduction consisted of 1) organizing the data by population and activity into separate data bases, 2) transferring data from handwritten records and computer printouts to computerized spreedsheets, and 3) performing basic computational manipulations that "reduced" the raw data to more manageable formats, such as 5 minute and 30 minute averages. The latter was done in spreadsheet form, utilizing MICROSOFT EXCEL™ version 3.0. All data records and analysis were stored on a SyQuest Technology SQ400 44 Megabyte Disk Cartridge. The third phase of the data management plan, data analysis, is described in the subsequent statistical analysis section.

Prior to initiating the statistical analysis phase of the data management plan, a retrospective quality control program for all data bases was conducted. The purpose of this program was to stringently screen the master data sheets and the spreadsheet data bases for validity to ensure that no spurious data had been entered, and that any aberrant subject responses were identified and remediated. This program consisted of a review of both the original data records and the individual average responses for each subject contained in the computerized spreedsheet data bases. If any data were discovered outside the expected range for a specific group and activity, the experimental records were reviewed to ensure validity. If the data were found to be unsatisfactory, remedial steps were taken to appropriately complete the data base (e.g., elimination of that data and use of the multiple bits of remaining data to characterize the entire protocol, or requiring that the subject repeat the protocol).

The retrospective quality control program for the laboratory protocols resulted in repeating for each posture (with the sampling period continuing to occur during the last 10 min). This, together with parents (and, in some cases, lab technicians) reading to these young children kept them in what was felt to be a reasonably "quiet state" while measurements were being taken.

Because of this group's very small body size (and resultant low V_E during treadmill walking), their expired air was collected in the Tissot tank for 2 min at each speed, utilizing the same procedures as described previously for the resting protocol. All subjects walked at 3 speeds for 6 min each (1.5, 1.88, and 2.25 mph), but most only sporadically jogged and walked at speeds ranging from 2.7 to 3.8 mph. Even when the length of time at each jog/running speed was reduced from 6 to 4 min, with data secured during the last 2 (rather than 3) min, only 3 of this group's 12 subjects were able to complete one or more speeds ranging from 2.7 to 3.8 mph.

Measurement of HR, V_E, and f_B during spontaneous play activities, utilizing the same "backpack" container for data collection instruments and procedures described above for older children, was accomplished for all 12 children in this study. However, the two 30-min periods used with the older children, were reduced to two 20-min play protocols for this age group.

7. Quality Control and Assurance.

a. Heart rate monitor. In our laboratory, the UNIQ CIC Heart Watch Monitor™ has been shown to be a valid measurement device (± 1 b/min, when compared to simultaneous standard ECG method values). This degree of accuracy is closely similar to that reported by Treiber et al. (1989) for simultaneous ECG recorded data obtained on children in the laboratory and the field. The UNIQ CIC Heart Watch Monitor™ is capable of both instantaneous display and storage of 1-min average HR for over 30 min, which was particularly useful in this study.

b. Ventilation measurement devices. The PC high-speed gasometer utilized in the active laboratory protocols had not been calibrated against the "gold" standard Tissot tank (Consolazio et al., 1963, pp. 24-30) at ventilation rates typical of those expected for small people engaged in slow and moderate speed walking (i. e., < 20 l/min). Calibration was completed, showing that this device provided valid measurements over the full range of ventilation values characteristic of activity from low to heavy levels (i.e., from 15 to in excess of 100 l/min) in both small and large individuals. However, for small children walking at slow speeds, which entailed less than 15 l/min, it was necessary to obtain 2 min expired air collections with the Tissot tank in the same manner as that used during the laboratory resting protocols.

Ventilation volume values obtained by the two Harvard respirometers were tested for validity and reliability by comparing those values obtained with the Harvard instruments vs. those measured on the VMM turbotachometer and the PC meter (used for measuring V_E during the active laboratory protocols). All were calibrated vs. the "gold" standard Tissot tank, and were recalibrated following any maintenance or repair work. The initial Harvard respirometer #1 V_E

RESULTS

1. Subject's Anthropometry.

A total of 160 subjects participated in the primary part of this study. In addition, 40 children (ages 6-12.9 yrs.) served as subjects in the cross-validation study, and 12 young children (3-5.9 yrs.) served as subjects in a pilot study of this age group. The ethnicity representation described earlier was strictly adhered to in each of the 8 base population groups of 20 each. In addition, 16 of the 40 cross-validation subjects were non-Caucasian, as were 4 of the 12 young children subjects. A summary of group anthropometry is given in Table 2. There were no statistically significant differences between the male and female children's anthropometry except for % body fat. The cross-validation gender groups did not differ significantly from each other for any anthropometrical variable, nor did they differ significantly from the base population children's groups. This was as expected, since there are no substantive anthropometric differences between genders until puberty. The adolescent male and the adult male groups were significantly larger than their female counterparts, but had significantly lower % body fat. The adolescent female group was somewhat smaller than the adult female groups and had significantly less % body fat than the female +60 yrs. group. The adolescent male group was significantly smaller than the adult male groups, and had a lower % body fat than the male +60 yrs. group.

2. Resting Protocols.

a. Original Group of Children. The male and female children's group mean responses (and standard deviation) for V_E, HR, f_B, VO_2 (l/min), VO_2 (ml/min per kg LBM), and V_E/BSA for the three resting positions are given in Appendix Table 1. There were no significant gender differences for any of these measures. Hence, the data for both groups were combined for subsequent statistical analyses. As shown in Table 3, except for f_B, the mean values for standing were significantly higher than those for lying and for sitting. The differences between lying and sitting were not statistically significant, except for HR. Thus, the lying and sitting conditions imposed similar demands on the metabolic and ventilatory systems, but not for HR, which was progressively greater acccording to the hydrostatic pressure effects of the three postures (means were: lying = 83 b/min; sitting = 88 b/min; standing = 96 b/min).

A frequency distribution of the male and female children group's V_E (together with the mean for each gender) during lying, sitting, and standing is depicted in Appendix Fig. 1. It can be seen that there is no appreciable gender difference in the dispersion of values over the entire range for each of the three postures. The HR frequency distribution of the male and female children for lying, sitting, and standing also revealed no notable gender difference (Appendix Fig. 2).

The simple regression correlation coefficients (r), coefficients of determination (r^2), and standard error of estimates (SEM) produced when lying, sitting, and standing V_E is predicted from BSA, HR, and f_B for the male and female children combined are given in Table 4. The r is a only one of 212 active protocols, but portions (or all) of 27 of the 212 resting protocols completed. In the resting protocols, the need for repeats appeared to involve a small "sticking open" of the rubber fenestrations on the inlet side of the respiratory valve, such that part of the expired air was exhaled back into the atmosphere, thus resulting in a reduced collection of expired air in the Tissot tank. However, most of the resting protocol repeats were due to an apparent initial subject "discomfort" with the mouthpiece, resulting in hyperventilation (i.e., more rapid, somewhat shallow breathing than is normal), thus producing a higher ventilation volume than normal with little, if any, effect on heart rate. (This aberration is rather easily identified after data analysis via observation of a respiratory quotient (RQ) of >1.0.)

The retrospective quality control program for all field protocol data bases revealed that 5 children, 1 adolescent, 3 adults, and 1 senior needed to repeat 1 or 2 field protocols (TOTAL = 16 protocols, which represented 3.0% of all field protocols completed). Elimination of aberrant bits of data (due to the result of momentary saliva blockage in the Harvard respirometer, Heart Watch heart rate artifacts, etc.), which rarely included more than one or two 1-min "glitches" in any one protocol, were part of the aforementioned quality control program. When this was done, the remaining data for the 5-min period, or the 30-min protocol, was used to calculate an average for the full time period in question. A significant number of field protocols were completed with incomplete, or no, f_B data. This occurred because there was no way to determine whether the expiration electronic pulse from the Harvard respirometer was being recorded on the tape cassette until after the field protocol was completed. However, since these were random occurrences, and f_B was not of such prime concern as HR and V_E, these protocols were not repeated.

8. Statistical Analysis.

Descriptive statistics included determination of group means, standard errors, and frequency distributions for anthropometric data and for each of the following physiological measurements: 1) V_E , 2) f_B, 3) HR and, when available, 4) VO_2. Simple linear and multiple regression analysis were performed on the relationship between the independent variables of: 1) population, 2) activity, 3) anthropometric measures (i.e., BSA in m^2), and 4) HR and f_B, and the dependent variable of V_E in order to assess the potential for indirect assessment of V_E. Comparative statistical analyses (utilizing analysis of variance and, when appropriate, *post hoc* t tests) across populations were performed to determine the potential for, and validity of, collapsing the regression analysis across gender and age groups. Statistical analyses were conducted in the Human Performance Laboratory utilizing computer-based statistical software programs, including STATVIEW™ and CRICKET GRAPH™.

TABLE 3. Male and female children combined group mean response, (SD) and comparison between lying, sitting and standing protocols.

	LYING (1)	SITTING (2)	STANDING (3)	
V_E (L/min)	7.51 (2.12)	7.28 (1.34)	8.49 (1.61)	*1-3,2-3
HR (bts/min)	83 (10)	88 (9)	96 (11)	*1-3,2-3 1-2
f_B (br/min)	20.5 (6.3)	19.5 (5.1)	20.1 (4.1)	
VO_2 (L/min)	0.194 (0.050)	0.198 (0.050)	0.213 (0.051)	*1-3,2-3
VO_2/LBM (ml/kg/min)	7.53 (2.35)	7.67 (2.01)	8.24 (2.15)	*1-3,2-3
V_E/BSA	6.99 (2.67)	6.75 (1.58)	7.79 (1.58)	*1-3,2-3

* Denotes significant differences for these measures at $p < 0.05$. V_E, ventilation; HR, heart rate; f_B, breathing frequency; VO_2, volume of oxygen consumption; VO_2/LBM, volume of oxygen consumption/ lean body mass; V_E/BSA, ventilation/ body surface area.

TABLE 2. Summary of group anthropometry

Group No. and Gender	Age, yr.	Ht., cm.	Wt., kg.	BSA, m^2	% Fat
1-F	9.5 (6.5-12.2)	136.54 (111.8-151.1)	33.6 (17.6-80.4)	1.12 (0.74-1.86)	20.75 (10.8-35.3)
1-M	9.4 (6.4-12.6)	136.51 (111.8-163.2)	33.4 (18.6-76.4)	1.12 (0.76-1.75)	13.47 (8.2-32.8)
2-F	15.3 (13.7-18.2)	161.93 (155.0-169.7)	56.8 (45.1-67.8)	1.60 (1.44-1.78)	23.41 (9.5-31.1)
2-M	15.6 (13.2-18.9)	171.30 (154.0-182.4)	67.3 (44.8-103.0)	1.78 (1.43-2.20)	15.51 (8.5-32.4)
3-F	40.4 (19.3-59.8)	162.71 (153.7-172.7)	62.9 (48.1-88.8)	1.67 (1.43-1.99)	25.42 (12.6-37.3)
3-M	39.1 (20.5-58.4)	177.17 (168.4-184.9)	80.8 (59.1-103.6)	1.98 (1.74-2.25)	15.80 (5.6-31.4)
4-F	67.8 (60.7-77.5)	159.40 (147.8-170.7)	65.5 (48.6-80.9)	1.68 (1.43-1.87)	30.19 (18.0-37.0)
4-M	66.9 (60.6-75.2)	175.77 (161.3-186.7)	84.6 (62.2-107.0)	2.01 (1.66-2.31)	26.14 (16.0-35.6)
5-F	5.0 (4.1-5.8)	109.41 (100.3-112.3)	19.5 (15.7-22.8)	0.76 (0.65-0.82)	22.07 (17.5-27.4)
5-M	4.8 (3.6-5.8)	105.96 (96.0-114.3)	16.9 (14.1-19.0)	0.70 (0.61-0.78)	16.30 (14.1-19.1)
X-F	9.5 (6.3-12.8)	135.94 (109.7-162.6)	32.0 (17.3-50.9)	1.10 (0.73-1.53)	18.36 (8.8-30.0)
X-M	9.4 (6.0-12.9)	135.46 (118.9-166.4)	32.5 (22.7-61.0)	1.10 (0.87-1.68)	15.68 (5.3-30.0)

Numerical values are group means, with those in parentheses indicating range of minimum and maximum for each group.

statistical measure of how well the data fit the equation generated by the statistical technique called best fit, least-squares linear regression. An r of 0.0 is produced when there is no relationship between the two variables, while an r of 1.0 indicates a perfect relationship. The r^2 indicates the percent of the variance in the dependent measure, in this case V_E, that is associated with changes or variance in the independent variables such as HR, f_B, or BSA. The SEM indicates the accuracy of prediction in terms of the ocurrence of 67% of the sample VE values within +/- the SEM value given at any point along the regression line. The specific linear and multiple regression equations for the variables best predicting V_E for the combined male and female children's group, together with their respective r and SEM values, are also presented in Table 4. It is apparent that f_B has a greater effect on predicting V_E, as is reflected by higher r values for the lying and sitting protocols, than does HR or BSA. However, the addition of BSA with f_B increases the r values except in the standing protocol, in which V_E is as well predicted by BSA alone as by a combination of BSA and f_B.

b. Cross-Validation Group. The male and female group mean responses (and standard deviation) for V_E, HR, f_B, VO_2 (l/min), VO_2 (ml/min per kg LBM), and V_E/BSA for the sitting and standing rest protocols are given in Appendix Table 2. Except for VO_2 (l/min), there were no significant gender differences. The higher VO_2 (l/min) for the male group (which was numerically similar to the original group males' values for sitting and standing), can be attributed in part to their greater LBM (males = 15.7% and females = 18.4% body fat), as VO_2/LBM was not significantly different between genders. Thus, the data for both groups were combined for subsequent analyses. As shown in Table 5, except for V_E and f_B, the mean values for standing were significantly higher than those for for sitting. Thus, the lying and sitting conditions imposed similar demands on the ventilatory system, but not on the circulatory system, with HR being less for sitting (88 b/min) than for standing (95 b/min).

A frequency distribution of the cross-validation male and female children's V_E (together with the mean for each gender) during sitting and standing is depicted in Appendix Fig. 3. It can be seen that there is no appreciable gender difference. The HR frequency distribution of the male and female children's groups for sitting and standing also revealed no notable gender difference (Appendix Fig. 4).

The r, r^2, and SEM values calculated from simple regression analysis for the prediction of sitting and standing V_E for the combined male and female cross-validation children's group are given in Table 6. All of these values closely approximate those obtained for the original group of male and female children, which are presented in Table 4. Also presented in Table 6 are the r and SEM values obtained when V_E for the combined male and female cross-validation children's group is predicted utilizing the equations developed from the original children's group data (Table 4). The standing r and SEM values obtained following the insertion of the cross-validation group's

TABLE 4. Male and female children combined group r, r^2 and SEM for predicting V_E using simple linear and multiple regression analysis for resting conditions.

V_E:

	LYING			SITTING			STANDING		
	r	(SEM)	r^2	r	(SEM)	r^2	r	(SEM)	r^2
BSA	0.13	(2.13)	0.017	0.26	(1.31)	0.070	**0.48**	(1.43)	**0.230**
HR (bts/min)	0.07	(2.14)	0.005	0.004	(1.35)	0.00002	0.08	(1.62)	0.007
f_B (br/min)	**0.63**	(1.67)	**0.393**	**0.32**	(1.28)	**0.104**	0.15	(1.61)	0.023

SIMPLE EQUATIONS:

Equation	Condition	r	SEM
$V_E = 0.212\ f_B + 3.159$	lying	0.63	1.67
$V_E = 0.085\ f_B + 5.627$	sitting	0.32	1.23
$V_E = 3.007\ BSA + 5.127$	standing	0.48	1.43

MULTIPLE REGRESSION EQUATIONS:

Equation	Condition	r	SEM
$V_E = 0.247\ f_B + 2.875\ BSA - 0.778$	lying	0.71	1.54
$V_E = 0.151\ f_B + 2.781\ BSA + 1.229$	sitting	0.57	1.13
$V_E = 3.261\ BSA + 0.034\ f_B + 4.158$	standing	0.49	1.43

TABLE 6. Male and female cross-validation children combined group r, r^2 and SEM for predicting V_E using simple linear and multiple regression analysis for resting conditions and subsequent r and SEM using resting equations derived from original group of children.

V_E:

	SITTING			STANDING		
	r	(SEM)	r^2	r	(SEM)	r^2
BSA	0.24	(1.54)	0.057	**0.44**	(1.48)	**0.197**
HR (bts/min)	0.09	(1.58)	0.008	0.06	(1.65)	0.004
f_B (br/min)	**0.34**	(1.50)	**0.116**	0.38	(1.53)	0.144

SIMPLE EQUATIONS:

Equation from Original Group of Children	Condition	Cross-Validation r	Cross-Validation SEM
$V_E = 0.085\ f_B + 5.627$	sitting	0.34	0.45
$V_E = 3.007\ BSA + 5.127$	standing	0.44	0.57

MULTIPLE REGRESSION EQUATIONS:

Equation from Original Group of Children	Condition	Cross-Validation r	Cross-Validation SEM
$V_E = 0.151\ f_B + 2.781\ BSA + 1.229$	sitting	0.45	0.84
$V_E = 3.261\ BSA + 0.034\ f_B + 4.158$	standing	0.52	0.60

TABLE 5. Male and female cross-validation children combined group mean response, (SD) and comparison between sitting and standing protocols.

	SITTING (2)	STANDING (3)	
V_E (L/min)	8.22 (1.57)	8.35 (1.63)	
HR (bts/min)	88 (9)	95 (9)	*2-3
f_B (br/min)	21.6 (5.5)	21.8 (4.4)	
VO_2 (L/min)	0.196 (0.035)	0.208 (0.037)	*2-3
VO_2/LBM (ml/kg/min)	7.60 (1.25)	8.09 (1.39)	*2-3
V_E/BSA	7.64 (1.78)	7.71 (1.51)	

* Denotes significant differences for these measures at $p < 0.05$. V_E, ventilation; HR, heart rate; f_B, breathing frequency; VO_2, volume of oxygen consumption; VO_2/LBM, volume of oxygen consumption/ lean body mass; V_E/BSA, ventilation/ body surface area.

TABLE 7. Young male and female children combined group mean response, (SD) and comparison between lying, sitting and standing protocols.

	LYING (1)	SITTING (2)	STANDING (3)	
V_E (L/min)	6.19 (1.49)	6.48 (1.44)	6.76 (1.25)	*1-3
HR (bts/min)	101 (7)	104 (9)	106 (10)	*1-3
f_B (br/min)	26.3 (4.7)	24.5 (4.6)	25.3 (2.8)	
VO_2 (L/min)	0.135 (0.024)	0.147 (0.028)	0.156 (0.024)	*1-2,1-3
VO_2/LBM (ml/kg/min)	9.29 (1.66)	10.10 (1.83)	10.74 (1.70)	*1-2,1-3
V_E/BSA	8.47 (1.96)	8.89 (1.99)	9.25 (1.65)	*1-3

* Denotes significant differences for these measures at $p < 0.05$. V_E, ventilation; HR, heart rate; f_B, breathing frequency; VO_2, volume of oxygen consumption; VO_2/LBM, volume of oxygen consumption/ lean body mass; V_E/BSA, ventilation/ body surface area.

data into the simple and multiple regression equations were very similar to those obtained for the original group of children, but those for the sitting protocol indicated somewhat less predictive precision than that obtained for the original group of children (Table 4).

c. Young Children's Group. The male and female group mean responses (and standard deviation) for V_E, HR, f_B, VO_2 (l/min), VO_2 (ml/min per kg LBM), and V_E/BSA for the three rest protocols are presented in Appendix Table 3. There were no significant gender differences for any of these measures. Hence, the data for both groups were combined for subsequent analyses. As shown in Table 7, except for f_B, the mean values for standing were significantly higher than those for lying. Except for VO_2 and VO_2 per kg LBM, the differences between lying and sitting were not statistically significant.

A frequency distribution of the young children group's V_E (together with the mean for both genders) during lying, sitting, and standing is depicted in Appendix Fig. 5. It can be seen that, with one exception, both genders distribute rather evenly over the whole range of observations. The HR frequency distribution for the young children group for the three resting protocols also revealed no notable gender difference (Appendix Fig. 6).

d. Adolescent & Adult Female Groups. The female adolescent, young/middle-aged adult, and older adult groups' mean responses (and standard deviation) for V_E, HR, f_B, VO_2 (l/min), VO_2 (ml/min per kg LBM), and V_E/BSA for the three resting protocols are given in Appendix Table 4. The adolescent group had a higher HR than the young/middle-aged adult group only for the standing protocol. The older adult group had a significantly lower VO_2 than the young/middle-aged group for the lying protocol and the adolescent group for the sitting protocol. However, there were no significant differences between groups for V_E and V_E/BSA. Thus, the data were combined for subsequent analyses. The combined group's response comparisons between the lying, sitting, and standing protocols are presented in Table 8. Except for f_B, the mean values were significantly different between all protocols. Thus, the hydrostatic and/or metabolic demands imposed were progressively greater for sitting and standing than for lying.

A frequency distribution of the female group's V_E (together with the mean for each group) during lying, sitting, and standing is depicted in Appendix Fig. 7. It can be seen that there is no appreciable age group difference in the dispersion of values over the entire range for each of the three postures. The HR frequency distribution of the adolescent and adult female groups shows a tendency for the adolescents to have somewhat higher values for lying, sitting, and standing than the young/middle-aged adult females, with the older adult females typically having intermediate values (Appendix Fig. 8).

The simple regression r, r^2, and SEM values calculated for predicting V_E for the combined adolescent and adult female groups in the three resting postures are given in Table 9. In all three conditions, f_B is the single variable that best predicts V_E, although the r values tend to be

TABLE 9. Female adolescent, young/middle-aged adult and older adult combined group r, r^2, SEM for predicting V_E using simple linear and multiple regression analysis for resting conditions.

V_E:

	LYING			SITTING			STANDING		
	r	(SEM)	r^2	r	(SEM)	r^2	r	(SEM)	r^2
BSA	0.33	(1.42)	0.112	0.33	(1.80)	0.111	0.33	(2.01)	0.109
HR (bts/min)	0.15	(1.49)	0.023	0.14	(1.89)	0.020	0.18	(2.09)	0.032
f_B (br/min)	**0.35**	(1.41)	**0.121**	**0.46**	(1.70)	**0.207**	**0.38**	(1.97)	**0.142**

SIMPLE EQUATIONS:

Equation	Condition	r	SEM
$V_E = 0.112\ f_B + 5.512$	lying	0.35	1.41
$V_E = 0.194\ f_B + 4.775$	sitting	0.46	1.70
$V_E = 0.186\ f_B + 5.576$	standing	0.38	1.97

MULTIPLE REGRESSION EQUATIONS:

Equation	Condition	r	SEM
$V_E = 0.128\ f_B + 4.389\ BSA - 1.941$	lying	0.52	1.30
$V_E = 0.212\ f_B + 5.599\ BSA - 4.720$	sitting	0.60	1.54
$V_E = 0.202\ f_B + 5.943\ BSA - 4.458$	standing	0.53	1.83

TABLE 8. Female adolescent, young/middle-aged adult and older adult combined group mean response, (SD) and comparison between lying, sitting and standing protocols.

	LYING (1)	SITTING (2)	STANDING (3)	
V_E (L/min)	7.12 (1.49)	7.72 (1.89)	8.36 (2.11)	*1-2,1-3 2-3
HR (bts/min)	68 (11)	71 (11)	79 (14)	*1-2,1-3 2-3
f_B (br/min)	14.4 (4.6)	15.2 (4.4)	15.0 (4.3)	
VO_2 (L/min)	0.195 (0.028)	0.206 (0.032)	0.218 (0.034)	*1-2,1-3 2-3
VO_2/LBM (ml/kg/min)	4.37 (0.67)	4.62 (0.76)	4.87 (0.79)	*1-2,1-3 2-3
V_E/BSA	4.34 (0.84)	4.70 (1.06)	5.08 (1.19)	*1-2,1-3 2-3

* Denotes significant differences for these measures at $p < 0.05$. V_E, ventilation; HR, heart rate; f_B, breathing frequency; VO_2, volume of oxygen consumption; VO_2/LBM, volume of oxygen consumption/ lean body mass; V_E/BSA, ventilation/ body surface area.

TABLE 10. Male adolescent, young/middle-aged adult and older adult combined group mean response, (SD) and comparison between lying, sitting and standing protocols.

	LYING (1)	SITTING (2)	STANDING (3)	
V_E (L/min)	8.93 (1.97)	9.30 (1.87)	10.65 (2.88)	*1-3,2-3
HR (bts/min)	66 (11)	68 (10)	77 (12)	*1-2,1-3 2-3
f_B (br/min)	13.2 (3.8)	13.8 (3.8)	14.3 (4.3)	*1-3
VO_2 (L/min)	0.269 (0.044)	0.280 (0.046)	0.307 (0.049)	*1-2,1-3 2-3
VO_2/LBM (ml/kg/min)	4.40 (0.76)	4.57 (0.69)	5.00 (0.78)	*1-2,1-3 2-3
V_E/BSA	4.64 (0.83)	4.84 (0.75)	5.53 (1.25)	*1-3,2-3

* Denotes significant differences for these measures at $p < 0.05$. V_E, ventilation; HR, heart rate; f_B, breathing frequency; VO_2, volume of oxygen consumption; VO_2/LBM, volume of oxygen consumption/ lean body mass; V_E/BSA, ventilation/ body surface area.

somewhat lower than those obtained for the original group of children. Specific linear and multiple regression equations that best predict V_E (and their respective r and SEM values) for the combined adolescent and adult female data are also presented in Table 9. The inclusion of BSA in the multiple regression equations increases the r values obtained and lowers those for SEM.

e. Adolescent & Adult Male Groups. The male adolescent, young/middle-aged adult, and older adult groups' mean responses (and standard deviation) for V_E, HR, f_B, VO_2 (l/min), VO_2 (ml/min per kg LBM), and V_E/BSA for the three resting protocols are presented in Appendix Table 5. The adolescent group had a significantly higher VO_2 (per kg LBM) than the older groups for the lying and standing protocols. The older adult group had a significantly higher VE than that for the two younger groups which, when expressed as V_E/BSA, was significant only for the standing protocol. There were no significant differences between groups for HR response for any of the three resting protocols. Thus, the data were combined for subsequent analyses. The combined group's response comparisons between the lying, sitting, and standing protocols are presented in Table 10. Except for f_B comparisons between lying and sitting and between sitting and standing, the mean values were significantly different between all protocols. Thus, the hydrostatic and/or-metabolic demands imposed were progressively greater for sitting and standing than for lying.

A frequency distribution of the male group's V_E (together with the mean for each group)-during lying, sitting, and standing is depicted in Appendix Fig. 9. The adolescent and young/middle-aged adults showed no appreciable age group difference in the dispersion of values over the entire range for each of the three postures. However, the older adult group's values were between 10 to 15% higher. The HR frequency distribution of the adolescent and adult male groups shows a tendency for the adolescents to have somewhat higher values for sitting and standing than the young/middle-aged adult males, with the older adult males having intermediate values (Appendix Fig. 10).

The simple regression r, r^2, and SEM values calculated for predicting V_E for the combined adolescent and adult male group's in the three resting postures are given in Table 11. These r values are somewhat higher than those for the combined adolescent and adult female group. In addition, BSA appears to be the best single variable for prediction of lying and sitting V_E, with f_B being the second best predictor (with r values very similar to those obtained for the adolescent and adult female group). The r and SEM values obtained from specific linear and multiple regression equations developed from the combined adolescent and adult male data for predicting V_E, are also presented in Table 11. The r values for the multiple regression equations for predicting V_E in the lying, sitting and standing protocols were somewhat higher than those obtained for the adolescent and adult female group, even with the inclusion of the same two predictive variables, BSA and f_B (Table 9).

3. Active Protocols.

a. Original Group & Cross-Validation Children's Group. The male and female children group's mean responses (and standard deviation) for V_E, HR, f_B, VO_2 (l/min), VO_2 (ml/min per kg BW), and V_E/BSA for three walking speeds (viz., 2.0, 2.5, and 3.0 mph) are given in Appendix Table 6. Except for VE/BSA at 2.0 mph, there were no significant gender differences for any of these measures. Hence, the data for both males and females were combined for subsequent statistical analyses. As shown in Table 12, all measures were significantly greater with increased walking speed (except for f_B, which was significantly different between 2.0 and 3.0 mph, but only numerically greater at 2.5 vs. 2.0 mph and at 3.0 vs. 2.5 mph). A frequency distribution (together with each gender mean) of the male and female children combined group's V_E for walking at 2.0, 2.5, and 3.0 mph is depicted in Appendix Fig. 11. It is apparent that there is no appreciable gender difference in the dispersion of values over the entire range for each of the three speeds. The HR frequency distribution of the male and female children for the three walking speeds also revealed no notable gender difference (Appendix Fig. 12).

The male and female cross-validation children's group mean responses (and standard deviation) for V_E, HR, f_B, VO_2 (l/min), VO_2 (ml/min per kg BW), and V_E/BSA for the three walking speeds are given in Appendix Table 7. Except for HR at 2.0 and 3.0 mph, there were no significant gender differences for any of these measures. Since the original male and female children data were combined, the data for both cross-validation gender groups were combined to allow for similar statistical analyses. As shown in Table 13, all measures were significantly greater with increased walking speed (except for f_B, which was significantly different between 2.0 and 3.0 mph and between 2.5 and 3.0 mph, but only numerically greater at 2.5 vs. 2.0 mph). A frequency distribution (together with each gender mean) of the male and female cross-validation children group's V_E for walking at 2.0, 2.5, and 3.0 mph is depicted in Appendix Fig. 13. No appreciable gender difference in the dispersion of values over the entire range for each of the three speeds is evident. The HR frequency distribution of the male and female children's cross-validation group for the three walking speeds reveals somewhat higher values for females (Appendix Fig. 14).

Table 14 contains original (combined gender) group simple linear and multiple regression r, r^2, and SEM values produced when predicting V_E during walking from BSA, HR, and f_B. Also presented are the r, r^2, and SEM values from simple regression prediction of V_E during walking for the male and female combined cross-validation group. Finally, the r, r^2, and SEM values obtained when V_E for the cross-validation children's group is predicted using the equations developed from the original children's group data. The two sets of multiple regression values are nearly identical, suggesting very high reliability (i.e., reproducibility of measurement) and validity of the equations derived from the original group sample in predicting V_E during walking in other children of similar body size and composition.

TABLE 11. Male adolescent, young/middle-aged adult and older adult combined group r, r^2 and SEM for predicting V_E using simple linear and multiple regression analysis for resting conditions.

V_E:

	LYING			SITTING			STANDING		
	r	(SEM)	r^2	r	(SEM)	r^2	r	(SEM)	r^2
BSA	**0.57**	(1.63)	**0.324**	**0.63**	(1.47)	**0.393**	0.50	(2.52)	0.248
HR (bts/min)	0.03	(1.99)	0.001	0.01	(1.89)	0.0001	0.13	(2.88)	0.018
f_B (br/min)	0.47	(1.76)	0.217	0.56	(1.57)	0.309	**0.54**	(2.45)	**0.289**

SIMPLE EQUATIONS:

Equation	Condition	r	SEM
$V_E = 5.826 \text{ BSA} - 2.266$	lying	0.57	1.63
$V_E = 6.088 \text{ BSA} - 2.396$	sitting	0.63	1.47
$V_E = 0.360 f_B + 5.500$	standing	0.54	2.45

MULTIPLE REGRESSION EQUATIONS:

Equation	Condition	r	r^2
$V_E = 5.508 \text{ BSA} + 0.222 f_B - 4.587$	lying	0.71	1.41
$V_E = 5.086 \text{ BSA} + 0.212 f_B - 3.400$	sitting	0.75	1.25
$V_E = 0.321 f_B + 6.487 \text{ BSA} - 6.408$	standing	0.69	2.12

TABLE 13. Male and female cross-validation children combined group mean response, (SD) and comparison during walking at different velocities.

Velocity: (mph)	2.0 N = 31	2.5 N = 31	3.0 N = 31	
V_E (L/min)	13.59 (2.30)	15.15 (2.85)	17.36 (2.80)	*2-2.5,2-3 2.5-3
HR (bts/min)	115 (10)	119 (10)	127 (11)	*2-2.5,2-3 2.5-3
f_B (br/min)	32.1 (6.6)	33.7 (7.9)	35.8 (8.6)	*2-3,2.5-3
VO_2 (L/min)	0.385 (0.080)	0.464 (0.091)	0.557 (0.111)	*2-2.5,2-3 2.5-3
VO_2 (ml/kg/min)	13.0 (2.0)	15.6 (2.1)	18.8 (2.7)	*2-2.5,2-3 2.5-3
V_E/BSA	12.96 (1.66)	14.44 (2.00)	16.58 (2.10)	*2-2.5,2-3 2.5-3

* Denotes significant differences for these measures at $p < 0.05$. V_E, ventilation; HR, heart rate; f_B, breathing frequency; VO_2, volume of oxygen consumption; VO_2 (ml/kg/min), volume of oxygen consumption/ body weight; V_E/BSA, ventilation/ body surface area.

TABLE 12. Male and female children combined group mean response, (SD) and comparison during walking at different velocities.

Velocity: (mph)	2.0 N = 38	2.5 N = 40	3.0 N = 38	
V_E (L/min)	14.13 (2.58)	15.58 (3.07)	17.79 (3.58)	*2-2.5,2-3 2.5-3
HR (bts/min)	112 (8)	118 (9)	126 (10)	*2-2.5,2-3 2.5-3
f_B (br/min)	29.2 (5.1)	31.3 (4.6)	33.2 (4.1)	*2-3
VO_2 (L/min)	0.423 (0.138)	0.501 (0.156)	0.588 (0.175)	*2-2.5,2-3 2.5-3
VO_2 (ml/kg/min)	13.2 (1.8)	15.7 (2.3)	18.6 (2.7)	*2-2.5,2-3 2.5-3
V_E/BSA	13.02 (1.90)	14.31 (1.92)	16.34 (2.39)	*2-2.5,2-3 2.5-3

* Denotes significant differences for these measures at $p < 0.05$. V_E, ventilation; HR, heart rate; f_B, breathing frequency; VO_2, volume of oxygen consumption; VO_2 (ml/kg/min), volume of oxygen consumption/ body weight; V_E/BSA, ventilation/ body surface area.

Because of the close agreement between groups in predicting V_E during walking, and since there was some variation in the particular speeds at which the children ran, both males and females from the original group and the cross-validation group who did the running protocol at 3.5, 4.0, and 4.5 mph, were used in the analysis for running. This resulted in a combined group size similar to that for other analyses (Table 15). This male and female combined children's group mean responses (and standard deviation) for V_E, HR, f_B, VO_2 (l/min), VO_2 (ml/min per kg BW), and V_E/BSA for the three running speeds are presented in Table 15. Except for HR, there were no significant gender differences for any of these measures. A frequency distribution (together with each gender mean) of this combined male and female children group's V_E for running at 3.5, 4.0, and 4.5 mph is depicted in Appendix Fig. 15. No appreciable gender difference in the dispersion of values over the entire range for each of the three speeds is evident. The HR frequency distribution of this combined male and female children's group for the three running speeds reveals approximately 10% higher values for the females at all speeds (Appendix Fig. 16).

Because of the significant gender HR difference during running, separate regression analyses were completed for males and females. The r, r^2, and SEM produced from simple linear and multiple regression for predicting V_E from BSA, HR, and f_B for the male and female children's groups are given in Table 16. Because of the closer relationship between BSA and V_E during running than during walking (Table 14), the r values obtained from the multiple regression formulas for both males and females were higher than that for walking.

b. <u>Young Children's Group</u>. The male and female group mean responses (and standard deviation) for V_E, HR, f_B, VO_2 (l/min), VO_2 (ml/min per kg BW), and V_E/BSA for walking at 1.5, 1.88, and 2.25 mph are presented in Appendix Table 8. Except for a significantly greater VO_2 (ml/min per kg BW)for the males, there were no significant gender differences for any of these measures. The data for these measures for both groups combined are shown in Table 17. While there were numerically consistent increases in V_E, HR, and f_B with faster walking speeds, only the 1.5 vs. 2.25 mph comparisons for VO_2 (l/min), VO_2 (ml/min per kg BW), and V_E/BSA were statistically significant. However, lack of a clear significant difference in these measures as a function of walking speed, as was seen with the older children's groups, may be due primarily to the small sample size (N=12), rather than an indication of a more "blunted" response. In any case, the small sample size of this young children's group participating in this pilot testing protocol precluded meaningful regression analyses for predicting V_E.

A frequency distribution (together with each gender mean) of the male and female young children group's V_E for walking at 1.5, 1.88, and 2.25 mph is depicted in Appendix Fig. 17. It is apparent that there were no appreciable gender differences in the dispersion of values over the entire range for each of the three speeds. The HR frequency distribution for the young children's group for the three walking speeds also revealed no notable gender differences (Appendix Fig.

TABLE 14. Original group of children and cross-validation children group r, r^2 and SEM for predicting V_E using simple linear and multiple regression analysis during walking and subsequent cross-validation r and SEM using walking equations derived from original group of children.

V_E:

	Original M & F WALKING			Cross-Valid. M & F WALKING		
	r	(SEM)	r^2	r	(SEM)	r^2
BSA	**0.67**	(2.93)	**0.453**	**0.66**	(2.89)	**0.436**
HR (bts/min)	0.20	(3.89)	0.039	0.17	(3.79)	0.030
f_B (br/min)	0.17	(3.91)	0.027	0.22	(3.75)	0.050

SIMPLE EQUATION:

Walking Equation	Group	r	SEM
$V_E = 10.48\ BSA + 4.490$	Original M & F	0.67	2.93
	Cross-Valid. M & F	0.66	2.89

MULTIPLE REGRESSION EQUATION:

Walking Equation	Group	r	SEM
$V_E = 13.49\ BSA + 0.310\ f_B + 0.063\ HR - 16.04$	Original M & F	0.83	2.23
	Cross-Valid. M & F	0.79	2.36

TABLE 16. Male children combined (original and cross-validation groups) and female children combined (original and cross-validation groups) r, r^2 and SEM for predicting V_E using simple linear and multiple regression analysis during running.

V_E:

	Original & X-V.* MALE RUNNING			Original & X-V.* FEMALE RUNNING		
	r	(SEM)	r^2	r	(SEM)	r^2
BSA	**0.84**	(5.58)	**0.710**	**0.77**	(5.58)	**0.586**
HR (bts/min)	0.75	(6.83)	0.565	0.36	(8.09)	0.129
f_B (br/min)	0.16	(10.23)	0.024	0.28	(8.32)	0.079

* X-V., cross-validation

SIMPLE EQUATIONS :

Equation	Group	r	SEM
$V_E = 36.93\ BSA - 9.573$	Original & X-V. Males	0.84	5.58
$V_E = 31.22\ BSA - 3.856$	Original & X-V. Females	0.77	5.58

MULTIPLE REGRESSION EQUATIONS:

Equation	Group	r	SEM
$V_E = 27.71\ BSA + 0.331\ HR - 49.48$	Original & X-V. Males	0.94	3.56
$V_E = 33.48\ BSA + 0.151\ HR + 0.267\ f_B - 44.09$	Original & X-V. Females	0.90	3.82

TABLE 15. Group mean response, (SD) and comparison of male children combined (original and cross-validation groups) and female children combined (original and cross-validation groups) during running at different velocities.

Velocity: (mph)	3.5			4.0			4.5		
	males N = 19		females N = 20	males N = 19		females N = 21	males N = 16		females N = 10
V_E (L/min)	25.61 (5.16)		27.87 (7.00)	30.51 (5.07)		32.11 (5.84)	36.54 (7.90)		38.31 (7.22)
HR (bts/min)	140 (10)	**	156 (15)	152 (11)	**	167 (14)	159 (10)	**	175 (11)
f_B (br/min)	41.4 (6.9)		42.3 (9.8)	46.4 (10.6)		48.6 (9.0)	48.1 (13.5)		52.0 (9.6)
VO_2 (L/min)	0.848 (0.235)		0.876 (0.287)	1.026 (0.221)		1.015 (0.209)	1.265 (0.293)		1.208 (0.298)
VO_2 (ml/kg/min)	28.4 (3.0)		26.6 (3.5)	31.8 (2.4)		30.6 (2.7)	34.4 (2.0)		33.4 (2.4)
V_E/BSA	24.52 (3.15)		24.71 (3.50)	27.57 (3.50)		28.17 (3.72)	30.34 (3.63)		31.98 (3.30)

** Denotes significant differences for these measures at $p < 0.05$. V_E, ventilation; HR, heart rate; f_B, breathing frequency; VO_2, volume of oxygen consumption; VO_2 (ml/kg/min), volume of oxygen consumption/ body weight; V_E/BSA, ventilation/ body surface area.

18). Since only three young children ran at one or more speeds, no group analyses of these data were attempted.

c. Adolescent & Adult Female Groups. Because of the wide variation in age and fitness levels of the female adolescent, young/middle-aged adult, and older adult groups, there was substantial variation in the number in each age group who walked at the same three speeds. For example, while all of the older adult (> 60 years-old) females were able to walk successfully at three different speeds (usually between 2.0 and 3.0 mph), many of the adolescent and young adult female subjects walked at a faster range of speeds (2.5 to 4.0 mph). The mean responses (and standard deviation) for V_E, HR, f_B, VO_2 (l/min), VO_2 (ml/min per kg BW), and V_E/BSA for walking at 2.5 and 3.0 mph are given in Table 18. There were no significant group differences at 3.0 mph, but the older adult females had significantly greater V_E, VO_2 (l/min), and VE/BSA than did the young/middle-aged adult group at 2.5 mph. Also, the adolescent's mean HR was significantly higher than that for the young/middle-aged group at 2.5 mph.

A frequency distribution (together with the mean for each group) of the female group's V_E during walking at 2.5 and 3.0 mph is depicted in Appendix Fig. 19. The higher V_E for the older females, especially notable at 2.5 mph, may be more due to those few subjects of this age group being of larger size than the average size of subjects from the two younger groups. Whatever the reason, the HR frequency distribution of the young/middle-aged adult female group appears to have somewhat lower values, especially for 2.5 mph, compared to the adolescent and the older adult female groups (Appendix Fig. 20).

The simple linear and multiple regression equations, and r, r^2, and SEM values obtained for the adolescent and adult female groups (separately and combined) for predicting V_E during walking are given in Table 19. The r values for the simple and multiple regression equations for predicting walking V_E for these groups were somewhat lower than those obtained for both groups of children (Table 14).

We achieved only limited success in getting older women (above 60 years) to run on the treadmill. In fact, only 3 of 20 were able to run a: :n one speed (between 3.8-4.5 mph). This was much less of a problem in our middle-aged adults, ages 40-59 years, who except for three subjects (of 10 total) were able to run at from one to three speeds. All of the adolescent female subjects were able to run at from one to three speeds. However, as with walking, the range of speeds varied notably, being faster for young adults (20-30 years), somewhat slower for most adolescents, and slowest for middle-aged female subjects. This is evidenced in Appendix Fig. 21, in which a frequency distribution of V_E values for running at 4.0, 4.5, and 5.0 mph, together with means for the adolescent and young/middle-aged adult female groups, are depicted. The corresponding frequency distribution for HR response at these three running speeds for these two groups is presented in Appendix Fig. 22. The mean responses (and standard deviation) for V_E,

TABLE 17. Young male and female children combined group mean response, (SD) and comparison during walking at different velocities.

Velocity: (mph)	1.5 N = 12	1.875 N = 11	2.25 N = 11	
V_E (L/min)	10.25 (1.28)	10.53 (1.87)	11.68 (1.71)	
HR (bts/min)	127 (7)	130 (6)	134 (7)	
f_B (br/min)	34.8 (7.7)	35.6 (5.3)	37.6 (6.9)	
VO_2 (L/min)	0.251 (0.053)	0.273 (0.049)	0.312 (0.040)	*1.5-2.25
VO_2 (ml/kg/min)	13.9 (2.9)	14.8 (2.3)	17.0 (1.8)	*1.5-2.25
V_E/BSA	14.10 (2.12)	14.25 (2.32)	15.79 (1.93)	*1.5-2.25

* Denotes significant differences for these measures at $p < 0.05$. V_E, ventilation; HR, heart rate; f_B, breathing frequency; VO_2, volume of oxygen consumption; VO_2 (ml/kg/min), volume of oxygen consumption/ body weight; V_E/BSA, ventilation/ body surface area.

TABLE 19. Adolescent, young/middle-aged adult and older adult female group r, r^2 and SEM for predicting V_E using simple linear and multiple regression analysis during walking.

VE:	Adolescents r r^2 (SEM)	Yg/Mid. Adults r r^2 (SEM)	Older Adults r r^2 (SEM)	Groups Combined r r^2 (SEM)
BSA	0.23 0.052 (4.53)	0.45 0.202 (5.27)	0.40 0.158 (4.18)	0.40 0.157 (4.65)
HR (bts/min)	**0.55 0.301** (3.89)	**0.57 0.330** (4.82)	0.28 0.078 (4.37)	**0.43 0.186** (4.57)
f_B (br/min)	0.36 0.127 (4.35)	0.46 0.215 (5.23)	**0.55 0.300** (3.81)	0.42 0.174 (4.60)

SIMPLE EQUATIONS:

Equation	Group	r	SEM
$V_E = 0.147\ HR + 4.907$	adolescents	0.55	3.89
$V_E = 0.185\ HR + 3.739$	yg/mid. adults	0.57	4.82
$V_E = 0.565\ f_B + 9.976$	older adults	0.55	3.81
$V_E = 0.123\ HR + 9.309$	groups comb.	0.43	4.57

MULTIPLE REGRESSION EQUATIONS:

Equation	Group	r	SEM
$V_E = 0.173\ HR + 29.69\ BSA + 0.384\ f_B - 55.30$	adolescents	0.79	2.88
$V_E = 0.151\ HR + 16.53\ BSA + 0.298\ f_B - 27.38$	yg/mid. adults	0.77	3.80
$V_E = 0.062\ HR + 15.71\ BSA + 0.491\ f_B - 21.21$	older adults	0.70	3.33
$V_E = 0.118\ HR + 20.39\ BSA + 0.336\ f_B - 31.89$	groups comb.	0.72	3.51

TABLE 18. Group mean response, (SD) and comparison of female adolescents, young/middle-aged adults and older adults during walking at different velocities.

	V_E (L/min)	HR (bts/min)	f_B (br/min)	VO_2 (L/min)	VO_2 (ml/kg/min)	V_E/BSA
at 2.5 mph:						
Adoles:	19.58	109	24.7	0.693	12.3	12.28
(1) N = 20	(2.02)	(13)	(4.1)	(0.108)	(1.3)	(1.07)
Yg/Mid. Adults:	19.23	97	21.7	0.667	10.8	11.55
(2) N = 19	(3.13)	(14)	(5.5)	(0.116)	(0.8)	(1.30)
Older Adults:	22.18	104	23.3	0.774	11.9	13.24
(3) N = 19	(3.70)	(16)	(4.1)	(0.118)	(1.6)	(1.93)
SIGNIFICANT DIFFERENCES:	**1-3,2-3	**1-2		**2-3	**1-2	**2-3
at 3.0 mph						
Adoles:	22.55	111	25.6	0.811	14.1	14.02
(1) N = 14	(2.23)	(13)	(5.0)	(0.101)	(1.6)	(1.59)
Yg/Mid. Adults:	23.81	107	25.9	0.835	13.1	14.06
(2) N = 12	(3.94)	(14)	(5.1)	(0.152)	(1.4)	(1.36)
Older Adults:	25.83	111	24.4	0.922	13.8	15.21
(3) N = 17	(4.43)	(16)	(5.1)	(0.149)	(2.1)	(2.56)
SIGNIFICANT DIFFERENCES: NONE						

** Denotes significant differences for these measures at $p < 0.05$. Adoles, adolescents; Yg/Mid. Adults, young/middle-aged adults; V_E, ventilation; HR, heart rate; f_B, breathing frequency; VO_2, volume of oxygen consumption; VO_2 (ml/kg/min), volume of oxygen consumption/ body weight; V_E/BSA, ventilation/ body surface area.

TABLE 20. Group mean response, (SD) and comparison of female adolescents and young/middle-aged adults during running at different velocities.

	V_E (L/min)	HR (bts/min)	f_B (br/min)	VO_2 (L/min)	VO_2 (ml/kg/min)	V_E/BSA
at 4.0 mph:						
Adoles:	43.27	160	38.6	1.506	26.4	27.16
(1) N = 16	(6.70)	(18)	(5.7)	(0.180)	(3.2)	(4.79)
Yg/Mid. Adults:	50.44	145	35.5	1.594	24.0	29.03
(2) N = 10	(11.60)	(22)	(7.6)	(0.226)	(2.0)	(5.17)
Older Adults:	did not perform running protocols					
SIGNIFICANT DIFFERENCES:					**1-2	
at 4.5 mph						
Adoles:	47.04	164	35.9	1.694	29.1	28.65
(1) N = 10	(4.85)	(16)	(6.3)	(0.188)	(2.1)	(2.97)
Yg/Mid. Adults:	48.89	156	36.8	1.639	28.0	30.01
(2) N = 8	(12.72)	(12)	(6.1)	(0.252)	(2.9)	(5.21)
Older Adults:	did not perform running protocols					
SIGNIFICANT DIFFERENCES: NONE						
at 5.0 mph						
Adoles:	54.81	174	37.4	1.968	32.2	32.69
(1) N = 5	(3.48)	(20)	(8.2)	(0.109)	(0.96)	(2.24)
Yg/Mid. Adults:	48.26	163	32.4	1.701	30.6	30.53
(2) N = 8	(8.93)	(9)	(5.3)	(0.130)	(3.4)	(5.77)
Older Adults:	did not perform running protocols					
SIGNIFICANT DIFFERENCES:				** 1-2		

** Denotes significant differences for these measures at $p < 0.05$. Adoles, adolescents; Yg/Mid. Adults, young/middle-aged adults; V_E, ventilation; HR, heart rate; f_B, breathing frequency; VO_2, volume of oxygen consumption; VO_2 (ml/kg/min), volume of oxygen consumption/ body weight; V_E/BSA, ventilation/ body surface area.

HR, f_B, VO_2 (l/min), VO_2 (ml/min per kg BW), and V_E/BSA for the adolescent and young and middle-aged adult females during running at 4.0, 4.5, and 5.0 mph are given in Table 20. Except for VO_2 (l/min) at 5.0 mph, there were no statistically significant group mean differences for any of these measures

The simple linear and multiple regression equations, and r, r^2, and SEM values obtained for the adolescent and adult female groups (separately and combined) for predicting V_E during running are given in Table 21. The r values for the simple and multiple regression equations for predicting running V_E for these groups were only marginally higher than those for walking (Table 19), and somewhat lower than those obtained for both groups of children running (Table 16).

d. Adolescent & Adult Male Groups. As with females, because of the wide variation in age and fitness levels of the male adolescent, young/middle-aged adult, and older adult groups, there was substantial variation in the number in each age group who walked at the same three speeds. For example, while all of the older adult (> 60 years-old) males were able to walk successfully at three different speeds (usually between 2.5 and 3.5 mph), some of the adolescent and young adult male subjects walked at a faster range of speeds (3.0 to 4.0 mph). The mean responses (and standard deviation) for V_E, HR, f_B, VO_2 (l/min), VO_2 (ml/min per kg BW), and V_E/BSA for three common walking speeds are given in Table 22. Most of the significant differences between the three groups (of different numbers) appear to be related, at least in part, to body size.

A frequency distribution (together with the mean for each group) of the male group's V_E during walking at 2.5, 3.3 and 4.0 mph is depicted in Appendix Fig. 23. While 58 of the 60 total subjects from the three groups walked at 2.5 mph, the adolescents and older adult subjects usually walked at 3.0 and 3.5 mph. Thus, there were significantly fewer subjects who walked at 3.3 and 4.0 mph than at 2.5 mph. The approximately 10% lower mean V_E for the adolescent male group during walking at all three speeds, compared to the young and middle-aged male group's values, appears largely due to their smaller body size (Table 2). Similarly, the higher V_E for the older males at 2.5 mph is, in part, due to this group's larger size than that of the two younger groups. The HR frequency distribution (Appendix Fig. 24) shows that the mean HR of the adolescent group is consistently somewhat higher at all three speeds than that for the subjects from the young/ middle-aged and older adult male groups.

The simple linear and multiple regression equations, and r, r^2, and SEM values obtained for the adolescent and adult male groups (separately and combined) for predicting V_E during walking are given in Table 23. The r values for the simple and multiple regression equations for predicting V_E during walking for these groups were very similar to those obtained for the adolescent and adult female groups (Table 19). When walking velocity was added to BSA, HR, and f_B as an independent variable to predict V_E in the male adolescent and adult groups, the

TABLE 22. Group mean response, (SD) and comparison of male adolescents, young/middle-aged adults and older adults during walking at different velocities.

	V_E (L/min)	HR (bts/min)	f_B (br/min)	VO_2 (L/min)	VO_2 (ml/kg/min)	V_E/BSA
at 2.5 mph:						
Adoles:	20.90	99	21.1	0.835	12.4	11.69
(1) N = 20	(3.54)	(11)	(5.2)	(0.176)	(1.1)	(1.21)
Yg/Mid. Adults:	22.79	89	17.7	0.896	11.1	11.49
(2) N = 19	(3.83)	(14)	(5.3)	(0.149)	(1.2)	(1.72)
Older Adults:	28.89	93	21.9	0.988	11.7	14.29
(3) N = 19	(6.39)	(15)	(4.6)	(0.174)	(1.5)	(2.53)
SIGNIFICANT DIFFERENCES:	**1-3,2-3		**2-3	**1-3	**1-2	**1-3,2-3
at 3.3 mph						
Adoles:	25.64	107	21.6	1.047	16.0	14.43
(1) N = 11	(5.06)	(14)	(6.2)	(0.182)	(2.0)	(2.08)
Yg/Mid. Adults:	26.78	94	19.4	1.092	14.1	13.72
(2) N = 17	(4.26)	(10)	(5.3)	(0.147)	(1.2)	(1.97)
Older Adults:	33.39	99	22.5	1.186	16.0	17.70
(3) N = 8	(6.95)	(8)	(2.4)	(0.214)	(1.6)	(2.73)
SIGNIFICANT DIFFERENCES:	**1-3,2-3	**1-2			**1-2,2-3	**1-3,2-3
at 4.0 mph						
Adoles:	31.10	118	24.8	1.280	20.4	17.92
(1) N = 12	(4.70)	(13)	(6.3)	(0.144)	(2.4)	(2.41)
Yg/Mid. Adults:	35.56	107	21.9	1.456	18.9	18.18
(2) N = 17	(6.30)	(11)	(6.7)	(0.195)	(1.2)	(2.73)
Older Adults:	too few subjects for group representation					
SIGNIFICANT DIFFERENCES:		**1-2		**1-2		

** Denotes significant differences for these measures at $p < 0.05$. Adoles, adolescents; Yg/Mid. Adults, young/middle-aged adults; V_E, ventilation; HR, heart rate; f_B, breathing frequency; VO_2, volume of oxygen consumption; VO_2 (ml/kg/min), volume of oxygen consumption/ body weight; V_E/BSA, ventilation/ body surface area.

TABLE 21. Adolescent, young/middle-aged adult and older adult female group r, r^2 and SEM for predicting V_E using simple linear and multiple regression analysis during running.

V_E:	Adolescents r r^2 (SEM)	Yg/Mid. Adults r r^2 (SEM)	Older Adults r r^2 (SEM)	Groups Combined r r^2 (SEM)
BSA	0.21 0.043 (8.22)	0.42 0.173 (10.51)	one data point	0.37 0.136 (9.56)
HR (bts/min)	**0.62 0.382** (6.61)	0.46 0.209 (10.27)		**0.48 0.232** (9.02)
f_B (br/min)	0.42 0.173 (7.64)	**0.56 0.315** (9.56)		0.42 0.172 (9.36)

SIMPLE EQUATIONS:

Equation	Group	r	SEM
$V_E = 0.255\ HR + 4.264$	adolescents	0.62	6.61
$V_E = 1.035\ f_B + 14.521$	yg/mid. adults	0.56	9.56
one data point	older adults		
$V_E = 0.252\ HR + 7.680$	groups comb.	0.48	9.02

MULTIPLE REGRESSION EQUATIONS:

Equation	Group	r	SEM
$V_E = 46.70\ BSA + 0.538\ f_B + 0.272\ HR - 94.10$	adolescents	0.83	4.82
$V_E = 33.49\ BSA + 0.600\ f_B + 0.257\ HR - 65.93$	yg/mid. adults	0.74	7.93
one data point	older adults		
$V_E = 40.25\ BSA + 0.389\ f_B + 0.266\ HR - 74.26$	groups comb.	0.72	7.18

multiple regression r values for these groups (both separately and combined) were higher, and the SEM values reduced by 25 to 30% (Appendix Table 9). Similar results were obtained for other groups for both walking and running, but are not reported because of the impracticality of measuring walking/running velocity accurately in the field (This point will be examined in more detail in the discussion.).

We achieved limited success in getting older men (above 60 years) to run on the treadmill. Only six (of 20) were able to run at from one to three speeds (ranging from 4.5-6.0 mph). This was much less of a problem in our middle-aged adults, ages 40-59 years, who except for two subjects (of 10 total) were able to run at from one to three speeds (usually ranging from 5.0 to 6.5 mph). All of the adolescent male subjects were able to jog at from one to three speeds. However, as with walking, the range of speeds varied notably, being faster for young adults (20-30 years), somewhat slower for most adolescents, and slowest for middle-aged male subjects. This is evidenced in Appendix Fig. 25, in which a frequency distribution of V_E values for running at 4.5, 5.0, and 5.5 mph, together with means for the adolescent and young/middle-aged adult male groups are depicted. The corresponding frequency distribution for HR response at these three running speeds for these subjects is presented in Appendix Fig. 26. The mean responses (and standard deviations) for these three running speeds are given in Table 24.

The simple linear and multiple regression equations, and r, r^2, and SEM values obtained for the adolescent and adult male groups (separately and combined) for predicting V_E during running are given in Table 25. The r values for the simple and multiple regression equations for predicting V_E during running for these groups were only marginally higher than those for walking (Table 23), but somewhat higher than those obtained for the two female groups for running (Table 21).

4. Field Protocols.

a. Spontaneous play. The 20 female and 20 male original group children each completed two 30 min spontaneous play protocols. Since there were no significant differences for V_E, HR, f_B, and V_E/BSA between protocols, the data for the two protocols were combined for the male group and the female group (Appendix Table 10). There were no significant gender differences; hence, the V_E, HR, f_B, and V_E/BSA values presented in Table 26 represent the mean of these measures for the total 80 protocols completed (20 x 2 for females and 20 x 2 for males). Appendix Table 11 also reveals no significant gender differences between the cross-validation males and females for their 35 min spontaneous play protocol; hence, the male and female data were combined for further analysis as depicted in Table 27. Combined group mean values for play are very similar for the original and cross-validation populations (Tables 26 & 27).

Simple regression r, r^2 and SEM values calculated for the prediction of play V_E are lower (Table 28) than those obtained during cross-validation and original group children walking and

TABLE 23. Adolescent, young/middle-aged adult and older adult male group r, r^2 and SEM for predicting V_E using simple linear and multiple regression analysis during walking.

V_E:	Adolescents r r^2 (SEM)	Yg/Mid. Adults r r^2 (SEM)	Older Adults r r^2 (SEM)	Groups Combined r r^2 (SEM)
BSA	0.41 0.166 (5.09)	0.30 0.091 (6.90)	0.47 0.223 (8.57)	0.49 0.242 (7.30)
HR (bts/min)	0.53 0.280 (4.73)	0.57 0.320 (5.97)	0.46 0.213 (8.63)	0.32 0.104 (7.93)
f_B (br/min)	**0.58 0.335** (4.54)	**0.60 0.356** (5.81)	**0.63 0.392** (7.59)	**0.51 0.257** (7.22)

SIMPLE EQUATIONS:

Equation	Group	r	SEM
$V_E = 0.575\ f_B + 11.91$	adolescents	0.58	4.54
$V_E = 0.766\ f_B + 13.34$	yg/mid. adults	0.60	5.81
$V_E = 1.446\ f_B + 0.210$	older adults	0.63	7.59
$V_E = 0.802\ f_B + 11.52$	groups comb.	0.51	7.22

MULTIPLE REGRESSION EQUATIONS:

Equation	Group	r	SEM
$V_E = 0.327\ f_B + 0.202\ HR + 12.38\ BSA - 26.26$	adolescents	0.79	3.47
$V_E = 0.631\ f_B + 0.161\ HR + 12.67\ BSA - 24.89$	yg/mid. adults	0.75	4.90
$V_E = 1.043\ f_B + 0.152\ HR + 18.44\ BSA - 42.48$	older adults	0.73	6.71
$V_E = 0.615\ f_B + 0.134\ HR + 21.42\ BSA - 39.15$	groups comb.	0.72	5.85

TABLE 25. Adolescent, young/middle-aged adult and older adult male group r, r^2 and SEM for predicting V_E using simple linear and multiple regression analysis during running.

V_E:	Adolescents r	Adolescents r^2 (SEM)	Yg/Mid. Adults r	Yg/Mid. Adults r^2 (SEM)	Older Adults r	Older Adults r^2 (SEM)	Groups Combined r	Groups Combined r^2 (SEM)
BSA	0.49	0.241 (11.35)	0.47	0.225 (12.96)	0.34	0.117 (14.05)	**0.49**	**0.244** (12.36)
HR (bts/min)	**0.73**	**0.538** (8.87)	0.45	0.199 (13.18)	0.65	0.426 (11.32)	0.42	0.174 (12.92)
f_B (br/min)	0.49	0.238 (11.40)	**0.60**	**0.364** (11.75)	**0.82**	**0.673** (8.54)	0.45	0.204 (12.69)

SIMPLE EQUATIONS:

Equation	Group	r	SEM
$V_E = 0.658\ HR - 48.29$	adolescents	0.73	8.87
$V_E = 0.970\ f_B + 35.96$	yg/mid. adults	0.60	11.75
$V_E = 1.482\ f_B + 14.91$	older adults	0.82	8.54
$V_E = 36.73\ BSA - 13.92$	groups comb.	0.49	12.36

MULTIPLE REGRESSION EQUATIONS:

Equation	Group	r	SEM
$V_E = 0.549\ HR + 27.58\ BSA + 0.311\ f_B - 91.11$	adolescents	0.86	6.86
$V_E = 0.202\ HR + 41.38\ BSA + 0.757\ f_B - 68.04$	yg/mid. adults	0.75	9.89
$V_E = 0.419\ HR + 35.97\ BSA + 0.740\ f_B - 88.60$	older adults	0.88	7.76
$V_E = 0.268\ HR + 44.08\ BSA + 0.497\ f_B - 78.44$	groups comb.	0.75	9.56

TABLE 24. Group mean response, (SD) and comparison of male adolescents, young/middle-aged adults and older adults during running at different velocities.

	V_E (L/min)	HR (bts/min)	f_B (br/min)	VO_2 (L/min)	VO_2 (ml/kg/min)	V_E/BSA
at 4.5 mph:						
Adoles: (1) N = 12	53.96 (12.03)	158 (16)	38.7 (7.8)	2.063 (0.469)	30.6 (1.6)	30.14 (4.36)
Yg/Mid. Adults: (2) N = 4	64.82 (10.62)	150 (11)	33.3 (7.6)	2.455 (0.423)	28.3 (1.8)	31.52 (3.85)
Older Adults: (3) N = 5	59.30 (9.96)	137 (10)	30.4 (8.1)	2.194 (0.166)	36.7 (4.2)	30.86 (4.39)
SIGNIFICANT DIFFERENCES:		**1-3				
at 5.0 mph						
Adoles: (1) N = 12	55.89 (12.52)	159 (13)	34.6 (8.9)	2.237 (0.340)	34.4 (2.5)	31.71 (5.61)
Yg/Mid. Adults: (2) N = 16	58.74 (15.48)	141 (17)	26.1 (5.3)	2.422 (0.394)	31.1 (2.6)	29.88 (6.69)
Older Adults:	too few subjects for group representation					
SIGNIFICANT DIFFERENCES:		**1-2			**1-2	
at 6.0 mph						
Adoles: (1) N = 8	61.21 (10.60)	166 (9)	32.6 (7.8)	2.505 (0.193)	38.9 (2.5)	34.72 (5.16)
Yg/Mid. Adults: (2) N = 10	69.22 (15.56)	157 (17)	28.4 (9.4)	2.787 (0.390)	35.5 (2.3)	35.03 (6.58)
Older Adults:	did not perform running protocols at this velocity					
SIGNIFICANT DIFFERENCES:					** 1-2	

** Denotes significant differences for these measures at $p < 0.05$. Adoles, adolescents; Yg/Mid. Adults, young/middle-aged adults; V_E, ventilation; HR, heart rate; f_B, breathing frequency; VO_2, volume of oxygen consumption; VO_2 (ml/kg/min), volume of oxygen consumption/ body weight; V_E/BSA, ventilation/ body surface area.

TABLE 28. Original group of children and cross-validation children r, r^2 and SEM for predicting V_E using simple linear and multiple regression analysis for play and subsequent cross-validation r and SEM using play equations derived from original group of children.

V_E:

	Original M & F PLAY			Cross-Valid. M & F PLAY		
	r	(SEM)	r^2	r	(SEM)	r^2
BSA	**0.57**	(5.11)	**0.329**	0.46	(5.23)	0.208
HR (bts/min)	0.28	(6.00)	0.076	0.40	(5.40)	0.157
f_B (br/min)	0.41	(5.78)	0.165	**0.59**	(4.66)	**0.345**

SIMPLE EQUATION:

Walking Equation	Group	r	SEM
VE = 13.98 BSA + 2.250	Original M & F	0.57	5.11
	Cross-Valid. M & F	0.46	2.60

MULTIPLE REGRESSION EQUATION:

Walking Equation	Group	r	SEM
$V_E = 16.97$ BSA + 0.445 f_B + 0.082 HR - 26.96	Original M & F	0.80	3.83
	Cross-Valid. M & F	0.82	3.15

TABLE 26. Male and female children (original group) combined group mean response and (SD) for play (protocols 1 and 2 combined).

	V_E (L/min)	HR (bts/min)	f_B (br/min)	V_E/BSA
ORIGINAL GROUP MALES AND FEMALES COMBINED:				
	17.89	139	32.3	16.02
N = 40 x 2	(6.20)	(16)	(6.6)	(4.78)

V_E, ventilation; HR, heart rate; f_B, breathing frequency; V_E/BSA, ventilation/ body surface area.

TABLE 27. Male and female cross-validation children combined group mean response and (SD) for play.

	V_E (L/min)	HR (bts/min)	fB (br/min)	VE/BSA
CROSS-VALIDATION MALES AND FEMALES COMBINED:				
	18.22	143	32.0	16.64
N = 40	(5.80)	(16)	(6.5)	(5.11)

V_E, ventilation; HR, heart rate; f_B, breathing frequency; V_E/BSA, ventilation/ body surface area.

TABLE 29. Group mean and combined group mean response, (SD) and comparison of young male and female children for play (protocols 1 and 2 combined).

	V_E (L/min)	HR (bts/min)	f_B (br/min)	V_E/BSA
MALES:				
N = 6 x 2	10.44	133	31.4	17.67
	(5.35)	(21)	(9.0)	(8.65)
FEMALES:				
N = 6 x 2	12.18	145	24.0	18.94
	(4.39)	(21)	(17.3)	(5.66)
SIGNIFICANT DIFFERENCES: NONE				
MALES AND FEMALES COMBINED:				
	11.31	139	28.4	18.30
N = 12 x 2	(4.87)	(22)	(11.4)	(7.18)

No significant differences for these measures at $p < 0.05$. V_E, ventilation; HR, heart rate; f_B, breathing frequency; V_E/BSA, ventilation/ body surface area.

running (Table 16). The simple and multiple regression equations (and their respective r and SEM values) derived from the original group of children's data are also presented in Table 28. The r and SEM values obtained following the insertion of cross-validation children's data into these equations were very similar to those calculated for the original group of children (Table 28).

A frequency distribution of the male and female children group's and the cross-validation children group's play V_E (together with the mean for each gender) is depicted in Appendix Figs. 27a and 27b, respectively. It can be seen that there is no appreciable gender difference in the dispersion of values over the entire range for either group. The HR frequency distribution of both groups of children for play also revealed no notable gender or group difference (Appendix Fig. 28). The 5 min mean V_E values for the combined group of original children depicted in Appendix Fig. 29a, revealed a significantly lower V_E value for the first 5-min period, compared to the subsequent 5 min values, which did not differ significantly from each other. Appendix Fig. 29b shows that there was a significant difference between mean V_E values at minutes 5 and 10 for the group of cross-validation children, and that 5 min mean values beyond minute 10 were variable though not significantly different from each other. Lower first 5 min means, compared to all other 5 min measurement periods, were observed for HR for both groups of children (Appendix Fig. 30).

The male and female group mean response and the combined group mean response for spontaneous play variables for the young children are displayed in Table 29. There were no significant 20 min protocol 1 and 2 differences, and no significant gender differences; therefore, all play protocols were combined, increasing the N to a total of 24 protocols. Despite similar HR and V_E/BSA values as the two groups of older children, the group of young children had significantly lower values for V_E and f_B (28.4 vs. 32.3 br/min for the older children).

A V_E and HR frequency distribution (together with each gender mean) for the young group of children are presented in Appendix Fig. 31. Although not significant, the young female children tend to have numerically higher V_E and HR than the young males. There were no significant differences between the 5-min mean values for either V_E or HR, although the first 5-min means were each numerically lower (Appendix Fig. 32).

b. <u>Car Drive & Ride</u>. Thirty-seven of the 60 female adolescent, young/middle-aged adult, and older adult groups completed the car driving and riding protocol. Their mean responses (and standard deviation) for V_E, HR, f_B, and V_E/BSA for the driving and riding protocols are given in Appendix Table 12. There were no significant differences between the groups for any of these variables; thus, the data for all groups were combined for subsequent analyses. V_E during the laboratory sitting rest protocol for this group of 37 female adolescents, young/middle-aged adults, and older adults was 7.77 l/min, which was not significantly different from that for the total group (7.72 l/min). This group's mean responses for the driving and riding protocols are presented in

TABLE 30. Female adolescent, young/middle-aged adult and older adult combined group mean response, (SD) and comparison for car driving and riding.

	V_E (L/min)	HR (bts/min)	f_B (br/min)	V_E/BSA
DRIVING COMBINED:	8.95	80	17.4	5.39
(SD) N = 37	(2.10)	(14)	(3.8)	(1.21)
RIDING COMBINED:	8.19	78	17.6	4.93
(SD) N = 37	(2.35)	(14)	(3.8)	(1.33)
SIGNIFICANT DIFFERENCES:	**	**		**

** Denotes significant differences for these measures at $p < 0.05$. V_E, ventilation; HR, heart rate; f_B, breathing frequency; V_E/BSA, ventilation/ body surface area.

TABLE 31. Male adolescent, young/middle-aged adult and older adult combined group mean response, (SD) and comparison for car driving and riding.

	V_E (L/min)	HR (bts/min)	f_B (br/min)	V_E/BSA
DRIVING COMBINED:	10.79	72	16.8	5.61
N = 39	(2.40)	(9)	(3.4)	(1.24)
RIDING COMBINED:	9.83	70	16.2	5.08
N = 39	(2.37)	(9)	(3.7)	(1.05)
SIGNIFICANT DIFFERNECES:	**	**		**

** Denotes significant differences for these measures at $p < 0.05$. V_E, ventilation; HR, heart rate; f_B, breathing frequency; V_E/BSA, ventilation/ body surface area.

Table 30. The mean values for V_E, HR, and V_E/BSA were significantly different between the two protocols. The group mean V_E during riding was 5.4% greater than that for the laboratory sitting protocol, while that during driving the automatic shift car was 15.2% higher (Heart rate and f_B during driving were 11.3% and 15.1% greater than during the laboratory sitting protocol.).

A frequency distribution of the female group's V_E (together with the mean for each group) during car driving and riding is depicted in Appendix Fig. 33. With the exception of one high value during driving (older adult) and two during riding (one each young/middle-age and older adult), there was no appreciable age group difference in the dispersion of values. The HR frequency distribution of the adolescent and adult female groups, given in Appendix Fig.34, shows a tendency for the older adults to have somewhat higher values for both driving and riding than the adolescent and the young/middle-aged adult females. The 5-min mean V_E values for the combined group of females during driving are depicted in Appendix Fig. 35a, with those for riding given in Appendix Fig. 35b. In both cases, the value for the first 5-min period was significantly higher (~10-15%) than the last three 5 min values, which did not differ significantly from each other. The only significant difference between the 5-min mean HR values for either driving or riding was between minutes 5 and 15 for driving (Appendix Fig. 36).

Thirty-nine of the 60 male adolescent, young/middle-aged adult, and older adult groups completed the car driving and riding protocol. Their mean responses (and standard deviation) for V_E, HR, f_B, and V_E/BSA for each protocol are given in Appendix Table 13. There were no significant differences between groups for any of these variables; thus, the data were combined for subsequent analyses. The combined group's response comparisons between the driving and riding protocols are presented in Table 31. The mean values for V_E, HR, and V_E/BSA were significantly different between the two protocols. V_E during the laboratory sitting rest protocol for this group of 39 subjects was 9.33 l/min, which was not significantly different from that for the total group (9.31 l/min). Their V_E during riding was 5.4% greater than that for the laboratory sitting protocol, while that for driving the automatic shift car was 15.6% higher. Their mean values for HR and f_B during driving were 5.4% and 20.8% greater than those observed during the laboratory sitting protocol.

A frequency distribution of the male group's V_E (together with the mean for each group) for car driving and riding is depicted in Appendix Fig. 37. There was no appreciable age group difference in the dispersion of values over the entire range. The HR frequency distribution of the adolescent and adult male groups, given in Appendix Fig.38, showed no appreciable age group difference in the dispersion of values over the entire range for either driving or riding. The 5-min mean V_E values for the combined group of males during driving are depicted in Appendix Fig. 39a, with those for riding given in Appendix Fig. 39b. In both cases, the mean value for the first 5-min period was significantly higher (~10-15%) than the last three 5 min values, which did not

TABLE 32. Adolescent, young/middle-aged adult and older adult combined male and combined female group r, r^2, and SEM for predicting V_E using simple linear and multiple regression analysis for car driving and riding.

V_E:

	Male Driving r r^2 (SEM)	Male Riding r r^2 (SEM)	Female Driving r r^2 (SEM)	Female Riding r r^2 (SEM)
BSA	0.26 0.068 (2.34)	0.51 0.262 (2.06)	0.26 0.069 (2.06)	0.26 0.066 (2.30)
HR (bts/min)	0.09 0.008 (2.42)	0.06 0.004 (2.40)	0.003 0.00001 (2.13)	0.02 0.0005 (2.38)
f_B **(br/min)**	**0.35 0.119** (2.06)	**0.52 0.266** (2.04)	**0.26 0.067** (2.17)	**0.38 0.146** (2.23)

SIMPLE EQUATIONS:

Equation	Group/Condition	r	SEM
$V_E = 0.220\ f_B + 6.881$	male driving	0.35	2.06
$V_E = 0.327\ f_B + 4.413$	male riding	0.52	2.04
$V_E = 0.151\ f_B + 6.338$	female driving	0.26	2.17
$V_E = 0.239\ f_B + 4.021$	female riding	0.38	2.23

MULTIPLE REGRESSION EQUATIONS:

Equation	Group/Condition	r	SEM
$V_E = 0.208\ f_B + 0.037\ HR + 5.447\ BSA - 6.088$	male driving	0.53	1.92
$V_E = 0.234\ f_B + 8.144\ BSA - 9.738$	male riding	0.73	1.65
$V_E = 0.185\ f_B - 0.003\ HR + 5.026\ BSA - 2.290$	female driving	0.42	2.11
$V_E = 0.246\ f_B + 0.014\ HR + 4.649\ BSA - 4.881$	female riding	0.48	2.18

differ significantly from each other. There were no significant differences between the 5-min mean HR values for either driving or riding (Appendix Fig. 40).

The simple regression r, r^2, and SEM values calculated for predicting V_E for the combined adolescent and adult female groups, and for the combined adolescent and adult male groups, during car driving and riding are given in Table 32. In both protocols, f_B was the single variable that best predicted V_E, although the r values tended to be somewhat lower than those obtained for the two groups during the laboratory sitting protocol. Specific linear and multiple regression equations that best predicted V_E (and their respective r and SEM values) for the combined adolescent and adult female, and for the combined adolescent and adult male, data are also presented in Table 32. The inclusion of BSA in the multiple regression equations increased the r values obtained and lowered those for SEM for both genders during driving and riding.

c. Yardwork. Each of the 20 young/middle aged adults and 20 older adult females completed two 30-min yardwork protocols. Since there were no significant protocol differences for V_E, HR, f_B, and V_E/BSA, the data for the two protocols were combined for the young/middle-aged adult group and the older adult group (Appendix Table 14). In addition, there were no significant group differences for V_E, HR, f_B, and V_E/BSA; hence, the data for the two female adult groups were combined as presented in Table 33.

Frequency distributions for the female adult groups' V_E and HR (together with the mean for each group) for yardwork are depicted in Appendix Fig. 41. There were no appreciable group differences in the dispersion of values over the entire range for either V_E or HR. The 5 min mean V_E values for the combined group of females for yardwork are displayed in Appendix Fig. 42a, with those for HR given in Appendix Fig. 42b. In both cases, the value for the first 5 min period was significantly lower than subseqent 5 min values, which did not differ significantly from each other.

As with the female adults, there were no significant protocol differences between the two 30 min yardwork bouts completed by the 20 young/middle-aged males and the 20 older adult males. Hence, the data for protocol 1 and 2 were combined for each group. Both group mean responses (and standard deviation) for V_E, HR, f_B, and V_E/BSA for yardwork are given in Table 34. The older adult males had significantly greater V_E, HR, and V_E/BSA responses for the combined 30 min protocols.

The male group differences are again apparent in the V_E and HR frequency distributions for the male adult groups for yardwork (Appendix Fig. 43), in which the older adult male values are consistently higher than those for the young/middle-aged males. This 30 min male group V_E difference occurred despite the fact that the older group's initial 5 min V_E mean for yardwork was 11.6% lower than the mean for the last five 5-min periods, while the young/middle-aged adult group's 5 min V_E means were not significantly different from each other (Appendix Fig. 44). The

5 min HR means for the young/middle-aged and adult male groups for yardwork were not significantly different from each other (except for the initial 5 min HR mean compared to the last for the older subjects) (Appendix Fig. 45).

Simple linear and multiple regression r, r^2 and SEM values calculated for predicting V_E (and the equations) for the combined young/middle-aged and older adult female groups, and for the young/middle-aged adult males and older adult males for yardwork, are given in Table 35. For the combined female group and the young/middle-aged adult males, V_E was best predicted by f_B, with r values similar to those obtained for walking and running for both of those groups (Tables 19, 21, 23, 25). Values for r were increased (similar to those for walking and running) and (SEM lowered) for these two groups when BSA and HR were included in the regression analysis. BSA was the only variable that predicted yardwork V_E for the older adult male group, with relatively poor values that were similar to those for BSA alone for the other two groups.

d. Housework. Each of the 20 young/middle-aged adult and 20 older adult females, as well as 9 of 20 adolescent females, completed two 30 min housework protocols. Since there were no significant protocol differences, the data for protocols 1 and 2 were combined for each group of females. Their mean responses (and standard deviation) for V_E, HR, f_B, and V_E/BSA for the combined housework protocols are presented in Table 36. There were no significant differences between the three groups of females; therefore, their data were combined. The combined group mean HR response for housework was 99 b/min, while their mean V_E response was 17.38 l/min. The simple linear and multiple regression r, r^2 and SEM values (and the equations) obtained when predicting V_E for housework for the combined group of females are shown in Table 37. The simple regression r values for housework were the same or slightly lower than those obtained for walking for the combined group of females (Table 19). The same was true for multiple regression r's for housework (0.57 vs 0.72 walking).

Housework frequency distributions for V_E and HR for the adolescent, young/middle-aged adult and older adult females (together with the mean for each group) are depicted in Appendix Fig. 46. Female adolescents tended to have a slightly lower V_E response, yet higher HR response, than die the adult female groups. The combined group 5-min V_E mean values for housework are displayed in Appendix Fig. 47a, with those for HR given in Appendix Fig. 47b. On both graphs, it is shown that the initial 5-min values were numerically lower than the values for the other measurement periods, which did not differ significantly from each other.

e. Car Maintenance and Repair. A total of 16 adolescent and young/middle-aged adult males performed two 30-min protocols of car maintenance and repair. The adolescent and young/middle-aged males were treated as one group due to the small number in each group (5 and 11, respectively). Since there were no significant protocol differences, the data for protocols 1 and 2 were combined. The group mean response (and standard deviation) for V_E, HR, f_B, and

TABLE 33. Female young/middle-aged adult and older adult combined group mean response and (SD) for yardwork (protocols 1 and 2 combined).

	V_E (L/min)	HR (bts/min)	f_B (br/min)	V_E/BSA
GROUPS COMBINED:	19.23	102	22.8	11.50
N = 40 x 2	(3.86)	(14)	(4.3)	(2.11)

V_E, ventilation; HR, heart rate; f_B, breathing frequency; V_E/BSA, ventilation/ body surface area.

TABLE 34. Group mean response, (SD) and comparison of male young/middle-aged adults and older adults for yardwork (protocols 1 and 2 combined).

	V_E (L/min)	HR (bts/min)	f_B (br/min)	V_E/BSA
YARDWORK:				
Young/Middle Adults:	26.07	102	21.1	13.19
N = 20 x 2	(5.99)	(15)	(5.0)	(2.87)
Older Adults:	31.89	110	23.3	15.93
N = 19 x 2 + 1	(7.03)	(15)	(3.6)	(3.26)
SIGNIFICANT DIFFERENCES:	***	***		***

** Denotes significant differences for these measures at $p < 0.05$. V_E, ventilation; HR, heart rate; f_B, breathing frequency; V_E/BSA, ventilation/ body surface area.

TABLE 36. Group mean and combined group mean response, (SD) and comparison of female adolescents, young/middle-aged adults and older adults for housework (protocols 1 and 2 combined).

	V_E (L/min)	HR (bts/min)	f_B (br/min)	V_E/BSA
Adoles:	16.34	104	22.2	10.00
(1) N = 9 x 2	(3.77)	(14)	(3.8)	(2.18)
Young/Middle Adults:	17.47	97	21.9	10.43
(2) N = 20 x 2	(3.40)	(12)	(4.3)	(1.63)
Older Adults:	17.76	98	22.4	10.60
(3) N = 20 x 2	(4.29)	(16)	(4.6)	(2.47)
SIGNIFICANT DIFFERENCES: NONE				
FEMALE GROUPS COMBINED:	17.38	99	22.2	10.42
(SD) N = 49 x 2	(3.85)	(14)	(4.3)	(2.10)

No significant differences for these measures at $p < 0.05$. V_E, ventilation; HR, heart rate; f_B, breathing frequency; V_E/BSA, ventilation/ body surface area.

TABLE 35. Young/middle-aged adult and older adult female combined group and young/middle-aged and older adult males group r, r^2, and SEM for predicting V_E using simple linear and multiple regression analysis for yardwork (protocols 1 and 2 combined).

V_E:

	Combined Females			Yg/Mid. Adult Males			Older Adult Males		
	r	(SEM)	r^2	r	(SEM)	r^2	r	(SEM)	r^2
BSA	0.39	(3.57)	0.153	0.30	(5.79)	0.089	**0.33**	(6.72)	**0.111**
HR (bts/min)	0.22	(3.79)	0.048	0.43	(5.49)	0.182	0.01	(7.12)	0.0002
f_B (br/min)	**0.50**	(3.44)	**0.253**	**0.55**	(5.19)	**0.307**	0.13	(7.28)	0.017

SIMPLE EQUATIONS:

Equation	Group	r	SEM
$V_E = 0.466 f_B + 8.700$	female groups combined	0.50	3.44
$V_E = 0.688 f_B + 11.26$	yg/mid. adult males	0.55	5.19
$V_E = 13.66 BSA + 4.536$	older adult males	0.33	6.72

MULTIPLE REGRESSION EQUATIONS:

Equation	Group	r	SEM
$V_E = 0.483 f_B + 12.40 BSA + .061 HR - 18.81$	female groups combined	0.68	2.97
$V_E = 0.693 f_B + 14.01 BSA + .117 HR - 28.41$	yg/mid. adult males	0.72	4.50
$V_E = 13.66 BSA + 4.536$	older adult males	0.33	6.72

V_E/BSA for the combined car maintenance protocols are presented in Table 38. The mean HR response was 99 b/min, and the mean V_E response was 23.2 l/min.

The simple linear and multiple regression r, r^2, and SEM values (and the equations) obtained when predicting V_E for car maintenance for this combined male population are shown in Table 39. The prediction of V_E for car maintenance from measured variables was limited to BSA, since the r values for both f_B and HR were less than 0.04.

Car maintenance frequency distributions for V_E and HR (together with the group means) for the combined group of adolescent and young/middle-aged adult males are depicted in Appendix Fig. 48. The five adolescents that comprised part of the group tended to have lower V_E, yet similar HR values. The combined group 5-min V_E mean values for car maintenance are displayed in Appendix Fig. 49a with those for HR provided in Appendix Fig. 49b. The initial 5-min mean for V_E was significantly different from the fourth and last measurement periods, whereas the initial 5-min mean HR was significantly different from the remaining 5-min means. None of the other 5-min V_E and 5-min HR means differed significantly from each other.

f. Lawn Mowing. A total of 14 young/middle-aged and older adult males completed two 30 min mowing protocols, while two other subjects completed one 30 minute protocol. Due to the small number of subjects in each group (10 and 6, respectively), the young/middle-aged and older adult males were treated as one group for analysis. Since there were no significant protocol differences, the data for protocols 1 and 2 were combined. The group mean response (and standard deviation) for V_E, HR, f_B, and V_E/BSA for combined mowing protocols are presented in Table 40. The mean HR response was 109 b/min, and the mean V_E response 36.6 l/min.

The simple linear and multiple regression r, r^2 and SEM values (and the equations) obtained when predicting V_E for mowing for this combined male population, are shown in Table 41. V_E for mowing was best predicted by the single variable of f_B, followed by BSA (r = 0.49) and then HR (r = 0.25). These single variable regression r values and that obtained for multiple regression (r = 0.64) were nearly identical to those calculated for the combined group of males during walking (f_B = 0.52, BSA = 0.49, HR = 0.32 and multiple = 0.72) (Table 23).

Mowing frequency distributions for V_E and HR for the combined group of young/middle aged and older adult males (together with the group means) are depicted in Appendix Fig. 50. The older adult males that comprised part of the group tended to have lower V_E and HR values. The combined group 5-min V_E mean values for mowing are displayed in Appendix Fig. 51a, with those for HR given in Appendix Fig. 51b. In both cases, the initial 5-min mean value was significantly different from the last five 5-min mean values, which did not differ significantly from each other.

g. Woodworking. A total of 9 young/middle-aged and older adult males completed two 30 minute protocols of woodworking. Due to the small number in each group (7 and 2, respectively),

TABLE 37. Adolescent, young/middle-aged adult and older adult female combined group r, r^2, and SEM for predicting V_E using simple linear and multiple regression analysis for housework (protocols 1 & 2 combined).

V_E:

	Combined Female Groups r	(SEM)	r^2
BSA	**0.43**	(3.49)	**0.186**
HR (bts/min)	0.25	(3.74)	0.063
f_B (br/min)	0.33	(3.60)	0.109

SIMPLE EQUATION:

Equation		r	SEM
$V_E = 12.39\ BSA - 3.255$	groups combined	0.43	3.49

MULTIPLE REGRESSION EQUATION:

Equation		r	SEM
$V_E = 12.48\ BSA + 0.281\ f_B + 0.030\ HR - 12.70$	groups combined	0.57	3.17

TABLE 40. Combined group mean response and (SD) of young/middle-aged and older adult males for mowing (protocols 1 and 2 combined).

	V_E (L/min)	HR (bts/min)	f_B (br/min)	V_E/BSA
YOUNG/MIDDLE-AGED AND OLDER ADULT MALES COMBINED:				
N = 14 x 2 + 2	36.55 (7.83)	109 (17)	24.0 (3.8)	18.48 (3.50)

V_E, ventilation; HR, heart rate; f_B, breathing frequency; V_E/BSA, ventilation/ body surface area.

TABLE 41. Young/middle-aged and older adult male combined group r, r^2, and SEM for predicting V_E using simple linear and multiple regression analysis for mowing (protocols 1 and 2 combined).

V_E:

	Combined Male Groups r	(SEM)	r^2
BSA	0.49	(6.97)	0.235
HR (bts/min)	0.25	(7.73)	0.060
f_B (br/min)	**0.52**	(5.71)	**0.274**

SIMPLE EQUATION:

Equation		r	SEM
$V_E = 0.912\, f_B + 13.09$	groups combined	0.52	5.71

MULTIPLE REGRESSION EQUATION:

Equation		r	SEM
$V_E = 0.533\, f_B + 16.16\, BSA + 0.024\, HR - 12.33$	groups combined	0.64	5.40

TABLE 38. Combined group mean response and (SD) of adolescent and young/middle-aged adult males for car maintenance (protocols 1 and 2 combined).

	V_E (L/min)	HR (bts/min)	f_B (br/min)	V_E/BSA
ADOLESCENT AND YOUNG/MIDDLE-AGED ADULT MALES COMBINED:				
N = 16 x 2	23.21 (5.95)	99 (11)	23.0 (5.1)	12.16 (2.70)

V_E, ventilation; HR, heart rate; f_B, breathing frequency; V_E/BSA, ventilation/ body surface area.

TABLE 39. Adolescent and young/middle-aged adult male combined group r, r^2, and SEM for predicting V_E using simple linear and multiple regression analysis for car maintenance (protocols 1 and 2 combined).

V_E:

	Combined Male Groups r	(SEM)	r^2
BSA	**0.55**	(5.06)	**0.299**
HR (bts/min)	0.04	(6.04)	0.002
f_B (br/min)	0.004	(6.30)	0.00001

SIMPLE EQUATION:

Equation		r	SEM
$V_E = 20.59$ BSA - 15.90	groups combined	0.55	5.06

MULTIPLE REGRESSION EQUATION:

Equation		r	SEM
$V_E = 20.60$ BSA - 0.002 HR - 15.74	groups combined	0.55	5.15

TABLE 42. Combined group mean response and (SD) of young/ middle-aged and older adult males for woodworking (protocols 1 and 2 combined).

	V_E (L/min)	HR (bts/min)	f_B (br/min)	V_E/BSA
YOUNG/MIDDLE-AGED AND OLDER ADULT MALES COMBINED:				
N = 9 x 2	24.42 (7.35)	93 (14)	22.0 (4.2)	12.54 (3.77)

V_E, ventilation; HR, heart rate; f_B, breathing frequency; V_E/BSA, ventilation/ body surface area.

TABLE 43. Young/middle-aged and older adult male combined group r, r^2, and SEM for predicting V_E using simple linear and multiple regression analysis for woodworking (protocols 1 and 2 combined).

V_E:

	Combined Male Groups r	r^2	(SEM)
BSA	0.06	0.004	(7.56)
HR (bts/min)	0.38	0.145	(7.01)
f_B (br/min)	**0.68**	**0.459**	(5.57)

SIMPLE EQUATION:

Equation		r	SEM
$V_E = 1.175 f_B - 1.465$	groups combined	0.68	5.57

MULTIPLE REGRESSION EQUATION:

Equation		r	SEM
$V_E = 1.175 f_B - 1.465$	groups combined	0.68	5.57

the young/middle-aged and older adult males were combined as one group for analysis. Since there were no significant protocol differences, the data for protocols 1 and 2 were combined. The group mean response (and standard deviation) for V_E, HR, f_B, and V_E/BSA are shown in Table 42. The mean HR response was 93 b/min, with the mean V_E response being 24.4 l/min.

The simple linear and multiple repression r, r^2 and SEM values (and the equations) obtained when predicting V_E for woodworking for this combined male population, are presented in Table 43. The prediction of V_E for woodworking from measured variables was limited to f_B, since the inclusion of BSA and HR in a multiple regression analysis did not improve single variable calculated r values.

Woodworking frequency distributions for V_E and HR for the combined group of young/middle-aged and older adult males (together with the group means) are shown in Appendix Fig. 52. There were no appreciable group differences in the dispersion of values over the entire range for both variables. The combined group 5 min V_E mean values woodworking are presented in Appendix Fig. 53a, with those for HR given in Appendix Fig. 53b. There were no significant differences between 5 min mean values for either variable.

DISCUSSION

1. Subject's Anthropometry. Review of mean and variability data for body height, BW, BSA, and percent body fat of the average American population (Malina and Bouchard, 1991; pp. 46, 98; McArdle et al., 1991; p. 664; Simopoulos and Van Itallie, 1984)) revealed no notable differences from the mean values for our groups given in Table 2. The range of minimum and maximum values for each anthropometric variable extend well beyond those at +/- 1 standard deviation (S.D.) and, in most cases, approach 2 S.D. (i.e., 95% of the normal distribution). Thus, with respect to body size and body composition, according to well known differences associated with age and gender, the subject population of this study appears to closely approximate the average American population. Thus, associations of V_E with BSA in this study are likely to be similarly applicable to the general population.

2. Potential Overestimation of Pulmonary Ventilation via Use of Mouthpiece and Noseclip.

Numerous authors have studied the effects of utilizing a mouthpiece and noseclip on breathing pattern and V_E during rest (Askanazi et al., 1980; Barlett et al., 1972; Gilbert et al., 1972; Sackner et al., 1980; Weissman et al., 1984) and during exercise (Bartlett et al., 1972; Paek & McCool, 1992; Sackner et al., 1980). Unencumbered breathing in these studies has been measured by a noninvasive canopy system (Askanazi et al., 1980; Weissman et al., 1984) and by induction pleththysmography (McCool et al., 1986; Paek & McCool, 1992; Sackner et al., 1980). Subjects were almost all young adult males.

3. Rationale for BSA Normalization of Pulmonary Ventilation during Rest and Activity.

Whether at rest or during exercise, the ultimate purpose of the pulmonary ventilation is to provide the body with the appropriate amount of ambient air to obtain adequate O_2 and to expire CO_2. Snyder et al. (1974), in the Report of the Task Group on Reference Man, cite means for liters of air breathed by the reference man (170 cm, 68.5 kg, BSA=1.77 m^2), the reference woman (160 cm, 54 kg, BSA=1.54 m^2), and a 10 yr.-old boy (140 cm, 36.5 kg, BSA=1.18 m^2) as 7.5, 6.0, and 4.8 l/min for rest, and 20, 19, and 13 l/min for light activity. The daily activities were assumed to consist of 8 h rest and 16 h of light activities, including 8 h of light occupational work activity. When these data were expressed as liters of air breathed for the 24-h day, the totals were very nearly proportional to the reference man, woman, and child's BSA in m^2.

Since maximal aerobic capacity (VO_{2max}) is related as a function of 2/3 of BW (Astrand and Rodahl, 1977; p. 376-378), and thus very nearly BSA in m^2, it follows that the latter should be well related to VO_{2max}, and that V_E for light, moderate, and heavy exercise should be more closely related to BSA than BW for the children and adult female populations who weigh significantly less than the 70 kg adult male. Indeed, Johnson (1989), of PEI Associates, has used the assumption that V_E and BSA vary together in such a way that their quotient (i.e., V_E/BSA, which he called the equivalent liters per minute, or ELPM) is nearly constant at a given level of exertion for populations and individuals who vary significantly in body size. When he applied this calculation to the resting V_E data for Robinson's (1938) boys, ages 5.7-19 yrs. (N=41), he obtained an R^2 of 0.96. Adams & Ireton (1990) examined use of the ELPM concept (i.e., V_E/BSA) in young adult males and females exercising at light, moderate, and heavy intensities as assessed by HR, which is directly related at submaximal workloads to the percent of maximal aerobic capacity, i.e., $\%VO_{2max}$ (McArdle et al.,1991 p. 436). It was observed that both the intercept and slope for predicting V_E from HR were significantly different for the males compared to the females when V_E was expressed in l/min. However, when V_E was "normalized" by dividing by BSA, the gender differences for the intercept and slope were not statistically significant. The correlation coefficient for the pooled data of both groups was 0.88, with a standard error of 4.32 l/min per m^2 BSA.

4. Laboratory Resting Protocols.

a. Pulmonary Ventilation During Basal and Resting Conditions. Studies of V_E measured during basal and resting conditions have been reported rather infrequently on large numbers of male and female children and adults, primarily because V_E has been considered only ancillary data attendent to energy expenditure data obtained by indirect calorimetry (i.e., the measurement of O_2 consumed and CO_2 produced, which is calculated from measured V_E). Anderson et al. (1985) have summarized the mean (together with the minima and maxima) values for resting and light activity (presumably sitting and standing) for over 500 adult male and female subjects. However, In general, use of a mouthpiece and noseclip increases V_E, both as a result of a greater depth of breathing (V_T) and an increased f_B. Oxygen consumption, however, remains unaffected. These breathing change effects have been attributed to mouthpiece dead space (Barlett et al., 1972; Sackner et al., 1980), to irritating effects of the mouthpiece and noseclip on the oral and nasal mucosa (Gilbert et al., 1972), and to the decreased airflow resistance with mouthpiece breathing vs. nasal breathing (Weismann et al., 1984). The latter authors noted no increase in V_E when using a small (9 mm diameter) mouthpiece, compared to unencumbered breathing, but a 20% increase when using the standard mouthpiece (17 mm diameter).

The effects of using a mouthpiece and noseclip are greater at rest, averaging 19% in three studies (Askanazi et al., 1980; Sackner et al., Weissman et al., 1984). However, Gilbert et al. (1972), using a mouthpiece with only 44 ml dead space, found no significant effect on V_E, as the significantly increased V_T was offset by a proportionally reduced f_B. Further, Barlett et al. (1972) observed no significant difference in V_E at rest using a mouthpiece with two small respiratory valves (36 and 48 ml, respectively), but an increase of 27% using a valve with 215 ml dead space, and an increase of 39% with a 300 ml dead space valve. Sackner et al. (1980) also have observed significant parallel increases in V_E with increasing dead space volume.

In general, there is less effect on V_E when using a mouthpiece and noseclip during cycle ergometer exercise than at rest (Sackner et al., 1980). Barlett et al. (1972) observed less than 5% higher V_E in moderate and heavy treadmill exercise when using a respiratory valve with 215 ml dead space, compared to one with 48 ml dead space. Paek and McCool (1992) also observed no significant difference in V_E measured with mouthpiece and noseclip vs. unencumbered breathing during heavy exercise (~40 l/min), but a 27% greater V_E in the mouthpiece and noseclip condition during light work (~15 l/min). When combining intensities of exercise, they also observed notable variations in the greater V_E for the mouthpiece and noseclip condition (6% for a pulling task, 20% for a lifting task, 12% for leg cycling, and 37% for arm egometry). However, the unencumbered breathing method used (induction plethysmography) may be subject to varied movement artifact and postural changes. Further, this instrumentation has not been miniaturized and will probably be too expensive for routine use in the field.

In the present study, we utilized a small mouthpiece (15 ml) and low dead space respiratory valves (laboratory protocols = 99 ml; field protocols = 38 ml). Thus, it is unlikely that our V_E values for rest are in excess of 10% greater (i.e., about 1 l/min) than if measured in unencumbered breathing. Since the percent difference falls with increasing work intensity, V_E determined in our active laboratory and field protocols was probably not more than 1 to 2 l/min greater than if measured in unencumbered breathing.

15% because of the decreased arterial loading capacity of the adult female's lower hemoglobin concentration, then V_E per m^2 BSA would be nearly equivalent (i.e., less than 5% greater). In the present study, the adolescent and adult male group's lying VO_2 (l/min) was 38% greater than that for the adolescent and adult female group. When divided by LBM, however, the male's value was only 1% greater than that for the female group. The male's V_E/BSA was 4.64 l/min per m^2, which was 7% greater than that for the female group.

Passmore and Durnin (1967; pp. 36-40) point out that the enhanced muscle activity to maintain sitting and standing postures necessitates increased metabolic energy expenditure above that required for lying at rest. They measured energy expenditure on male and female adults in their homes while they were lying at rest, sitting while engaged in such activities as reading, listening to the radio, and watching television, and while standing quietly. For all three postures, they observed an expected 33% greater values for the males per kg of BW, with no significant change with age (from 20 to 70 yrs) for either sex. The sitting activities required approximately 15% more energy than that measured for lying at rest, while standing quietly necessitated about 15% more energy than that for the sitting activities. Comparisons of young adults resting VO_2 when lying, sitting, and standing have been reported. Edholm et al. (1955) found that young adult males had a 8% greater VO_2 when sitting than when lying, and a 14% increase when standing than when sitting. Durnin and Namyslowski (1958) observed that young adult females experienced a similar increase in sitting rest VO_2, compared to that for lying, as did a group of young adult males (7.5%). In the present study, both the male and female groups showed a significant increase in VO_2 for sitting vs. lying (mean of 4.9%), and for standing vs. sitting (mean of 7.8%). These values approximate those observed by Durnin and Namyslowski (1958) and Edholm et al. (1955). The greater increases with sitting and standing reported by Passmore and Durnin (1967) is likely due to the "quiet" activities their subjects engaged in. Most of our subjects read, although a few listened to their "walkman" tape.

All of our groups also showed a consistent increase in HR and V_E (but not in f_B) when sitting vs. lying, and when standing vs. sitting. Although the adolescent and adult male group had a 3 to 4 b/min lower HR than the female group for all resting postures, both had similar increases in HR and V_E when sitting vs. lying (3.9% and 6.3%, respectively) and when standing vs. sitting (HR = 12.0%; VE = 11.5%). Of major interest is this study was the intent to predict V_E responses from other easily measured independent variables. The well established correlation between HR and V_E during exercise is a consequence of the necessary roles of each in meeting the large metabolic demands of muscular activity (McArdle et al., 1991; pp. 169-172). However, both HR and V_E are independently influenced by factors other than metabolic rate (McArdle et al., 1991; pp. 276-77 and 315-19). At rest, since metabolic demands are much less than during exercise, the they found very little similar data for adolescents (almost all for boys), almost none for boys under 10 yrs, and none for girls under 12 yrs of age.

Robinson (1938) reported lying rest V_E, f_B, and V_T on 93 normal non-athletic males ranging in age from 6 to 91 years. The range of V_E values in liters per minute (l/min) across the whole population was from 4.8 to 9.3. He classified the subjects into 11 groups according to age, and found a range of mean values from 6.5 l/min in the young children (6 yrs) to 8.12 l/min for one of the middle age groups whose mean BW was about 4 times that of the children. When the mean group values were expressed in liters per m^2 of body surface area (BSA), the children and early adolescents had 1 1/2 to 2 times greater values than the adult groups, who did not differ significantly from each other. Since group differences between the children and early adolescents (compared to the adult groups) in VO_2 directly paralleled those for V_E, it appears that the greater values per m^2 BSA for children and early adolescents is due primarily to their well documented additional growth energy expenditure (Malina & Bouchard, 1991--pp. 360-363).

In the present study, we observed no significant gender difference for V_E/BSA and VO_2 per kg of LBM within any of the four age groups. However, the combined male and female children group's lying VO_2/LBM and V_E/BSA were more than 60% greater than those values observed for the combined male and female adolescent and adult group. Further, the young children group's values for lying VO_2/LBM and V_E/BSA were about 15% greater than for the children's group. It seems likely that this was primarily due to the younger children's inability to lie as still as the older children were able to do. Robinson (1936) observed very little difference between the groups in V_T per m^2, which means that the higher V_E/m^2 for the children and early adolescents was associated with a siginificantly higher f_B (about 20/min) than that for the adult groups (about 13/min). In the present study, the combined male and female children group's lying f_B was 20.5 br/min, while that for the combined male and female adolescent and adult group was 13.8 br/min. The young children group's lying f_B was 26.3 br/min. Their lying HR was 101 b/min, which was substantially higher than the 83 b/min observed for the children's group and the 67 b/min observed for the adolescent and adult group. The additional hydrostatic, metabolic, and ventilatory demands of assuming the sitting and standing postures were similar for children, adolescents, and adults, such that there were no notable changes in the group differences that existed during the lying protocol.

In older adolescents and adults, there is a significant relationship between V_E and body size. This was apparent (though indirectly) when MacMillan et al. (1965) compared the lying rest VO_2 of young adult males and females. They observed that VO_2 for males was significantly greater for the males in l/min (39%), but substantially reduced when expressed per m^2 (23 %). Further, when expressed per unit of LBM, there was less than a 2% difference. They did not report V_E, but if one assumes a relationship of the V_E required per liter of VO_2 to be increased by children (about 2-fold vs. ~1 1/2-fold for the adolescent and adult groups). V_E in l/min per kg BW was significantly greater for the children and early adolescents, with no significant change with age thereafter. However, when expressed per m^2 of BSA, the children's and early adolescent's mean V_E were closely similar to values for the late adolescent and adult groups.

Montoye and Ayen (1986) compared the VO_2 values (per kg BW) for treadmill walking at 3 mph (zero grade) of 2 groups of male children (10-13 years) and 3 groups of adolescents (14-19 years) to that for a group of young adults (20-29 years). The values for the children and the young adolescents were 19% and 9% higher, respectively, than those of the older adolescent and young adult groups. However, when measured resting VO_2 was subtracted to obtain the net VO_2 for walking, the two children's groups had VO_2 values that were only about 10% greater than those for the adolescents and young adults. Pate (1981) compared the VO_2 values (per kg BW) for treadmill walking at 3 mph (zero grade) of a group of boys (9.7 yrs) to a group of young adult men (22.3 yrs). He found a significantly higher value for the boys, but when their resting VO_2 was subtracted, their net VO_2 was non-significantly higher than that of the young adult men (P>.40).

In the present study, most individuals in all groups walked at 2.5 mph, but it was necessary to estimate the VO_2 and V_E values for the adolescent and young/middle-age and older adult male group at 3 mph for comparison to other groups (this was done by linear interpolation of values obtained at 2.5 and 3.3 mph). VO_2 per kg BW for the adolescent and adult male group was nearly identical to that for the female group during walking at 2.5 and 3.0 mph. This was also true for the combined boys and girls original children's group and the combined boys and girls cross-validation group. However, the children's values were 34% higher at 2.5 mph and 36% higher at 3.0 mph than those for the male and female adolescent and adult groups. An interpolated value for the young children's group (3.6-5.9 years) was 60% higher at 2.5 mph than the adolescent and adult groups. However, when their 5 ml/min per kg BW higher VO_2 during standing rest was subtracted to obtain a net VO_2, it was reduced to 27% higher than the similarly obtained values for the adolescent and adult groups. Following subtraction of their 2.65 ml/min per kg BW higher standing rest value, the net VO_2 value during walking at 2.5 mph for the children's groups was 18% higher than the similarly obtained values for the adolescent and adult groups. In all of these comparisons, V_E per kg BW responded in a very similar manner. Thus, it is clear that young adolescents, older children, and especially young children, experience a substantially higher VO_2 (and V_E) per kg BW at any given walking speed than do older adolescents and adults, both because of their significantly elevated values at rest (due to metabolic growth energy needs) and an apparent inefficiency of walking gait (Montoye, 1982). Sallis et al. (1991) have observed that this combined effect results in a 1.37 times greater VO_2 (and, thus V_E) at age 5, which decreases rather steadily to 1.03 at age 17, than that for adults. This is of particular importance with regard to balance of chemical and neural inputs to the HR and V_E command centers located in the central nervous system may disrupt the tight coupling between HR and V_E seen during exercise.

The results of the present study suggest that HR and V_E responses are uncoupled to a significant extent during resting conditions, such that body size becomes an important additive predictor for V_E when the subject is at rest. HR was very poorly correlated with V_E in all postures for each group, ranging from an r of 0.01 to 0.18. On the other hand, f_B correlated notably better with V_E in all postures for each group comparison, ranging from an r of 0.32 to 0.63. BSA also was better correlated with V_E in all postures, ranging from an r of 0.13 to 0.48 in the children's group to an r of from 0.33 to 0.57 for the adolescent and adult groups. The best multiple regression analyses for predicting V_E for each group invariably included f_B and BSA, with better predictions being achieved for the two adolescent and adult groups than for the children's and cross-validation children's groups.

5. Laboratory Active Protocols. It is generally accepted that the metabolic, ventilatory, and HR response to increasing work rates is linear up to approximately 60% of the individual's maximum aerobic capacity (McArdle et al., 1991; pp. 171, 279). These relationships infer that not only should VO_2 increase in a linear manner with increases in walking/running speed, but that increases in V_E and HR should both rise as a linear function of VO_2. Hence, increased walking/running speed should elicit a linear relationship between V_E and HR. Indeed, this is what was observed in the present study within any particular age/gender group. Unfortunately, because of the very wide range of age and fitness of our subject population, there were only two walking speeds (viz., 2.5 and 3.0 mph) and one running speed (viz., 4.5 mph) that were common to a large enough number of subjects in our 2 children's groups (original and cross-validation) and the 2 (male and female) adolescent, young/middle-aged and older adult groups.

A very interesting controversy regarding the alleged inefficiency of children and young adolescents, in terms of VO_2 per kg of BW utilized while walking and running, vs. older adolescents and adults, has developed following a recent review (Sallis et al., 1991). These authors cite significantly higher VO_2 data for children than adults during walking and running, with only brief mention of an alleged 1 to 2 ml/min per kg BW higher VO_2 values observed at rest for children. Robinson (1938) examined the VO_2 (and V_E) response of male subjects (who were categorized into 10 groups according to age varying from 6-75 yrs) while walking on a treadmill at 3.5 mph. He observed the highest VO_2 per kg BW in the youngest group (6.0 years), with declining (but still higher than adults) values for older children (10.5 years) and young adolescents (14.1 years). However, when he calculated their mechanical efficiency for walking as a function of work performed, divided by total VO_2 minus resting VO_2 (which was 2 to 4 ml/min per kg BW higher for the children than the adolescents and adults), the children's values were about 10% lower than the adult's. He also observed that the range of V_E (l/min) was more variable in young

As expected, the r values obtained from regression equations predicting V_E during walking and running were notably higher than those obtained for the resting protocols. This can be attributed to the dramatic increase in the metabolic demands of walking and running over that for resting, such that the work demands become the overriding determinant of the individual V_E and HR responses, affecting both greatly and to near similar degrees. HR was reasonably well correlated with V_E in both walking and running for each group, ranging from an r of 0.20 to 0.75. The range of r values for f_B prediction of V_E during walking and running for each group comparison, was from 0.16 to 0.51, which was not quite as high as that for the resting V_E prediction equations. In general, BSA was better correlated with V_E during walking and running, ranging from an r of 0.66 to 0.84 in the children's group to an r of from 0.37 to 0.49 for the female and male adolescent and adult groups. The best multiple regression analyses for predicting V_E for each group invariably included BSA, with HR and f_B adding less to prediction precision. Better predictions were achieved for the children's and cross-validation children's groups during walking and running than for the combined male adolescent and adult group and for the combined female adolescent and adult group.

It was observed that the changes in V_E caused by walking and running at different speeds was linearly related to the HR response. As expected, however, the equations that best describe the relationship between V_E and HR were specific to the each activity. That is, a different equation must be used to describe the V_E increase with speed during walking, since the slope for V_E as a function of HR is greater for running than for walking (McArdle et al., 1991; p. 181).

6. Field Protocols.

a. Spontaneous Play in Children. In this study, we investigated the response of V_E, f_B, and HR in children engaged in spontaneous play, usually involving two 30-min protocols with a brief (~5-10 min) rest between. A consistent pattern of note, whether for a single 35-min protocol (cross-validation children's group), or for two 20-min (young children's group) or two 30-min protocols, was a lower V_E (10-20%) and HR (~10%) during the first 5 min period than for values observed for the remaining 5 min periods, which did not vary in a systematic manner (Appendix Figs. 29, 30, and 32). This was due in part to some children needing time to get enthused in the activity and, to some extent, to feel comfortable with the breathing apparatus they were wearing. Also, technicians were more likely to stop the subject briefly once or more during the first 5-min to be sure that the apparatus was functioning appropriately. The tendency for V_E to decrease between 20 min and 30 min of the single 35 min protocol used for the cross-validation group (Appendix Fig. 29b) may be due to a possible "boredom" effect, which was not seen during the last 5-min of the protocol. Heart rate, however, remained essentially constant for each 5 min period during the last 30-min for the cross-validation group (Appendix 30b). We chose to include the first 5-min period average, as well as all subsequent 5-min periods to obtain the total protocol potential air pollution health effects assessment, since lung size per kg BW does not change appreciably for males and females from age 7 to 25 years (Astrand, 1952; p. 65).

Astrand (1952) studied the VO_2 and V_E responses of both boys and girls and of young adult males and females during moderately heavy exercise (i.e., treadmill running at about 65% of VO_2 max). He found that the efficiency of breathing (in terms of the V_E required per liter of O_2 consumed, termed the ventilatory equivalent, V_{eq}) was significantly higher for children (ages 4-9 yrs) than for older children and early adolescents (ages 10-13 yrs). The female's mean values remained constant from ages 12 through 25 yrs, while the male's mean values decreased 10 to 15% during adolescence (probably due to increased O_2 loading efficiency with their ~15% greater blood hemoglobin concentration). The young adult male's values were not different from those for the late adolescents (16-18 yrs). Godfrey et al. (1971) studied the cardiorespiratory response of boys and girls (ages 6-16 years) to submaximal cycle ergometer exercise, and found little gender difference in V_E, V_T, and f_B until age 14. Krahnenbuhl and Williams (1992) also attribute decreased mechanical efficiency in children's running as being due to their disadvantaged stride rates and stride lengths (imposed by shorter limbs) at any given running speed. They also observed that running economy in children and young adolescents improves steadily with age in normally active individuals, and that short-term (up to 6 months) running instruction and practice are relatively ineffective in improving running efficiency.

In the present study, the only running speed common to our children's group and a substantial number of female and male adolescent and young/middle-aged adult subjects was 4.5 mph. The children's VO_2 value was about 20% higher than the mean for the adolescent and adult groups. V_E per kg of BW was about 33% higher for the children than for the adults. Clearly, children's inefficiency in running at any given speed presents similar concerns relative to potential air pollution health effects assessment as mentioned above for walking inefficiency.

The question arises as to whether VO_2 (and V_E) values obtained from treadmill walking and running accurately reflect those incurred during free-ranging walking and running. Ralston (1960) found that energy expenditure during treadmill walking was not significantly different from floor walking on a smooth surface at two equivalent speeds (vix. 1.83 and 3.66 mph). Passmore and Durnin (1967; pp. 42-43) confirmed these observations, but also presented data showing that energy expenditure increases significantly (i.e., 10-35%) when walking at the same speed on rough, uneven surfaces. They also observed that most subjects walk naturally on a treadmill after a few minutes of practice. The energy expenditure for treadmill running at a given speed has also been found not to differ significantly from running on a track within the speed ranges used in this study (i.e., 3.5 to 8.0 mph). At speeds faster than 9.0 mph, there is a progressively greater value obtained for running on a track (in which air resistance is incurred) compared to that on a treadmill (Daniels, 1985; Pugh, 1970).

(1992) have reported average HRs for 17 elementary school children (ages 10-12 yrs) and 19 high school students (ages 14-17 yrs) over a 3-day period (Sat.-Mon.) of free-ranging activity. Indoor HR values, during activities that entailed 74% and 81%, respectively, of the 2 groups' total time, ranged from an average of 86 to 96 b/min. Outside, vigorous activity entailed 15% and 9%, respectively, of the 2 groups' time, with HR ranging from an average of 106 to 119 b/min. In a study of 40 boys and girls, age 6 to 7 yrs, during 12 h free ranging summer activity, Gilliam et al. (1981) observed a resting HR of 82 and 86 b/min for the boys and girls, respectively, and a mean HR of 108 for the boys and 105 b/min for the girls. The boys had a HR of 150 b/min, or higher, for 38 min during the day, while the girls recorded values in excess of 150 b/min for 20 min.

The young children's group in this study also had about a 10% lower mean V_E and HR during the first 5-min period than for the three remaining 5-min periods, which did not deviate in a systematic manner. This response is somewhat in contrast to that presented in a 24-h continuous 2-min average HR profile for a 5-yr old girl presented by Saris (1986), in which there were numerous instances of rapid changes in HR during waking active time. He contends that the young child's preference for short, high-intensity activities can be explained by a shorter attention span and a lower socially induced motivation for prolonged exercise. While some of our young children showed substantial variation in HR pattern during the play protocols on occasion, there were near consistent 5 min averages following the first 5-min. However, there was wide inter-individual variability in the average total protocol V_E (5-23 l/min) and HR (100-185 b/min) in a group that varied only 35% in BSA (low of 0.61 m^2 vs. high of 0.82 m^2). This was primarily due to the type of play activity chosen by the child and, especially, the intensity of his/her participation.

Although the mean V_E for the young children's 20-min protocol was only 11.3 l/min, compared to an average of 18.0 l/min for the older children, when divided by BSA, they were nearly equivalent. The younger children had an average f_B of 28.5 br/min vs. the older children's average value of 32 br/min, while average HR was nearly equal (139 b/min for the young children and 141 b/min for the older children. The young children's average V_E and HR were closely similar to those observed for their "fast" walking speed (2.25 mph), i.e., 11.7 l/min and 134 b/min, respectively. However, their average f_B (37.6 br/min) was notably higher than that for the play protocol. Durant et al. (1992) have recently reported 12 h continuous HR monitoring observations obtained in 159 Anglo-, African-, and Mexican-American 3 to 5-yr old children. They found no significant ethnic, gender, day of week, or season of year differences in either mean resting HR, mean daily HR, or percent of the day with HR above 120 b/min. Mean resting HR for all groups was 92.6 b/min, while that for the entire 12-h day was 113.7 b/min. Perhaps surprisingly, during 1/3 of the 12-h period, HR was higher than 120 b/min. The mean longest duration of HR greater than 120 b/min was 18.4 min.

average V_E and HR values. This was done because free-ranging children (and, very likely, adults) may well start at a somewhat slower pace when inititating vigorous activity. Even if not so, the value obtained for the whole protocol in this manner would be only 2-3% lower (i.e., 10-20%/ six 5-min time periods) than that for the near steady-state last five 5-min periods.

In early active laboratory protocols, we observed that numerous children did not like to run at any speed for more than 3 or 4 min before stopping. In retrospect, it is rather unusual to observe children voluntarily running at a constant pace, or for extended periods of time. With the exception of organized running activities, children's spontaneous play is full of starts and stops, changes of speed and direction, and rarely any paced activity. Thus, play activities engaged in by our children's groups included intermittent periods of standing (brief), walking, and running, with increased amounts of arm activity relative to required locomotor "driven" leg work typical of walking and running. The relationship of HR to $\dot{V}O_2$ in arm work is known to be significantly higher than in leg work (McArdle et al., 1991; p. 340). Since V_E is metabolically driven in both arm work and leg work, we should expect a higher HR for a given V_E in our play activities than for walking and running. Indeed, when we calculated a regression predicting the combined children group's V_E response as a function of HR for walking and for running, we obtained a value of 22.37 and 22.50 l/min, respectively, for the mean spontaneous play HR of 141 b/min. However, the observed average V_E during spontaneous play was 20% lower (i.e., 18.05 l/min). This difference can not be reasonably attributed to difference in V_E measurement apparatus, as the adolescent and adult car driving and riding V_E values were appropriately higher than their laboratory sitting rest values. Thus, observations on children in this study underline the necessity of measuring V_E, as well as HR and f_B, in actual field conditions to more accurately determine the existent relationship in field activities of most interest. Alternatively, better laboratory simulations of these activities than can be obtained by walking and running alone, would be useful. The importance of this observation is evident when comparting Spier et al.'s (1992) predicted V_E for outdoor "medium" and "fast" activities in elementary school children with a mean HR of 115 and 119 b/min, respectively, as being 18 l/min and 19 l/min---values that are nearly identical to what we observed at a HR of 141 b/min, though in children who were about 1.5 yrs younger and somewhat smaller.

Treiber et al. (1989) have shown that the use of a Heart Watch monitor is highly valid, both when compared to simultaneous electrocardiographic (ECG) HR measurements in laboratory exercise and recovery periods and when engaged in field activities. They report r values of 0.98-0.99 for HR obtained by the Heart Watch vs. ECG for six 3-min bouts of field activities (including standing, walking, running, hitting a ball, throwing and catching a ball, and playing on a jungle gym) in 14 children, ages 7 to 9 yrs. The average HR for these activities ranged from 90 b/min for standing, to 164 b/min during running, with the overall average being 127 b/min. Spier et al.

Table 44. Summary of VE (l/min) data for outdoor bicycle riding.

Group	Riding Speed, mph		
	8.8	12.1	15.1
Adolescent Females	20.6 (17.4-27.0)	30.1 (23.2-38.5)	50.7 (44.1-60.9)
Adolescent Males	23.9 (21.0-31.3)	30.5 (25.0-40.9)	47.6 (43.8-53.0)
Adult Females	22.6 (16.7-30.0)	32.8 (24.4-41.1)	51.8 (41.0-70.1)
Adult Males	22.7 (17.5-29.0)	31.4 (25.8-34.0)	51.2 (44.6-61.3)

Values are group means, with range of group minimum and maximum values in parentheses

b. Outdoor Recreational Cycling. While adolescent males and females frequently engage in active recreational pursuits (Jenkins et al., 1991, Phillips et al., 1991), these activities represent a vast spectrum of modes whose V_E responses are predominantly intensity dependent. Further, the intensities at which they participate, in most cases, span the population's entire range of functional capacity. Thus, we did not propose to study recreational physical activity in the field for this population. We did, however, propose to analyze (from the results of a previous study; Adams, 1975) the VO_2 and V_E responses of adolescent males and females during outdoor bicycle riding, compared to young and middle-aged adults. The average age, height and weight of the 6 male and 6 female adolescent subjects studied closely resembled that observed for the 2 adolescent groups in the present study. Likewise, the average age, height and weight of the 12 male and 12 female young adult and middle-aged subjects closely approximated that observed for these 2 groups in the present study.

In the earlier study (Adams, 1975), subjects rode a standard 10-speed, narrow-tire bicycle in the upright, touring position along a level 2.4 km smooth, macadamized road. Oxygen uptake (and V_E) were determined for each subject during rides at speeds spanning the recreational riding speed range. The mean slow riding speed was 8.8 mph, the medium speed was 12.1 mph, and the fast speed was 15.1 mph. The mean V_E (together with the minimum and maximum values) for each group at the 3 riding speeds are given in Table 44. The mean values for the 2 adolescent groups were similar to those for the 2 adult groups. Since BSA for the adult males was 18% greater than the average for the other 3 groups, this means that they had similarly low V_E/BSA. This can be attributed to their 13% lower V_{eq} than that for the other groups (24 vs. 27.5 liters).

As expected, gross VO_2, expressed in ml/min per kg BW, increased as a geometric function of riding speed and, accordingly, a second degree polynomial regression line was fitted to the data. However, predicted values differed from measured values by more than 15 percent in 27 of 120 observations. Further, when the VO_2 data were analyzed by group comparisons according to age and gender, the adolescent groups and the adult female group had significantly higher values at a given speed than the adult male group. However, when VO_2 was divided by BSA (m^2) which is more truly reflective of the primary energy expenditure component of outdoor riding, viz., air resistance, there were no significant differences attributable to age or gender.

Lower efficiency than adults, in terms of greater VO_2 per kg of BW, has been observed for children and young adolescents when walking (Montoye & Ayen, 1986; Robinson, 1938) and running (Astrand, 1952; Daniels, 1985). This is due in part to a higher VO_2 at rest added to that required for performing the work of walking and running (Astrand, 1952; Robinson, 1938), but also, as Astrand and Rodahl (1977; p. 583) speculate, to inferior technique and/or less efficient body dimension relationships. As stated above, during outdoor bicycle riding, the VO_2 required for any speed is largely a function of air resistance, which is more closely related to BSA than to with V_E for each group comparison, ranging from an r of 0.26 to 0.52. BSA also was better correlated with V_E for both driving and riding, ranging from an r of 0.26 to 0.51. The best multiple regression analyses for predicting V_E for each group invariably included f_B and BSA, with better predictions being achieved for males (r = 0.53 for driving and 0.73 for riding) than for the female group (r = 0.42 for driving and 0.48 for riding).

d. Yardwork. Yardwork was the only field protocol that was completed by all young/middle-aged and older adult male and female subjects. As expected, the V_E, HR, and f_B responses of the male and female groups were significantly different; thus, they will be discussed separately. Passmore and Durnin (1967; p. 90) have presented data on the energy expenditure of gardening, showing a range of VO_2 values from 0.556 l/min for a 55 kg. woman spading with a trowel to 0.866 l/min for hoeing. For the average size young/middle-aged and older adult female subjects in this study, this range would increase to between 0.639 and 0.996 l/min. The mean V_E for the female subjects in this study was 19.2 l/min. Assuming a V_{eq} of 27 liters per liter of VO_2, their mean VO_2 would be 0.711 l/min.

The mean V_E and HR response for the first 5-min period of the females' yardwork protocol were both significantly lower (mean V_E = 9.4%; mean HR = 4.5%) than those for the remaining 5-min periods, which did not differ systematically. This was likely due to the fact that very few subjects started the yardwork protocol with one of their more demanding activities, such as hoeing or raking. Thus, for reasons identified above, we chose to include the first 5-min period average, as well as all subsequent 5-min periods to obtain the total protocol average V_E and HR values.

The range of individual mean V_E values observed for the females' yardwork protocol was from 10 l/min to 30 l/min, while that for mean HR was from 75 b/min to 140 b/min. While some of the variability in V_E was due to difference in subject size, as is reflected in the range of mean HR values, the primary reason for variability in V_E in this protocol was due to the individual tasks undertaken and the individual subject's intensity of effort in accomplishing them.

The mean HR for the adult females' yardwork protocol (102 b/min), as well as the range of these values, closely approximated those observed for treadmill walking at 2.5 mph (moderate speed). However, the mean V_E was 7.2% lower, and the range of values somewhat more variable than for the walking protocol. The mean f_B was the same as that for the walking protocol. A higher HR for a given V_E (l/min) for the adult females' yardwork than for walking, can be attributed to the greater HR to VO_2 (and, thus, V_E) in arm work compared to leg work (McArdle et al., 1991; p. 340). The precision of predicting V_E for the females' yardwork protocol was similar to that for walking in this group. The r between V_E and f_B was 0.50, while that between V_E and BSA was 0.39, and that between V_E and HR was 0.22. Adding BSA and HR to f_B in a multiple regression equation raised the r to 0.68.

BW. Adams (1975) observed that when VO_2 at each of the three average riding speeds for the adolescent and adult groups was divided by BSA, there were no significant differences attributable to age or gender. Thus, it is clearly evident that both adolescent groups demonstrated a similar mechanical efficiency in terms of VO_2 per m^2 BSA to that of the adults within the range of riding speeds studied. However, they still had a greater V_E per m^2 BSA than did the adult males, due to their ~15% greater V_{eq} per liter VO_2.

c. Car Driving & Riding. Both the male and female combined adolescent and adult groups had a closely comparable increased V_E during both car driving and riding than that observed for the laboratory sitting protocol. This amounted to 5.4% greater V_E for both genders during riding vs. sitting rest in the laboratory. V_E for driving the automatic shift car for 20 min in a mix of "in-town", country road, and freeway venues, was 15.2% greater than for laboratory sitting rest for the female group and 15.6% greater for the males. If it is assumed that VO_2 increased proportionally over that observed for laboratory sitting rest, then the females' value would be 0.237 l/min, while that for the males would be 0.324 l/min. Passmore and Durnin (1967; pp. 61-62) have reported a value of 0.278 l/min for a 65 kg male driving a truck on an open road, which was increased by more than 50% to 0.433 l/min when the truck was driven in city traffic. According to these authors, this still falls within the range of sedentary activity.

The absolute range of individual mean protocol V_E values (in l/min) for car driving and riding was closely similar to that for the laboratory sitting protocol for both genders. That is, most of the individual absolute values were shifted to the right by nearly the same amount as the group mean difference between laboratory sitting rest and car driving and riding (i.e., slightly greater values for car riding than for laboratory sitting rest and for car driving than for car riding). This same pattern across both genders was also true for the absolute range of individual mean protocol HR values for car driving and riding compared to that for the laboratory sitting protocol.

There was a small (10-15%) but significantly greater V_E during the first 5-min than for the 3 remaining 5-min periods for both genders during car driving and riding, which was not seen for the HR response. It seems probable that this might be due to individual subjects experiencing minor discomfort with the mouthpiece/noseclip assembly during the first several minutes of these very low breathing rate field protocols, which was not noticeable in other field protocols in which the metabolic demands of activity were significantly higher. The slightly higher V_E during the first 5-min for driving and riding could have occurred in both, since half of the subjects did the driving protocol first and half did the riding protocol first.

The results of the regression predictions of V_E from measured HR, f_B, and BSA for car driving and riding were very similar to those for predicting V_E during laboratory sitting rest. HR was very poorly correlated with V_E for both driving and riding, ranging from an r of 0.01 to 0.09 for the seaparate male and female group analyses. On the other hand, f_B correlated notably better

e. Housework. Passmore and Durnin (1967; pp. 50-52) provide energy expenditure data for a wide range of "domestic tasks" for a 55 kg. woman. They organized the tasks into 5 grades with VO_2 ranges for our larger size females (63 kg.) as follows: I = 0.236-0.354 l/min; II = 0.354-0.472 l/min (which included floor sweeping with a broom, ironing, and preparing food); III = 0.472-0.708 l/min (including cooking, dish washing, dusting, mopping floors, and cleaning cupboards); IV = 0.708-0.944 l/min (including bed making, vacuuming, polishing a floor with a mop, and window cleaning); and V = > 0.944 l/min (including scrubbing floors, and washing clothes by hand). Richardson (1965) studied the energy expenditure of women performing typical homemaking tasks on a repeated basis, virtually all of which fell within Passmore and Durnin's grades II and III, above. She found that repeated testing on subsequent days resulted in lower energy expenditure over time in 13 of 21 tasks measured (i.e., a learning effect). Comparing the energy expenditure for the first five trials to that for the last five trials resulted in lower values varying from 2 to 14%, being more for tasks with basic component movements involving manipulation compared to those with travel components. The mean V_E (l/min) combined female adolescent, young/middle-aged, and older adult group was 17.4 l/min. Assuming a V_{eq} of 27 l/min per liter of VO_2, this results in a VO_2 of 0.644 l/min, which falls in the upper end of Passmore and Durnin's grade III, above.

The range of individual mean V_E values observed for the housework protocol was from 10 l/min to 29 l/min, while that for mean HR was from 70 b/min to 145 b/min. While some of the variability in V_E was due to difference in subject size, as is reflected in the range of mean HR values, the primary reason for variability in V_E in this protocol was due to the individual tasks undertaken and the individual subject's intensity of effort in accomplishing them. The mean V_E and HR response for the first 5-min period of the housework protocol were both significantly lower (mean V_E = 7.9%; mean HR = 3.4%) than those for the remaining 5-min periods, which did not differ systematically. This was likely due to the fact that very few subjects started the housework protocol with one of their more demanding activities, such as vacuuming or scrubbing floors. Thus, for reasons identified above, we chose to include the first 5-min period average, as well as all subsequent 5-min periods to obtain the total protocol average V_E and HR values.

The mean HR for housework, as well as the range of these values, closely approximated those observed for treadmill walking at 2.0 mph (slow speed) for the combined adolescent, young/middle-aged adult, and older adult female group. However, the mean V_E was 10% lower, and the range of values somewhat more variable than for the walking protocol. However, the mean f_B was the same as that for the walking protocol. A higher HR for a given V_E (l/min) for houswork than for walking, can be ascribed to the greater HR to VO_2 (and, thus, V_E) in arm work compared to leg work (McArdle et al., 1991; p. 340). The precision of predicting V_E during housework was reduced over that for walking in this group due to the wide variation in activities

Passmore and Durnin (1967; p. 90) give VO_2 values for gardening ranging from 0.722 l/min for a 65 kg man weeding and raking to 1.690 l/min for digging dirt with a shovel. For the average size young/middle-aged and older adult male subjects in this study, this range would increase to between 0.889 and 2.079 l/min. Surprisingly, in this study, the older adult males had a significantly higher V_E, HR, and f_B during their yardwork protocol than did the young/middle-aged adult males. The mean V_E for the young/middle-aged adult males was 26.1 l/min. Assuming a V_{eq} of 24 liters per liter of VO_2, their mean VO_2 would be 1.088 l/min. The mean V_E for the older adult male group was 31.9 l/min, which would yield a mean VO_2 of 1.329 l/min. The primary reason for this unanticipated disparate response is not entirely certain, but the older male subjects reported a greater tendency to use gardening and yardwork, including more demanding activities such as hoeing, raking, and digging with a spade or shovel, as a routine form of preferred exercise than did the young/middle-aged male subjects.

The mean V_E and HR response for the first 5-min period of the young/middle-age males' yardwork protocol were not significantly different from the subsequent 5-min period values. This observation was also true for the older adult male group's 5-min HR responses. However, they had a significantly lower mean V_E (11.6%) during the first 5-min than those for the remaining 5-min periods, which did not differ systematically. Nonetheless, for reasons identified above, the first 5-min period average, as well as all subsequent 5-min periods were used to obtain the total protocol average V_E and HR values.

The mean HR for the young/middle-age adult males' yardwork protocol (102 b/min), as well as the range of these values, closely approximated those observed for treadmill walking at 3.3 mph (moderate speed). However, the mean V_E was 16.3% lower, and the range of values somewhat greater than for the walking protocol. The mean f_B was similar to that for the walking protocol. The older adult male group had a similar mean HR for the yardwork protocol (110 b/min) as for these subjects' fastest walking speed (108 b/min). While their mean yardwork f_B was similar to that during fast walking, their mean V_E was 19.2% lower. A higher HR for a given V_E (l/min) for the adult males' yardwork than for walking, can be attributed to the greater HR to VO_2 (and, thus, V_E) in arm work compared to leg work (McArdle et al., 1991; p. 340).

As was true for the adult females, the precision of predicting V_E during yardwork for the young/middle-age adult males was similar to that for walking. The r between V_E and f_B was 0.55, while that between V_E and BSA was 0.30, and that between V_E and HR was 0.43. Adding BSA and HR to f_B in a multiple regression equation raised the r to 0.72, compared to 0.77 for this group during walking. On the other hand, the older male group had an r from multiple regression analysis of 0.70 for walking, but only 0.33 for the yardwork protocol. The r between BSA and VE was 0.33, with that between fB and VE being 0.13 and that between HR and VE only 0.01.

completed the mowing protocol in this study. The mean V_E for gas-powered mowing for subjects in this study was 36.6 l/min. Assuming a Veq of 24 liters per liter of VO_2, their mean VO_2 value would be 1.53 l/min. The mean V_E and HR response for the first 5-min period of the mowing protocol, which was completed by 10 young/middle-aged male adults and 5 older male adults, were both significantly lower (mean V_E = 14.3%; mean HR = 8.5%) than those for the remaining 5-min periods, which did not differ systematically. For reasons identified above, the first 5-min period average, as well as all subsequent 5-min periods were included to obtain the total protocol average V_E and HR values.

The range of individual mean V_E values observed for the mowing protocol was from 25 l/min to 52 l/min, while that for mean HR was from 85 b/min to 145 b/min. Mean BSA for the subjects completing this protocol ranged from 1.66 to 2.27 m^2, so some of the variability in V_E can be accounted for by differences in body size. However, as is reflected in the range of mean HR values, the primary reason for variability in V_E in this protocol was due to the individual subject's intensity of effort.

The mean HR for mowing 109 b/min), closely approximated that observed for the fastest treadmill walking speed (usually 4 mph) for the young/middle-aged and older adult male subjects who completed this protocol (108.5 b/min), although the range of individual values was greater for mowing (85-145 b/min) than for walking (89-124 b/min). However, the mean V_E was 9% lower, though the range of values was similar to that for the walking protocol. Further, the mean f_B was 11.1% greater than for the walking protocol. A higher HR for a given V_E (l/min) for gas powered mowing than for walking, can be ascribed to the greater HR to VO_2 (and, thus, V_E) in arm work compared to leg work (McArdle et al., 1991; p. 340). The precision of predicting V_E during gas-powered mowing was reduced only slightly over that for walking in this group of subjects, even though there was a greater variation in intensity of effort as reflected in a wider range of individual HR values. The r between V_E and BSA was 0.49, while that between V_E and f_B was 0.52, and that between V_E and HR was 0.25. Adding HR and f_B to BSA in a multiple regression equation raised the r to 0.64.

h. Woodworking. Passmore and Durnin (1967; pp. 53-54) provide energy expenditure data for nine different tasks in a woodwork factory, ranging from 0.598 l/min to 1.155 l/min VO_2 for a 65 kg man. For our male young/middle-aged group's average size (75 kg), these values would be increased to 0.690 l/min and 1.332 l/min, respectively. Assuming a V_{eq} of 24 liters per liter of VO_2, this results in a range of V_E from 16.6 to 32.0 l/min. In the present investigation, the mean V_E for the woodworking protocol was 24.4 l/min.

The range of individual mean V_E values observed for the woodworking protocol was from 13 l/min to 40 l/min, while that for mean HR was from 76 b/min to 124 b/min. Most of the subjects (N=9) completing this protocol were of similar size (BSA range from 1.86 to 2.06 m^2)

performed, as well as in the intensity of effort. The r between V_E and BSA was only 0.43, while that between V_E and f_B was 0.33, and that between V_E and HR was 0.25. Adding HR and f_B to BSA in a multiple regression equation raised the r to 0.57.

f. Car Maintenance & Repair. For general repair garage work, Passmore and Durnin (1967; p. 53) report a range of VO_2 for a 65 kg. man of 0.742 l/min to 0.948 l/min, with a mean of 0.845 l/min. For our male adolescent and young/middle-aged group's average size (75 kg), the mean value can be estimated to be 0.975 l/min. The measured V_E for the 16 adolescent and young/middle-aged males who completed the car maintenance and repair protocol in this study was 23.2 l/min. Assuming a V_{eq} of 24 liters per liter of VO_2, their estimated VO_2 of 0.967 l/min closely approximates the value calculated from Passmore and Durnin's data.

The range of individual mean V_E values observed was from 11 l/min to 38 l/min, while that for mean HR was from 80 b/min to 124 b/min. Some of the large range in V_E can be explained on the basis of a substantial range in BSA (from 1.64 m^2 for the smallest adolescent to 2.18 m^2 for the largest adult male). However, as reflected in the range of mean HR values, the primary reason for variability in V_E in this protocol was due to the individual tasks undertaken and the individual intensity of effort in accomplishing them.

As occurred in other active field protocols, the mean V_E and HR responses for the first 5-min period of the car maintenance and repair protocol were somewhat lower than those for the remaining 5-min periods, which did not differ systematically. For reasons identified above, we chose to include the first 5-min period average, as well as all subsequent 5-min periods to obtain the total protocol average V_E and HR values.

The mean HR for car maintenance and repair, as well as the range of these values, closely approximated those observed for treadmill walking at 3.3 mph (moderate speed) for the adolescent and young/middle-aged adult males. However, the mean V_E was about 10% lower and the range of values more variable than for the walking protocol. Further, the mean f_B was about 10% greater than for the walking protocol. A higher HR for a given V_E (l/min) for car maintenance and repair than for walking, can be ascribed to the greater HR to VO_2 (and, thus, V_E) in arm work compared to leg work (McArdle et al., 1991; p. 340). These observations, together with the restricted sample size in this protocol, their significant range in body size, and the wide variation in activities performed, as well as in intensity of effort, resulted in a relatively poor prediction of V_E during car maintenance and repair. The r between V_E and f_B was < 0.01, while that between V_E and HR was 0.04. Thus, the r between V_E and BSA of 0.55 was not improved by adding either f_B or HR to a multiple regression equation.

g. Mowing (Gas-powered). Passmore and Durnin (1967; p. 90) cite a range of energy expenditure from 1.13 to 1.88 l/min of VO_2 for non-power driven lawn mowing; this range for a 65 kg. man would increase to about 1.30 to 2.17 l/min for the mean BW of the 15 subjects who than their male counterparts (1.95 m^2). The children's groups had a mean BSA of 1.11 m^2 (43.0% less than the adult males), while that for the young children was 0.73 m^2 (62.6% less than the adult males). The following table gives ranges for these three population groups referenced to their BSA percent of the adolescent, young/middle-aged, and older adult male criterion group.

MALES	FEMALES	CHILDREN	YG. CHILDREN
Light exercise ($V_E \leq 23$ l/min)	19.3 l/min	12.8 l/min	8.5 l/min
Moderate exercise ($V_E = 24$ to 43 l/min)	20.1-36.1 l/min	13.4-24.0 l/min	8.8-15.8 l/min
Heavy exercise ($V_E = 44$ to 63 l/min)	36.9-52.9 l/min	24.5-35.1 l/min	16.1-23.1 l/min
Very heavy exercise ($V_E \geq 64$ l/min)	(NOT APPLICABLE TO THIS STUDY)		

Utilizing this BSA "correction" of observed V_E in the field protocols conducted in this study, an initial categorization of exercise intensity can be described. The car driving/riding protocol was clearly very light (about 1/2 of the upper end of light exercise for both males and females). Young/middle-aged and older adult females participated in both housework and yardwork protocols. In both, their mean V_E (i.e., 17.4 and 19.2 l/min for housework and yardwork, respectively) was at the upper level of light exercise. Older adolescent (> 16 yrs.) and young/middle-aged adult males participated in the car maintenance and repair protocol. Their mean V_E was 23.2 l/min, which is at the upper level of light exercise. The young/middle-aged and older adult males participated in gas-powered mowing, woodworking, and yardwork. Their mean V_E for mowing was 36.6 l/min (which is categorized at the upper level of moderate exercise), while that for woodworking was 24.4 l/min (lower level of moderate exercise). V_E during yardwork for the adult females (no significant difference between the young/middle-aged and older adult female groups) was somewhat lower (19.2 l/min; upper level of light exercise) than that observed for the young/middle-aged adult males (26.1 l/min; lower level of moderate exercise). However, the V_E observed for the over 60-yr-old male group was 31.9 l/min (middle level of moderate exercise), which was a reflecton of their greater tendency to use gardening and yardwork, including demanding activities such as hoeing, raking, and digging with a spade or shovel, as a routine form of preferred exercise.

Spontaneous play for children resulted in a mean V_E of 18.0 l/min, which is categorized at the middle level of moderate exercise. This was also true for the young children's mean V_E of 11.3 l/min. Whether this protocol is actually characteristic of children playing outdoors, spontaneously, in ambient smog alert conditions is uncertain.

The retrospective oudoor bicycling study presents very interesting additional information relative to that acquired in the present study, in that observations over the range of V_E in active persons outdoors was obtained. The lower riding speed (8.8 mph) resulted in a near equivalent light exercise intensity for adolescents and both adult males and females. The intermediate speed

Thus, as is reflected in the range of mean HR values, the primary reason for variability in V_E in this protocol was due to the individual tasks undertaken and the individual subject's intensity of effort in accomplishing them. While the mean V_E response for the first 5-min period of the woodworking protocol was somewhat lower (mean = 7.4%) than those for the remaining 5-min periods, which did not differ systematically, the HR responses were very nearly steady-state (between 92-93 b/min) throughout.

The mean HR for woodworking, as well as the range of these values, closely approximated those observed for treadmill walking at 3.3 mph (moderate speed) for the young/middle-aged adult male group. However, the mean V_E was about 10% lower and the range of values somewhat more variable than for the walking protocol. Further, the mean f_B was about 15% greater than for the walking protocol. A higher HR for a given V_E (l/min) for woodworking than for walking, can be ascribed to the greater HR to VO_2 (and, thus, V_E) in arm work compared to leg work (McArdle et al., 1991; p. 340). Due to the restricted sample size in this protocol, the wide variation in activities performed, as well as in the intensity of effort, regression analyses to predict VE during woodworking resulted in only a moderately good prediction of V_E. The r between V_E and BSA was only 0.06, which is due to the rather tight range in body size of this protocol sample (N = 9). The r between V_E and fB was 0.68, while that between VE and HR was 0.38. Adding BSA and/or HR to fB in a multiple regression equation did not raise the r above 0.68.

7. Exercise Intensity Classification of Field Activities in this Study.

There have been numerous classification systems advanced to categorize the workload/physical demands of activities, particularly for tasks entailed in various occupations. Although many are based on workload assessment and measurement of physiological response of the workers, the various levels remain rather arbitrary. For example, the EPA identified the collapsed range of activities accepted in the EPA Environmental Criteria and Assessment Office for the ozone criteria document, as follows:

1. Light exercise ($V_E \leq 23$ L/min)
2. Moderate exercise ($V_E = 24$ to 43 L/min)
3. Heavy exercise ($V_E = 44$ to 63 L/min)
4. Very heavy exercise ($V_E \geq 64$ L/min)

While these values may be appropriate for a 70 kg. "reference man", Passmore and Durnin (1967; p. 47) present a similar classification scheme ranging from light to unduly heavy work, in which values for women are ~75% of those for men. Johnson (1989) contends that there is a close association between BSA and V_E at any given work intensity for people varying in gender, size, and age. Thus, the EPA work intensity classification given above is not suitable for use with children, adult females and, possibly, for the elderly. In the present study, the adolescent, young/middle-aged, and older adult females had a mean BSA of 1.65 m^2, which was 15.4% less

REFERENCES

1. Adams, W.C. Studies of metabolic energy expenditure in bicycling. Final Report to DeLeuw, Cather and Company, San Francisco, CA, 1975 (Physical Education Department, Univ. of California, Davis).

2. Adams, W.C. Effects of ozone exposure at ambient air pollution episode levels on exercise performance. Sports Med. 4:395-424, 1987.

3. Adams, W.C. and C.L. Ireton. Investigation of the relationship of pulmonary ventilation to heart rate during continuous exercise at selected submaximal workrates. Report to the American Petroleum Institute, Jun 1990.

4. Adams, W.C., M.M. McHenry, and E.M. Bernauer. Multistage treadmill walking performance and associated cardiorespiratory responses of middle-aged men. Clinical Science. 42:355-370, 1972.

5. Anderson, E., N. Browne, S. Duletsky, J. Ramig, and T. Warn. Development of Statistical Distribution or Ranges of Standard Factors used in Exposure Assessments. Report prepared by GCA Corporation, GCA/Technology Division, Chapel Hill, North Carolina for: U.S. Environmental Protection Agency. Exposure Assessment Group, Office of Health and Environmental Assessment, Washington, D.C. January 1985.

6. Askanazi, J., P.A. Silverberg, R.J. Foster, A.I. Hyman, J. Milic-Emili, and J.M. Kinney. Effects of respiratory apparatus on breathing. J. Appl. Physiol. 48:577-580, 1980.

7. Astrand, P-O. Experimental Studies of Physical Working Capacity in Relation to Sex and Age. Copenhagen: Ejnar Munksgaard, 1952

8. Astrand, P-O. Why exercise? An evolutionary approach. Acta Med. Scand. Suppl. 711:241-242, 1986.

9. Astrand, P-O., and K. Rodahl. Textbook of Work Physiology. (2nd ed.) New York: McGraw-Hill, 1977.

10. Barlett, H.L., J.L. Hodgson, and J. Kollias. Effect of respiratory valve dead space on pulmonary ventilation at rest and during exercise. Med. Sci. Sports. 4:132-137, 1972.

11. Consolazio, C.F., R.E. Johnson, and L.J. Pecora. Physiological Measurements of Metabolic Functions in Man. New York: McGraw-Hill (The Blakiston Division), 1963.

12. Daniels, J.T. A physiologist's view of running economy. Med. Sci. Sports Exer. 17:332-338, 1985.

13. DuBois, D., and E.F. DuBois. A formula to estimate the approximate surface area if height and weight be known. Arch. Intern. Med. 17:863-871, 1916.

14. Durant, R.H., T. Baranowski, H. Davis et al. Reliability and variability of heart rate monitoring in 3-, 4-, or 5-yr-old children. Med Sci Sports Exer. 24:265-271, 1992.

15. Durnin, J.V.G.A., and L. Namyslowski. Individual variations in the energy expenditure of standardized activities. J. Physiol. (London). 143:573-578, 1958.

(12.1 mph) resulted in V_E values that were equivalent to those for moderate exercise. The 15.1 mph speed, which is at the upper end of the recreational riding speed range and not typical of most of the non-athletic population for prolonged periods, produced V_E values that were in the heavy exercise range.

At least one essential question remains: does the equivalent liters per minute (ELPM) concept advanced by Johnson (1989)--i.e., V_E divided by BSA, really indicate equal intensity and, thus, equal capability for participation at that activity for a given period of time? In the present investigation, the vast majority of our subjects participated in only one common activity at the same speed, viz., walking on the treadmill at 2.5 mph, thus providing useful information to respond to the question posed. VO_2 per m^2 BSA was nearly equivalent for the three groups compared (children, adolescent and adult males, and adolescent and adult females), ranging from 0.432 to 0.464 l/min per m^2. Further, V_E/BSA was nearly equal for the adolescent and adult groups (12.3 and 12.5 l/min per m^2 for the males and females, respectively). However, the males' HR was significantly less (94 b/min) than that for the females (104 b/min). Further, the children had a 10% higher V_E per m^2 BSA, and a notably higher HR (118 b/min) than the two adolescent/adult groups. Since the capacity to perform prolonged work is highly related to the percent of VO_{2max} at which one is exercising (which, in turn is highly related to the HR; McArdle et al., 1991; pp. 434-435), this comparison indicates that groups varying widely in size and age, as well as gender, are not necessarily working at the same intensity if their V_E/BSA are equivalent. Clearly, more research is required to unravel this complex phenomenon.

8. Assessment of Breathing Rate and Volume and Heart Rate in Young Children (3.5 - 5.9 yrs.).

We conducted a feasibility pilot study of young children (N=12), who each completed the orientation session and the resting V_E and HR measurement protocol, though the length was reduced from 25 min for older subjects to 15-20 min for each posture in this group. This, together with parents reading to them resulted in a reasonably "quiet state" while measurements were obtained.

All subjects walked at 3 speeds for 6 min each (1.5, 1.88, and 2.25 mph), but even when the length of time at each jog/running speed was reduced from 6 to 4 min, only 3 of 12 subjects were able to complete one or more speeds ranging from 2.7 to 3.8 mph. Measurement of HR, V_E, and f_B during spontaneous play activities, utilizing the same "backpack" container for data collection instruments and procedures employed for older children, was accomplished for all 12 children, although the two 30-min periods used with the older children, were reduced to two 20-min periods in this group. Thus, breathing rate and volume, as well as HR, can be successfully measured during resting and active protocols in this age group, although we experienced a 25% subject attrition rate following the orientation session in this group, compared to only 3% in the 200 older subjects tested.

33. Montoye, H.J., and T. Ayen. Body size adjustment for oxygen in treadmill walking. Res. Quart. Exer. Sport. 57:82-84, 1986.

34. Paek, D., and F.D. McCool. Breathing patterns during varied activities. J. Appl. Physiol. 73:887-893, 1992.

35. Passmore, R., and J.V.G.A. Durnin. Energy, Work and Leisure. London: Heinemann Educational Books, 1967.

36. Pate, R.R. Oxygen costs of walking, running and cycling in boys and men (abstract). Med. Sci. Sports Exer. 13:123-124, 1981.

37. Phillips, T.J., P.L. Jenkins, and E. J. Mulberg. Children in California: Activity Patterns and Presence of Pollutant Sources. (DRAFT 4/26/91)

38. Pugh, L.G.C.E. Oxygen intake in track and treadmill running with observations on the effect of air resistance. J. Physiol. (London). 207:823-835, 1970.

39. Raizenne, M.E., and J. D. Spengler. Dosimetric model of acute health effects of ozone and acid aerosols in children. In: Atmospheric Ozone Research and Its Policy Implications. (T. Schneider, ed.). Amsterdam: Elsevier, 1989.

40. Ralston, H. J. Comparison of energy expenditure during treadmill walking and floor walking. J. Appl. Physiol. 15:1152, 1960.

41. Richardson, M. Effect of repetition on the energy expenditure of women performing selected activities. J. Appl. Physiol. 20:1312-1318, 1965.

42. Robinson, S. Experimental studies of physical fitness in relation to age. Arbeitsphysiol. 10:251-323, 1938.

43. Sackner, J.D., A.J. Nixon, B. Davis, N. Atkins, and M. A. Sackner. Non-invasive measurement of ventilation during exercise using a respiratory inductive plethysmograph. I. Am. Rev. Respir. Dis. 122:867-871, 1980.

44. Sallis, J.F., M.J. Buono, and P.S. Freedson. Bias in estimating caloric expenditure from physical activity in children: implications for epidemiological studies. Sports Med. 11:203-209, 1991.

45. Samet, J.M., W.E. Lambert, D.S. James, C.M. Mermier, and T.W. Chick. Ventilation, activity, and lung doses of air pollutants. Final Report to the Health Effects Institute, Cambridge, MA, 1991.

46. Saris, W.M. Habitual physical activity in children: methodolgy and findings in health and disease. Med Sci. Sports Exer. 18:253-263, 1986.

47. Shamoo, D.A., T.R. Johnson, S.C. Trim, D.E. Little, W.S. Linn, and J.D. Hackney. Activity patterns in a panel of outdoor workers exposed to oxidant pollution. J. Expos. Anal. Environ. Epidemiol. 1:423-438, 1991.

48. Simopoulos, A. P., and T.B. Van Itallie. Body weight, health and longevity. Ann. Intern. Med. 100:285-295, 1984.

16. Edholm, O.G., J.G. Fletcher, E.M. Widdowson, and R.A. McCance. The energy expenditure and food intake of individual men. Brit. J. Nutr. 9:286-300, 1955.

17. Gilbert, R., J.H. Auchincloss Jr., J. Brodsky, and W. Boden. Changes in tidal volume, frequency, and ventilation induded by their measurement. J. Appl. Physiol. 33:252-254, 1972.

18. Gilliam, T.B., P.S. Freedson, D.L. Geenen, and B. Shahraray. Physical activity patterns determined by heart rate monitoring in 6-7 year-old children. Med. Sci. Sports Exer. 13:65-67, 1981.

19. Godfrey, S., C.T.M. Davies, E. Wozniak, and C. A. Barnes. Cardiorespiratory response to exercise in normal children. Clin. Sci. 40:419-431, 1971.

20. Haskell, W.L., A.S. Leon, C.J. Caspersen et al. Cardiovascular benefits and assessment of physical activity and physical fitness in adults. Med. Sci. Sports Exer. 24:S201-S220, 1992.

21. Ikegami, Y., W. Hiruta, H. Ikegami, and M. Miyamura. Development of a telemetry system for measuring oxygen uptake during sports activities. Eur. J. Appl. Physiol. 57:622-626, 1988.

22. Jackson, A.S., and M.L. Pollock. Generalized equations for predicting body density of men. Br. J. Nutr. 40:497-504, 1978.

23. Jackson, A.S., M.L. Pollock, and A. Ward. Generalized equations for predicting body density of women. Med. Sci. Sports Exer. 12:175-182, 1980.

24. Jenkins, P.L., T.J. Phillips, and E.J. Mulberg. Activity Patterns of Californians: Use of and Proximity to Indoor Pollutant Sources. (DRAFT)

25. Johnson, T. Estimation of ventilation rates for the ozone NEM analysis. Durham, N.C.: PEI Associates, Inc. Report to Tom McCurdy, U.S. E.P.A., QAQPS, MD-12, Research Triangle Park, N.C., January 17, 1989.

26. Krahenbuhl, G.S., and T.J. Williams. Running economy: changes with age during childhood and adolescence. Med. Sc. Sport Exer. 24:462-466, 1992.

27. Lohman, T.G. Applicability of body composition techniques and constants for children and youths. In: Exercise and Sports Sciences Reviews. Vol. 14. (K.B. Pandolf, ed.). New York: Macmillan, 1986, pp. 325-357.

28. Malina, R.M., and C. Bouchard. Growth, Maturation, and Physcial Activity. Champaign, Ill.: Human Kinetics, 1991.

29. McArdle, W.D., F.I. Katch, and V.L. Katch. Exercise Physiology: Energy, Nutrition, and Human Performance. Philadelphia: Lea & Febiger, 1991 (3rd edition).

30. McCool, F.D., K.B. Kelly, S.H. Loring, I.A. Greaves, and J. Mead. Estimates of ventilation from body surface measurements in unrestrained subjects. J. Appl. Physiol. 61:1114-1119, 1986.

31. MacMillan, M.G., C.T. Reid, D, Shirling, R. Passmore. Body domposition, resting oxygen consumption, and urinary creatinine in Edinburgh students. Lancet. 1:728-729, 1965.

32. Montoye, H.J. Age and oxygen utilization during submaximal treadmill exercise in males. J. Gerontol. 37:396-402, 1982.

Glossary of Terms and Abbreviations

b/min	beats per minute
br/min	breaths per minute
BTPS	body temperature, standard pressure, saturated
BW	body weight
CF	correction factor
cm	centimeters
CV	coefficient of variation
ECG	electrocardiograph
ELPM	equivalent liters per minute
f_B	breathing frequency
h	hour
HR	heart rate
kcal	kilocalorie
kg	kilogram
km	kilometer
l/min	liters per minute
LBM	lean body mass
m	meter
min	minute
ml	milliliter
mph	miles per hour
P	probability
r	correlation coefficient
r^2	coefficient of determination
RQ	respiratory quotient
s	second
SD	standard deviation
SEM	standard error of estimate
V_E	minute ventilation
VO_2	oxygen uptake
VO_{2max}	maximal oxygen uptake
V_T	tidal volume
x	mean
yr	year

49. Snyder, W,S., M.J. Cook, E.S. Nasset et al. Report of the Task Group on Reference Man. Report to the International Commission on Radiological Protection. Oxford: Pergamon Press, 1974, pp. 346-347.

50. Spier, C.E., D.E. Little, S.C. Trim, T.R. Johnson, W.S. Linn, and J.D. Hackney. Activity patterns in elementary and high school students exposed to oxidant pollution. J. Expo. Anal. Environ. Epidemiol. 2:277-293, 1992.

51. Taylor, C.B., T. Coffey, K. Berra, R. Iaffaldano, K. Casey, and W.L. Haskell. Seven-day activity and self-report compared to a direct measure of physical activity. Am. J. Epidemiol. 120:818-824, 1984.

52. Terblanche, A.P.S., H. Ozkaynak, J.D. Spengler, and D.A. Butler. Relationship between self-reported activity levels and actual heart rates in teenagers. J. Air Waste Manage. Assoc. 41:942-946, 1991.

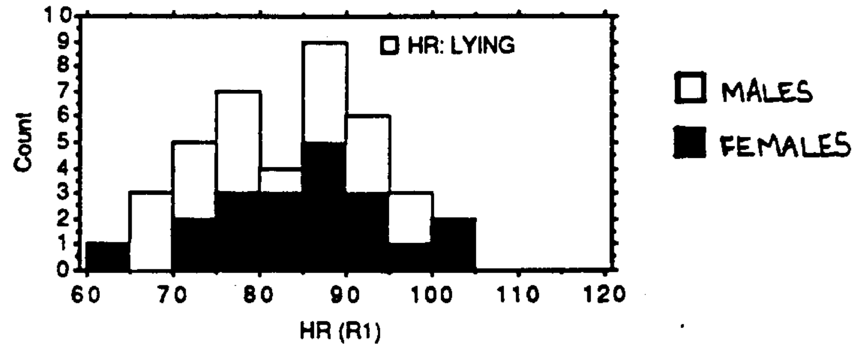
53. Treiber, F.A., L. Musante, S. Hardagan et al. Validation of a heart rate monitor with children in laboratory and field settings. Med. Sci. Sports Exer. 21:338-342, 1989.

54. Washburn, R.A., and H.J. Montoye. Validity of heart rate as a measure of mean daily energy expenditure. Exer. Physiol.: Current Selected Res. 2:161-172, 1986.

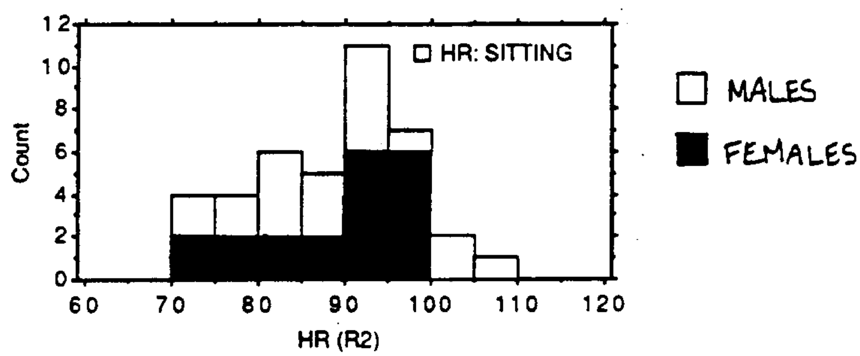
55. Waterlow, J.C. Notes on the new international estimates of energy requirements. Proc. Nutr. Soc. 45:351-360, 1986.

56. Weissman, C. J. Askanazi, J. Milic-Emili, and J.M. Kinney. Effect of respiratory apparatus on respiration. J. Appl. Physiol. 57:475-480, 1984.

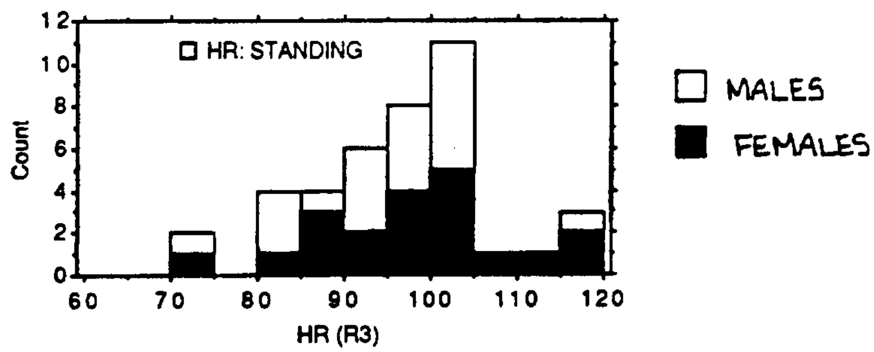
APPENDIX FIGURE 2. Male and female children group frequency distribution for HR for lying (a), sitting (b) and standing (c) protocols.



a: HR values for male (x = 81) and female (x = 85) children for lying protocols.

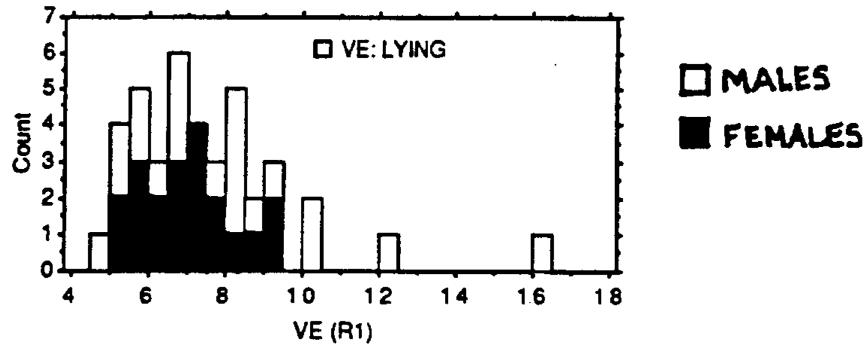


b: HR values for male (x = 88) and female (x = 88) children for sitting protocols.

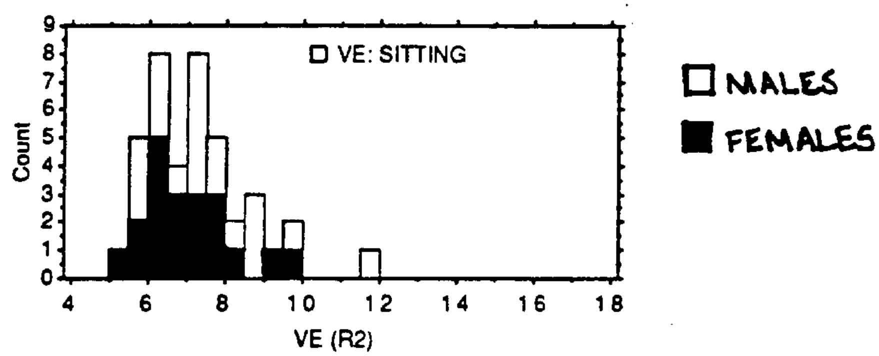


c: HR values for male (x = 95) and female (x = 98) children for standing protocols.

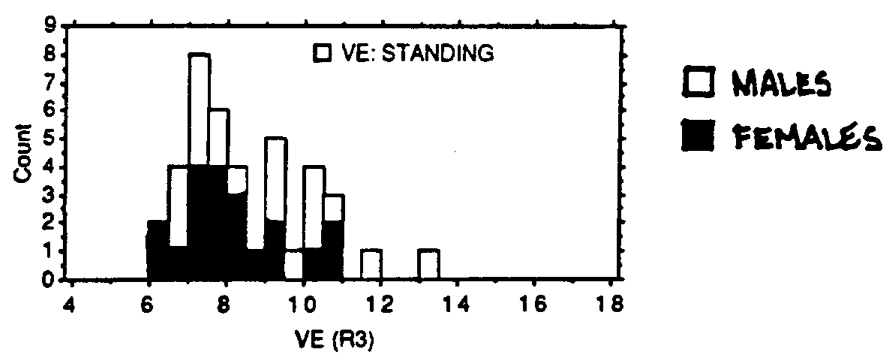
APPENDIX FIGURE 1. Male and female children group frequency distribution for V_E for lying (a), sitting (b) and standing (c) protocols.



a: V_E values for male (x = 8.04) and female (x = 6.99) children for lying protocols.

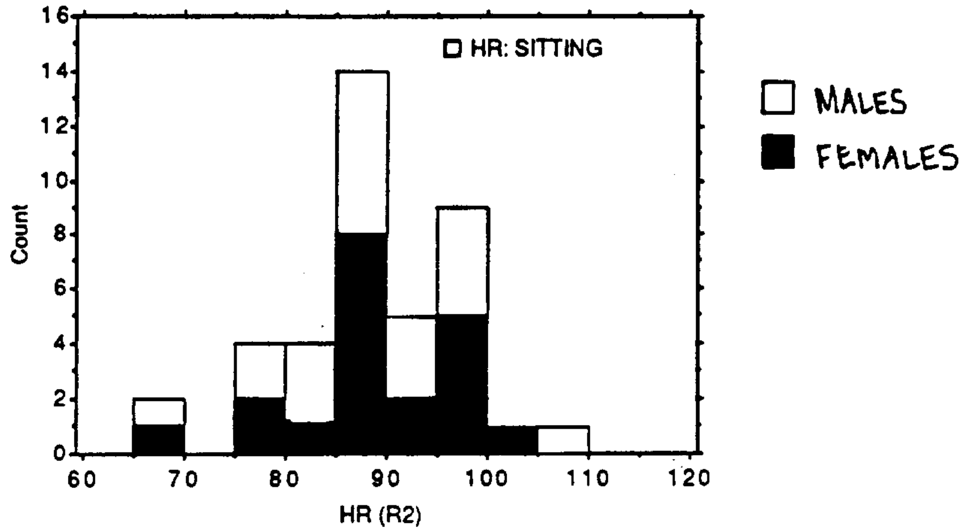


b: V_E values for male (x = 7.54) and female (x = 7.02) children for sitting protocols.

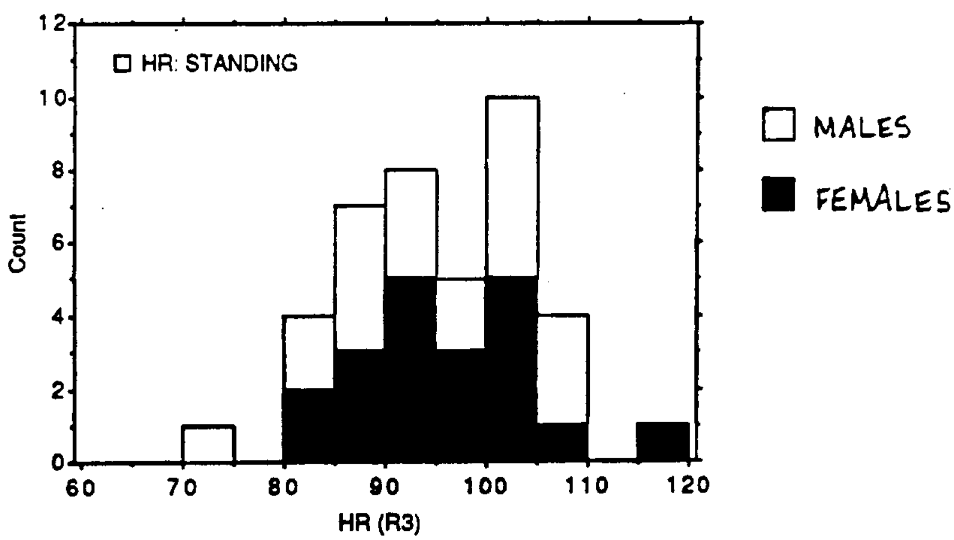


c: V_E values for male (x = 8.86) and female (x = 8.12) children for standing protocols.

APPENDIX FIGURE 4. Male and female cross-validation children group frequency distribution for HR for sitting (a) and standing (b) protocols.

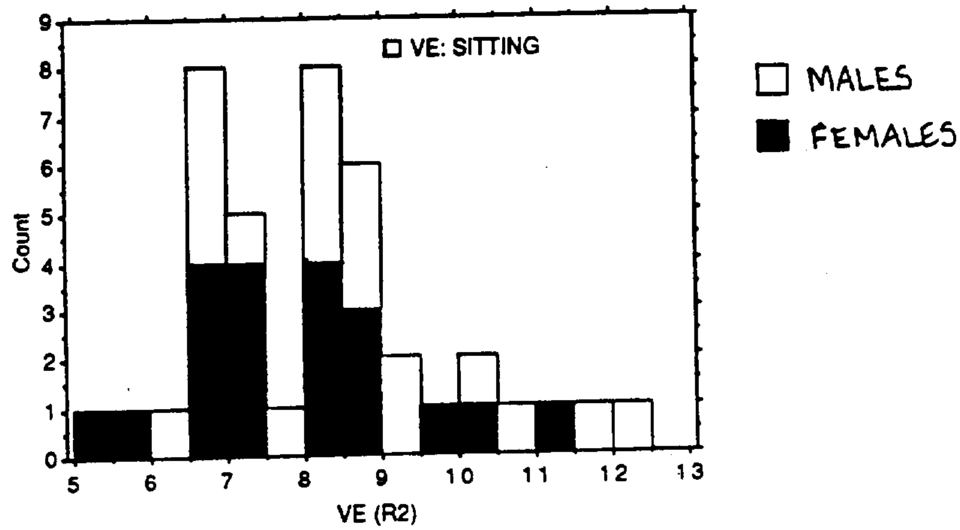


a: HR values for male (x = 88) and female (x = 88) cross-validation children for sitting protocols.

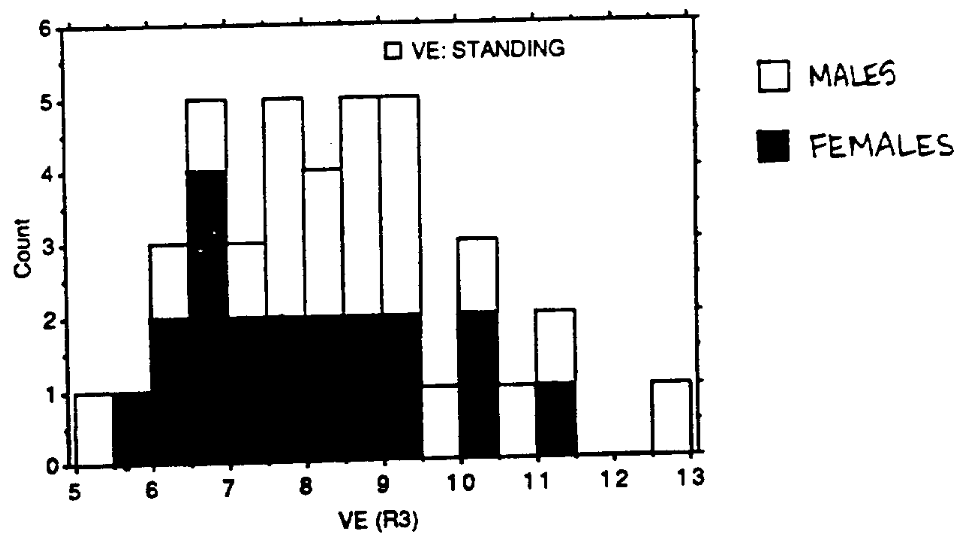


b: HR values for male (x = 94) and female (x = 96) cross-validation children for standing protocols.

APPENDIX FIGURE 3. Male and female cross-validation children group frequency distribution for V_E for sitting (a) and standing (b) protocols.

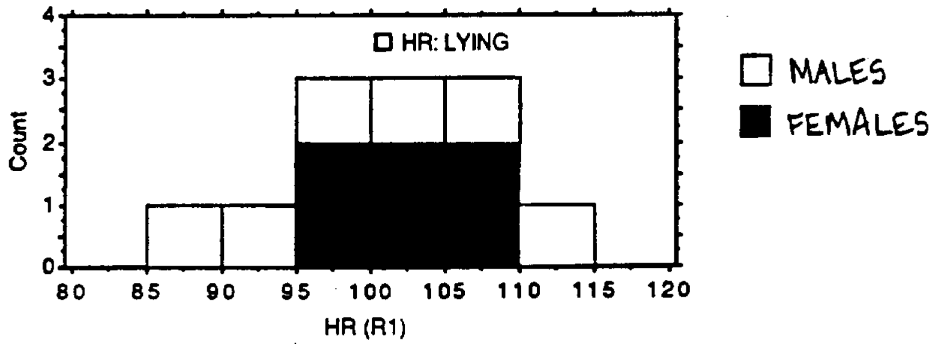


a: V_E values for male (x = 8.56) and female (x = 7.87) cross-validation children for sitting protocols.



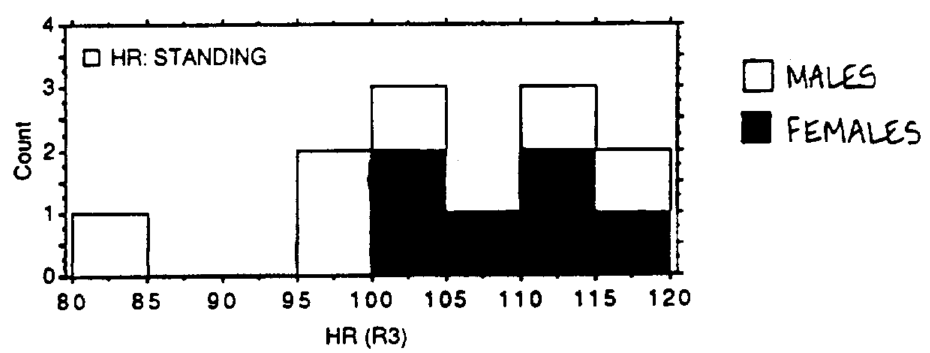
b: V_E values for male (x = 8.71) and female (x = 7.99) cross-validation children for standing protocols.

APPENDIX FIGURE 6. Young male and female children group frequency distribution for HR for lying (a), sitting (b) and standing (c) protocols.



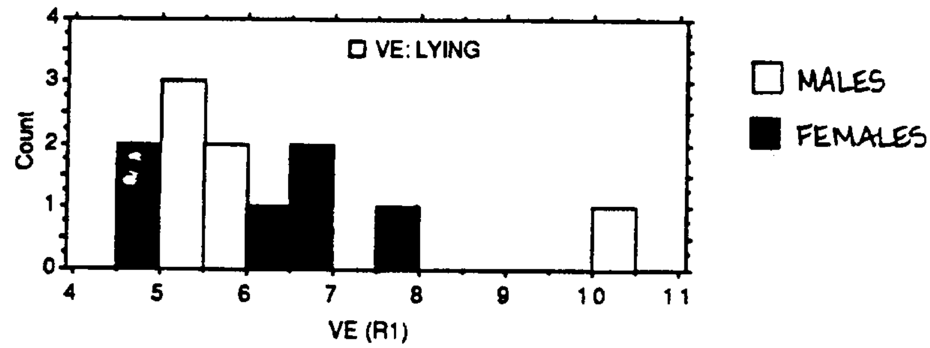
a: HR values for young male (x = 100) and female (x = 102) children for lying protocols.

b: HR values for young male (x = 102) and female (x = 105) children for sitting protocols.

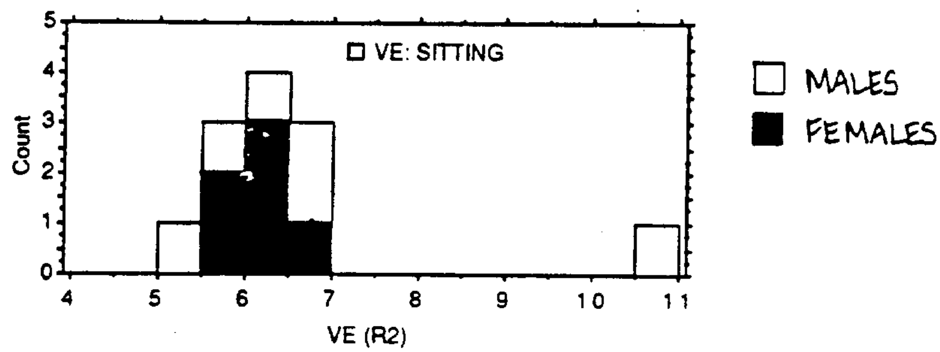


c: HR values for young male (x = 102) and female (x = 110) children for standing protocols.

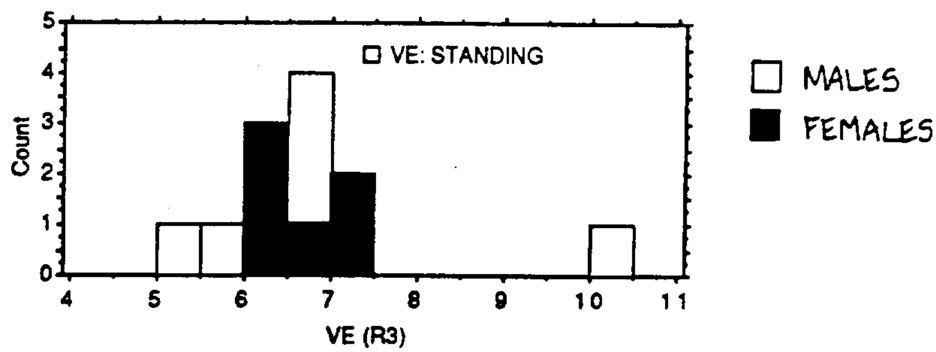
APPENDIX FIGURE 5. Young male and female children group frequency distribution for V_E for lying (a), sitting (b) and standing (c) protocols.



a: V_E values for young male (x = 6.28) and female (x = 6.09) children for lying protocols.

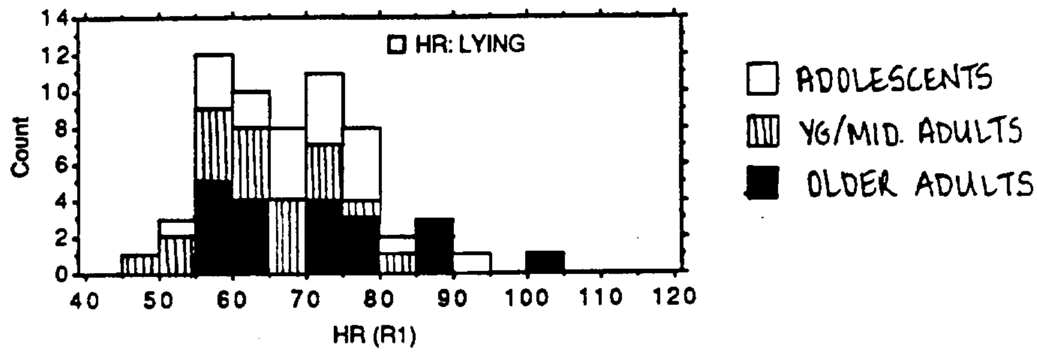


b: V_E values for young male (x = 6.84) and female (x = 6.12) children for sitting protocols.

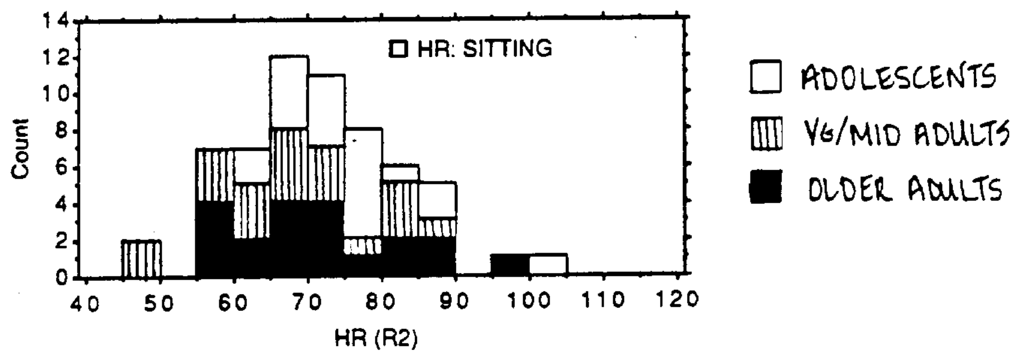


c: V_E values for young male (x = 6.96) and female (x = 6.56) children for standing protocols.

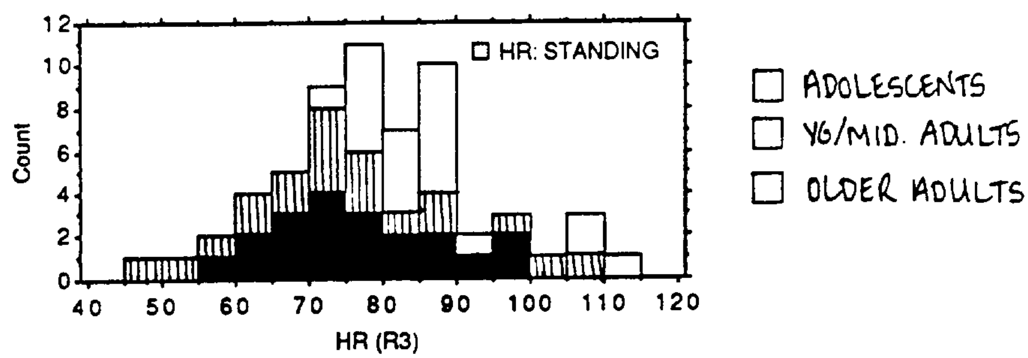
APPENDIX FIGURE 8. Female adolescent, young/middle-aged adult and older adult group frequency distribution for HR for lying (a), sitting (b) and standing (c) protocols.



a: HR values for female adoles. (x = 70), yg/mid. adults (x = 64) and older adults (x = 71) for lying protocols.

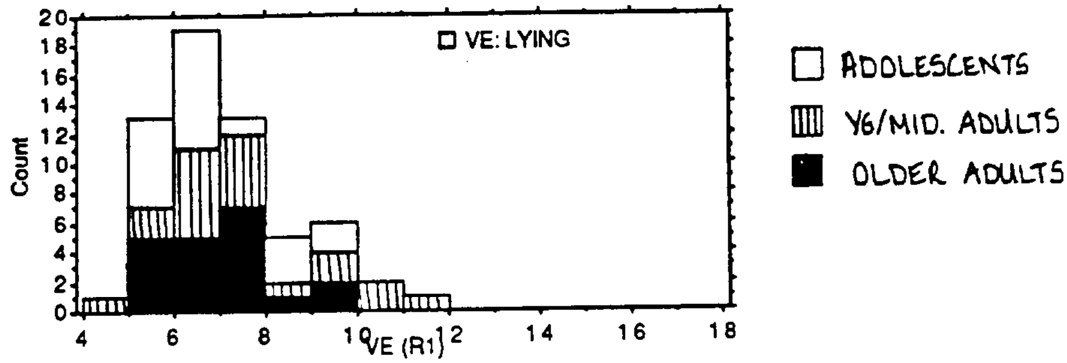


b: HR values for female adoles. (x = 75), yg/mid. adults (x = 67) and older adults (x = 71) for sitting protocols.

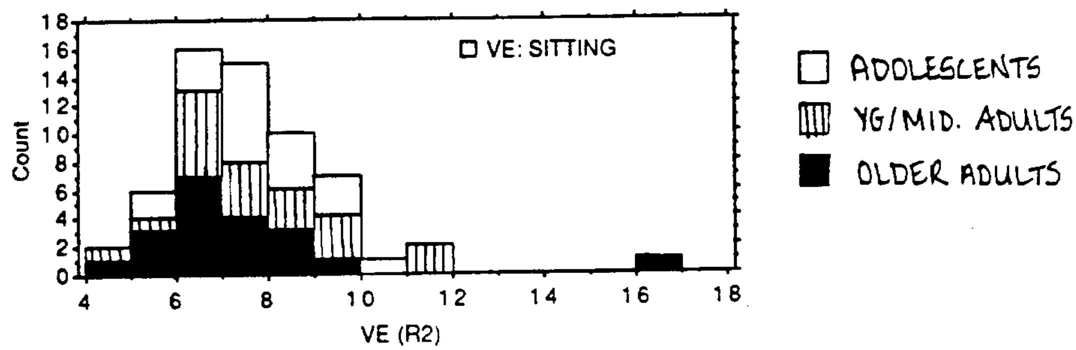


c: HR values for female adoles. (x = 86), yg/mid. adults (x = 75) and older adults (x = 76) for standing protocols.

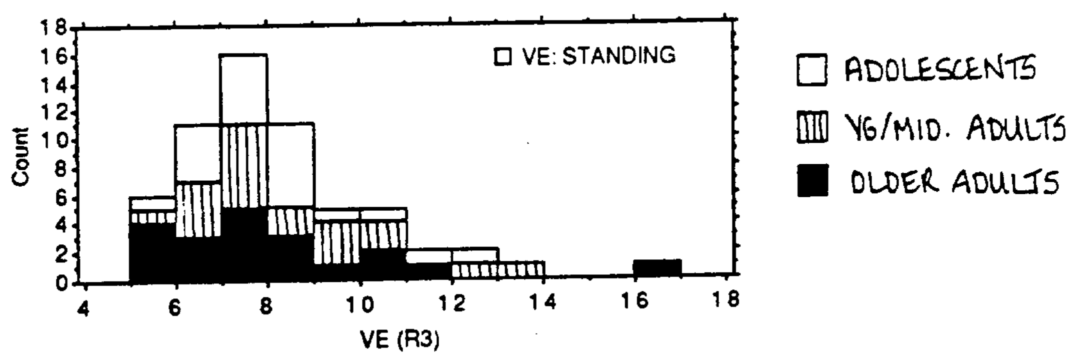
APPENDIX FIGURE 7. Female adolescent, young/middle-aged adult and older adult group frequency distribution for V_E for lying (a), sitting (b) and standing (c) protocols.



a: V_E values for female adoles. (x = 6.90), yg/mid. adults (x = 7.53) and older adults (x = 6.93) for lying protocols.

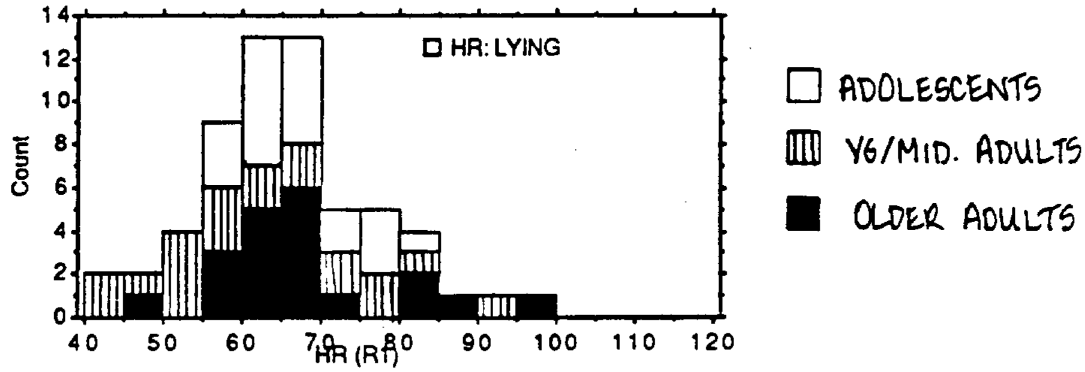


b: V_E values for female adoles. (x = 7.76), yg/mid. adults (x = 7.87) and older adults (x = 7.53) for sitting protocols.

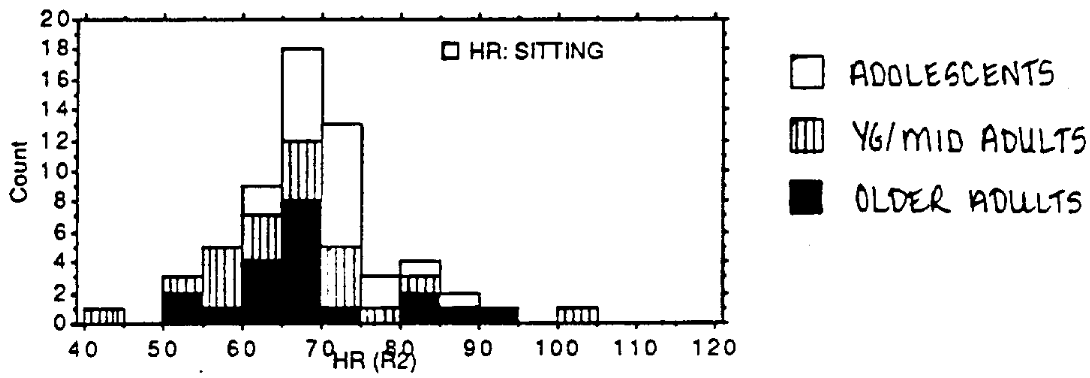


c: V_E values for female adoles. (x = 8.33), yg/mid. adults (x = 8.50) and older adults (x = 8.23) for standing protocols.

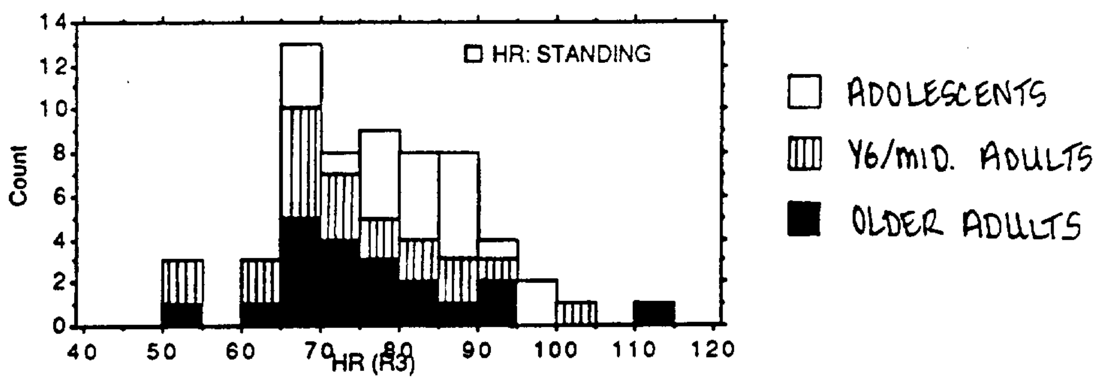
APPENDIX FIGURE 10. Male adolescent, young/middle-aged adult and older adult group frequency distribution for HR for lying (a), sitting (b) and standing (c) protocols.



a: HR values for male adoles. (x = 67), yg/mid. adults (x = 63) and older adults (x = 67) for lying protocols.

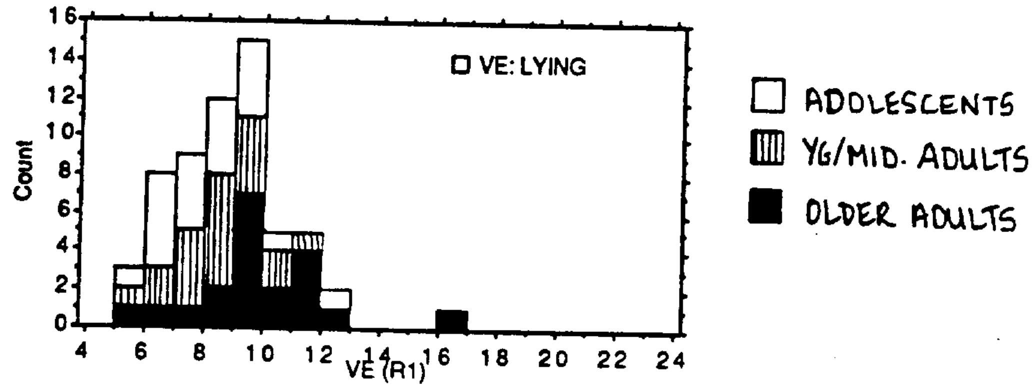


b: HR values for male adoles. (x = 71), yg/mid. adults (x = 66) and older adults (x = 68) for sitting protocols.

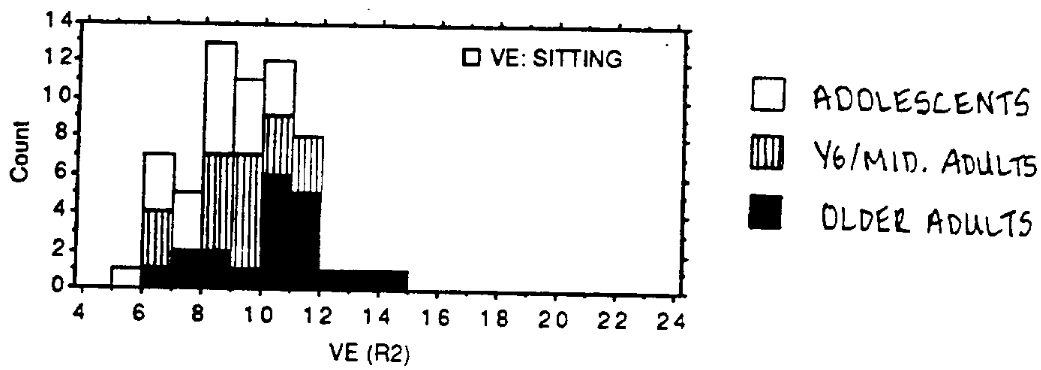


c: HR values for male adoles. (x = 81), yg/mid. adults (x = 73) and older adults (x = 76) for standing protocols.

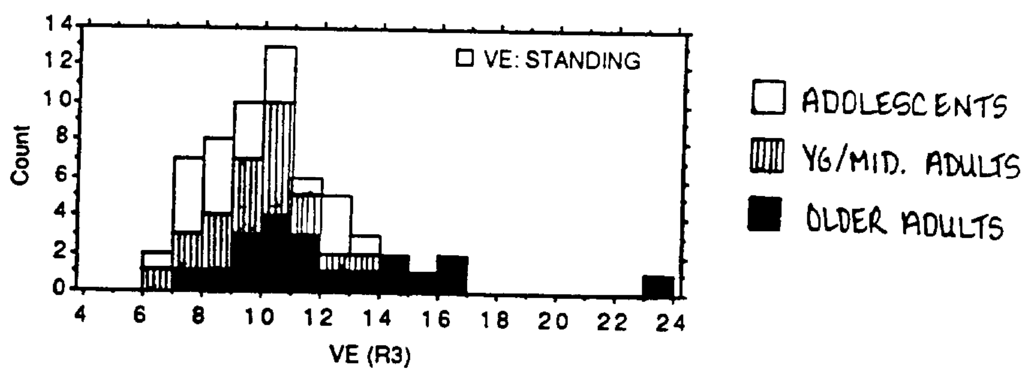
APPENDIX FIGURE 9. Male adolescent, young/middle-aged adult and older adult group frequency distribution for V_E for lying (a), sitting (b) and standing (c) protocols.



a: V_E values for male adoles. (x = 8.22), yg/mid. adults (x = 8.62) and older adults (x = 9.96) for lying protocols.

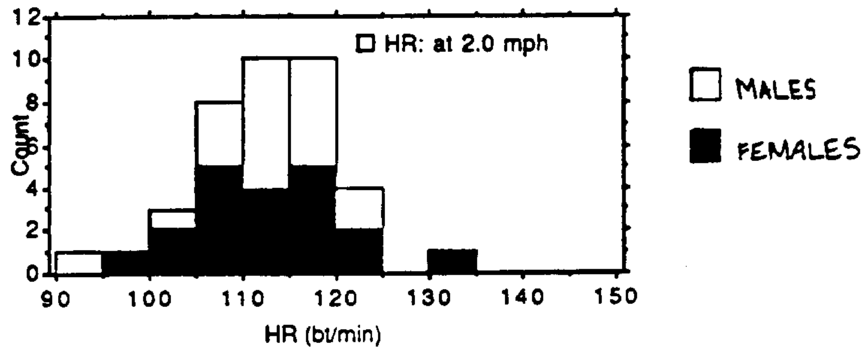


b: V_E values for male adoles. (x = 8.33), yg/mid. adults (x = 9.22) and older adults (x = 10.37) for sitting protocols.

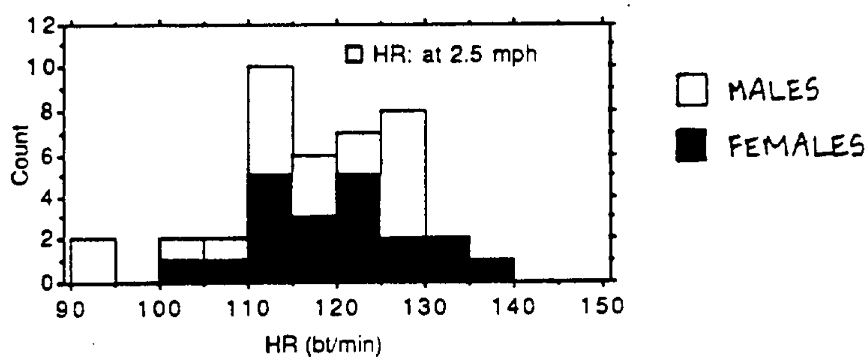


c: V_E values for male adoles. (x = 9.64), yg/mid. adults (x = 9.90) and older adults (x = 12.41) for standing protocols.

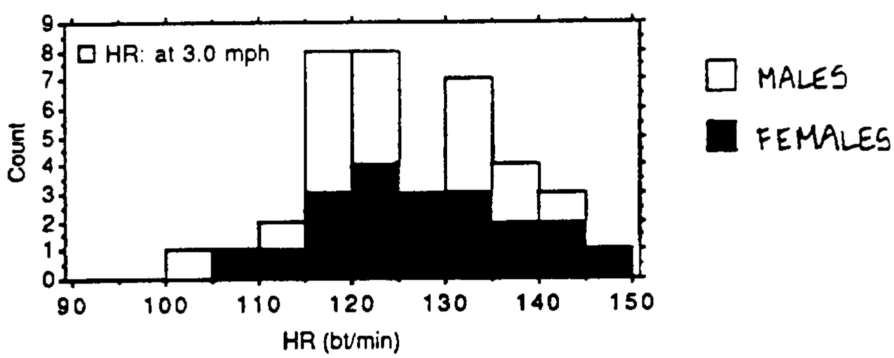
APPENDIX FIGURE 12. Male and female children group frequency distribution for HR during walking at 2.0 (a), 2.5 (b) and 3.0 mph (c).



a: HR values for male (x = 111) and female (x = 113) children during 2.0 mph walking.

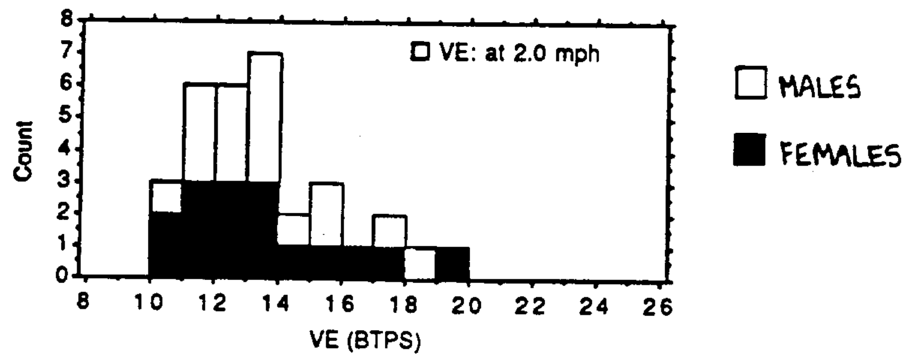


b: HR values for male (x = 116) and female (x = 119) children during 2.5 mph walking.

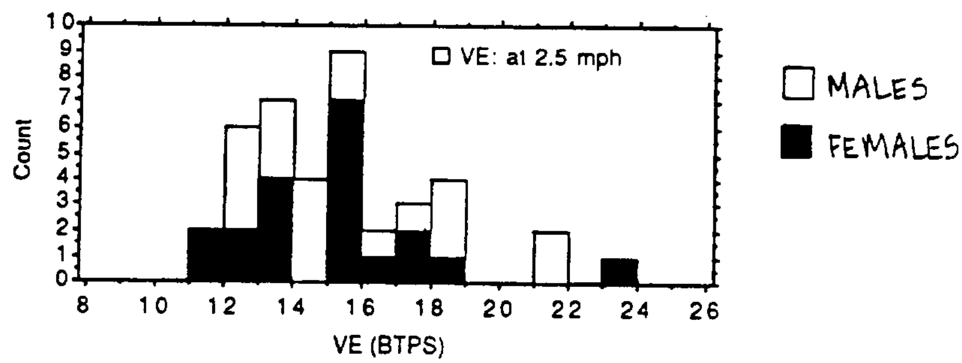


c: HR values for male (x = 124) and female (x = 128) children during 3.0 mph walking.

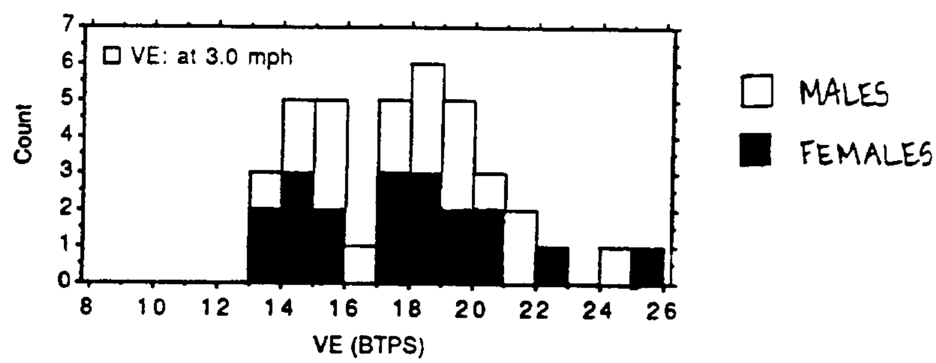
APPENDIX FIGURE 13. Male and female cross-validation children group frequency distribution for V_E during walking at 2.0 (a), 2.5 (b) and 3.0 mph (c).



a: V_E values for male (x = 13.55) and female (x = 13.51) cross-validation children during 2.0 mph walking.

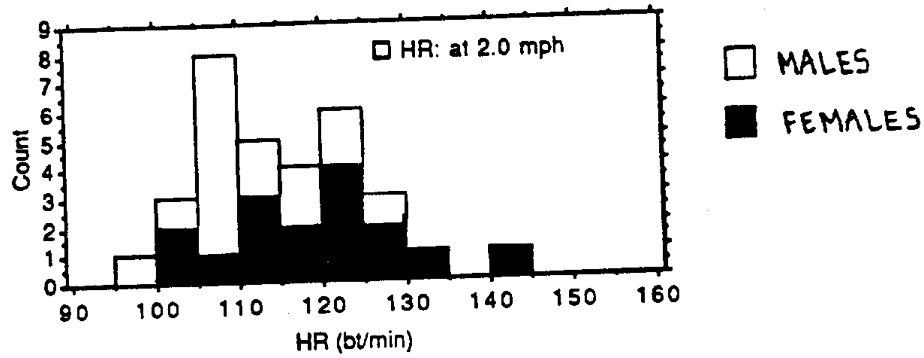


b: V_E values for male (x = 15.56) and female (x = 15.17) cross-validation children during 2.5 mph walking.

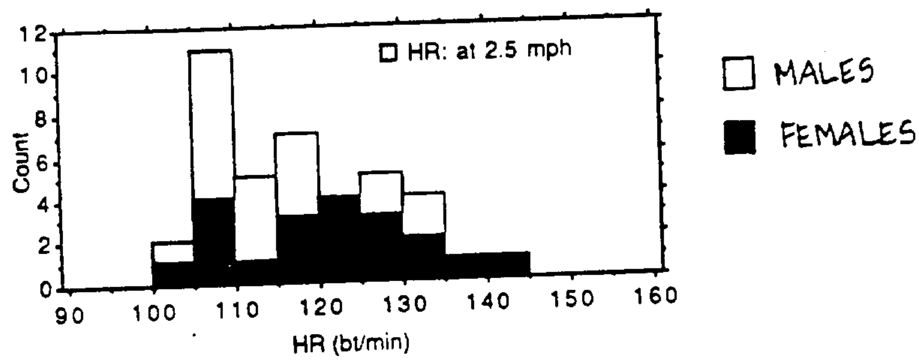


c: V_E values for male (x = 18.04) and female (x = 17.75) cross-validation children during 3.0 mph walking.

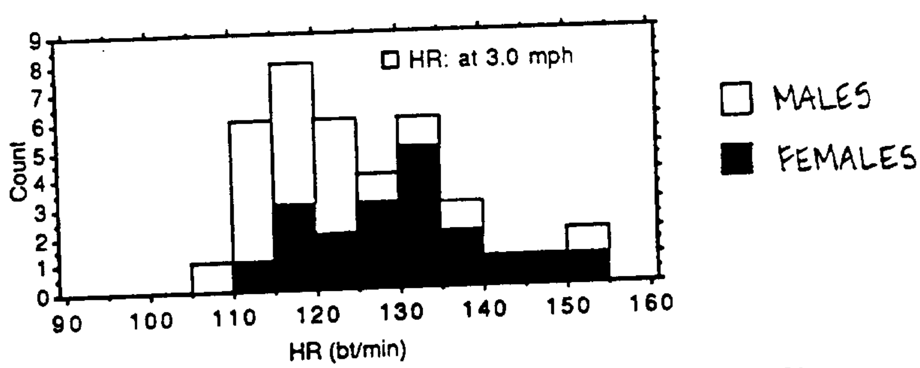
APPENDIX FIGURE 14. Male and female cross-validation children group frequency distribution for HR during walking at 2.0 (a), 2.5 (b) and 3.0 mph (c).



a: HR values for male (x = 111) and female (x = 119) cross-validation children during 2.0 mph walking.

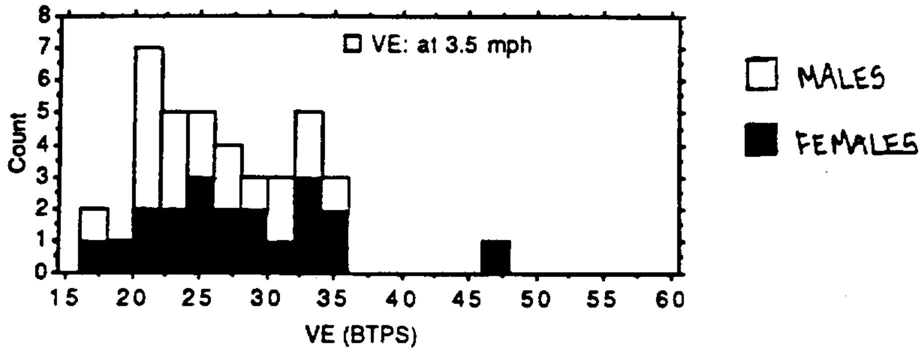


b: HR values for male (x = 114) and female (x = 120) cross-validation children during 2.5 mph walking.

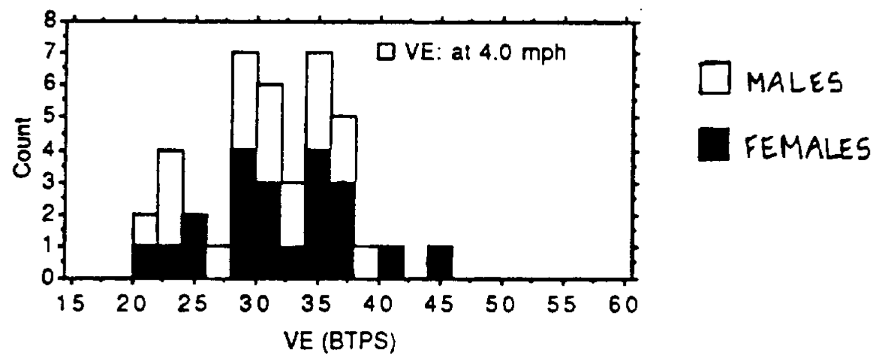


c: HR values for male (x = 121) and female (x = 129) cross-validation children during 3.0 mph walking.

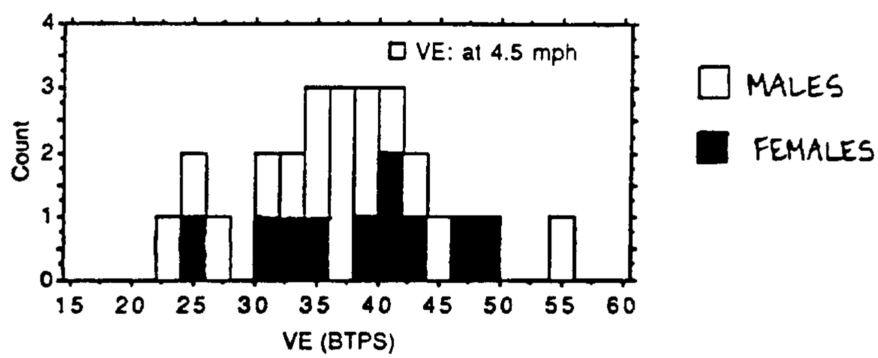
APPENDIX FIGURE 15. Male children combined (original and cross-validation groups) and female children combined (original and cross-validation groups) frequency distribution for V_E during running at 3.5 (a), 4.0 (b) and 4.5 mph (c).



a: V_E values for orig. and X-V. male (x = 25.61) and orig. and X-V. female (x = 27.87) children during 3.5 mph running.

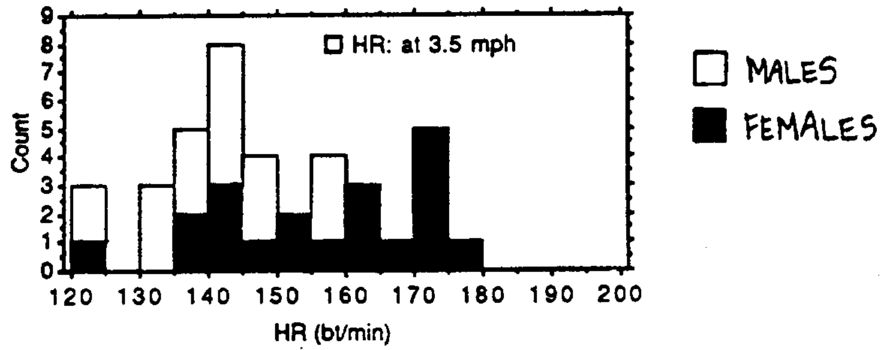


b: V_E values for orig. and X-V. male (x = 30.51) and orig. and X-V. female (x = 32.11) children during 4.0 mph running.

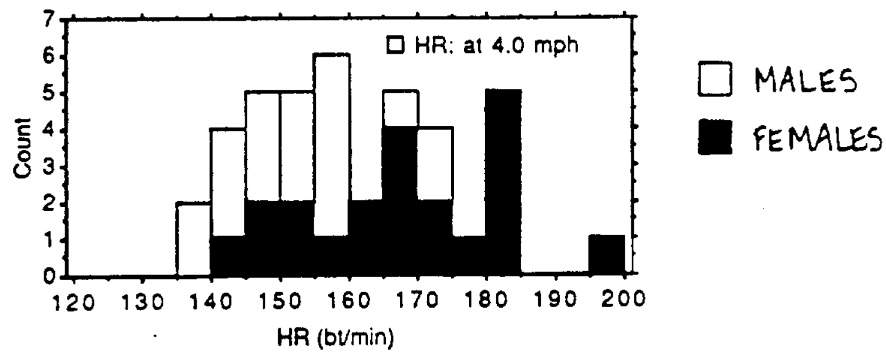


c: V_E values for orig. and X-V. male (x = 36.54) and orig. and X-V. female (x = 38.31) children during 4.5 mph running.

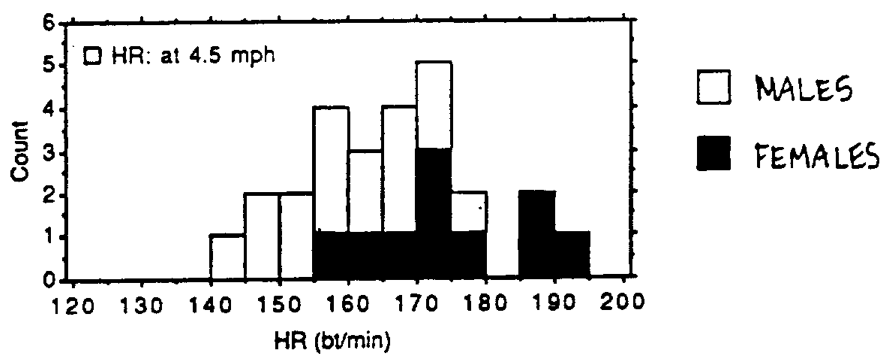
APPENDIX FIGURE 16. Male children combined (original and cross-validation groups) and female children combined (original and cross-validation groups) frequency distribution for HR during <u>running</u> at 3.5 (a), 4.0 (b) and 4.5 mph (c).



a: HR values for orig. and X-V. male (x = 140) and orig. and X-V. female (x = 156) children during 3.5 mph running.

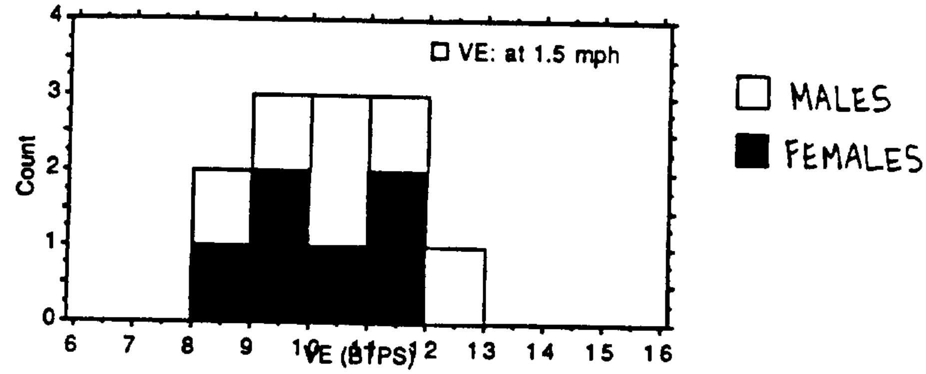


b: HR values for orig. and X-V. male (x = 152) and orig. and X-V. female (x = 167) children during 4.0 mph running.

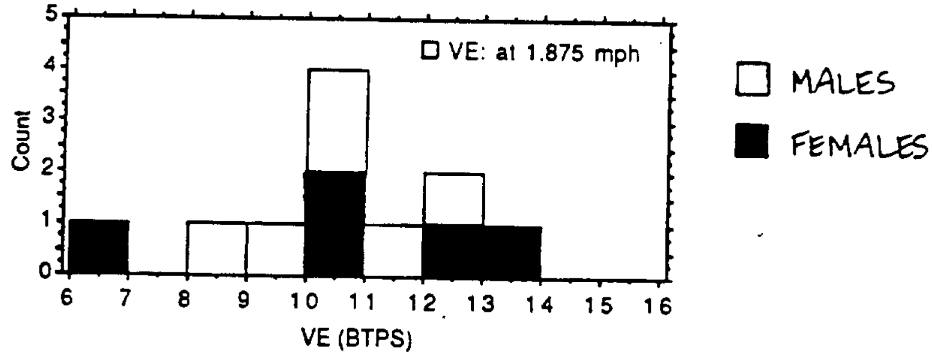


c: HR values for orig. and X-V. male (x = 159) and orig. and X-V. female (x = 175) children during 4.5 mph running.

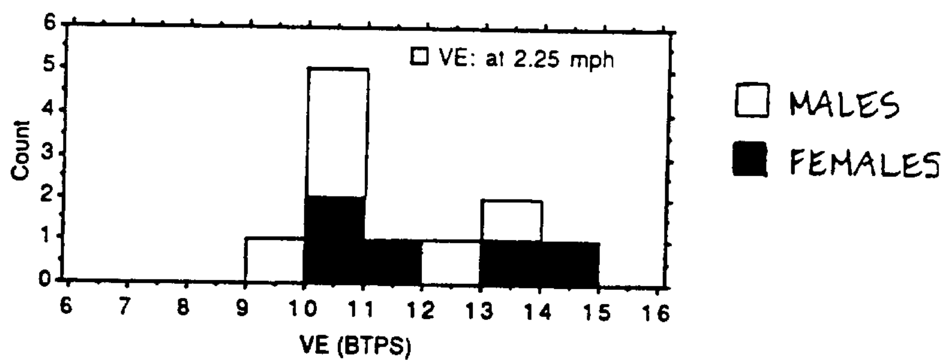
APPENDIX FIGURE 17. Young male and female children group frequency distribution for V_E during <u>walking</u> at 1.5 (a), 1.875 (b) and 2.25 mph (c).



a: V_E values for young male (x = 10.41) and female (x = 10.09) children during 1.5 mph walking.

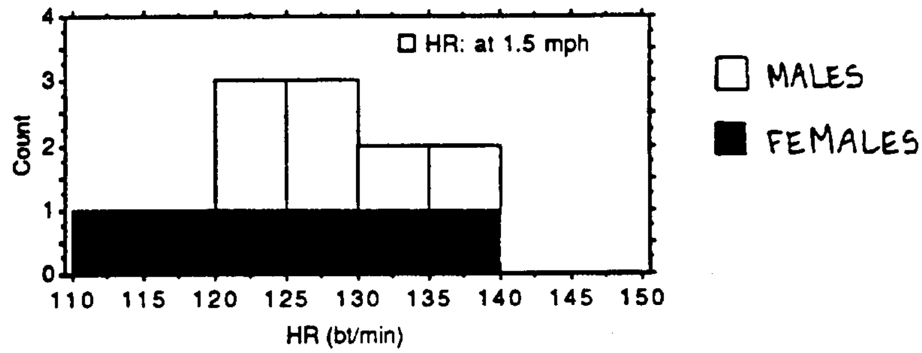


b: V_E values for young male (x = 10.54) and female (x = 10.52) children during 1.875 mph walking.

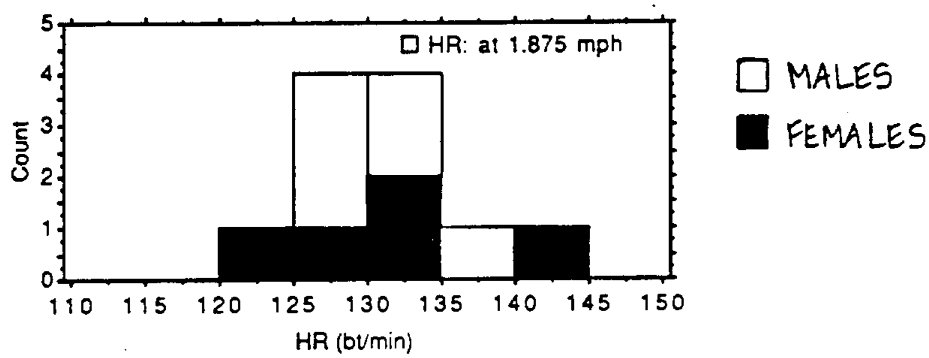


c: V_E values for young male (x = 11.15) and female (x = 12.31) children during 2.25 mph walking.

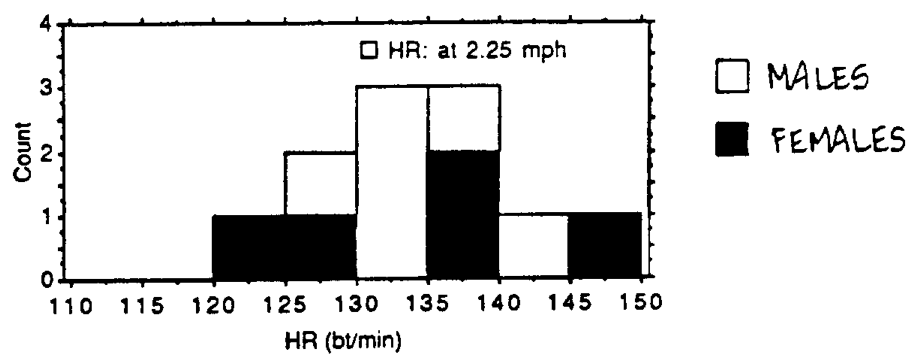
APPENDIX FIGURE 18. Young male and female children group frequency distribution for HR during walking at 1.5 (a), 1.875 (b) and 2.25 mph (c).



a: HR values for young male (x = 129) and female (x = 126) children during 1.5 mph walking.

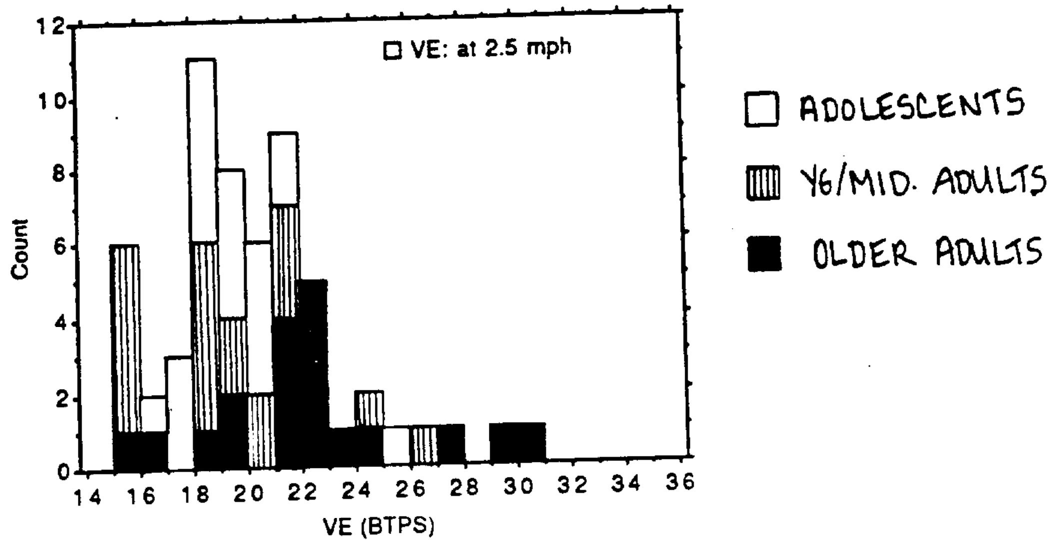


b: HR values for young male (x = 131) and female (x = 130) children during 1.875 mph walking.

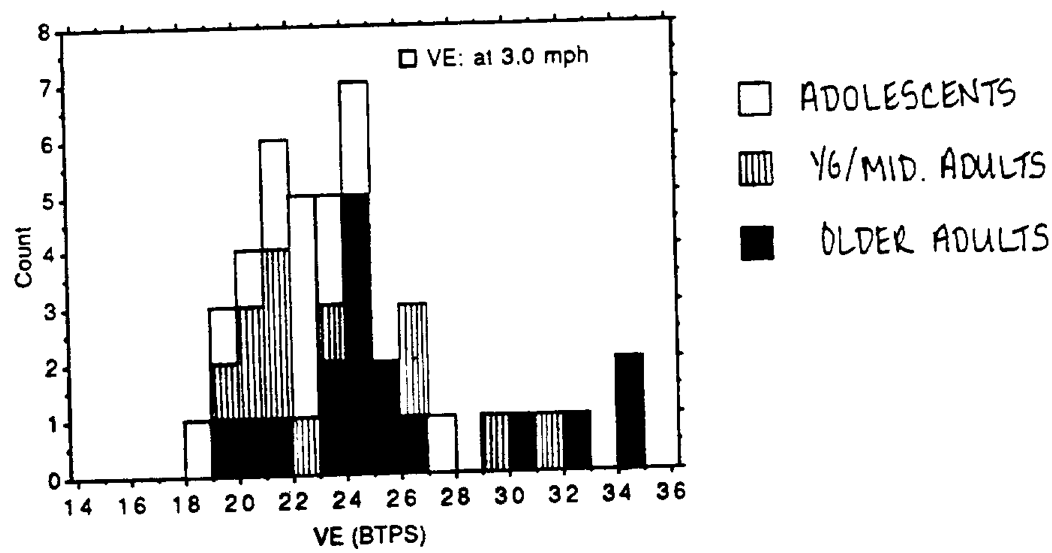


c: HR values for young male (x = 134) and female (x = 133) children during 2.25 mph walking.

APPENDIX FIGURE 19. Adolescent, young/middle-aged adult and older adult female group frequency distribution for V_E during walking at 2.5 (a) and 3.0 mph (b).

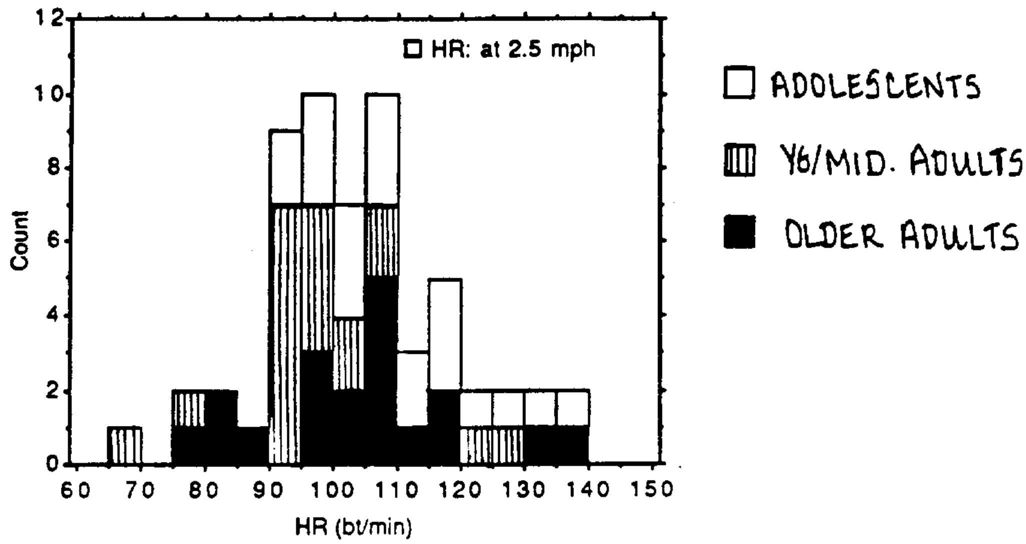


a: V_E values for female adoles. (x = 19.58), yg/mid. adults (x = 19.23), and older adults (x = 22.18) during 2.5 mph walking.

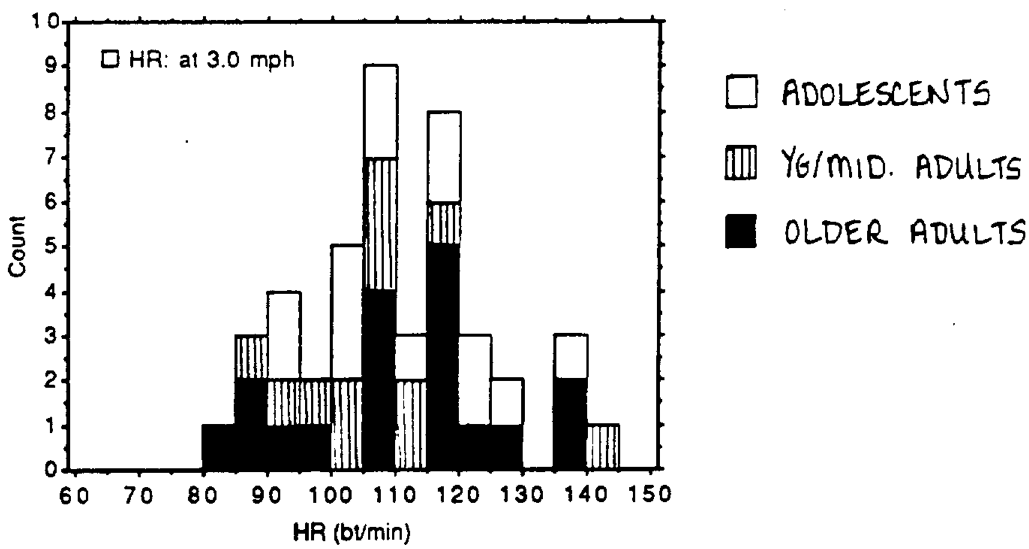


b: V_E values for female adoles. (x = 22.55), yg/mid. adults (x = 23.81), and older adults (x = 25.83) during 3.0 mph walking.

APPENDIX FIGURE 20. Adolescent, young/middle-aged adult and older adult female group frequency distribution for HR during walking at 2.5 (a) and 3.0 mph (b).

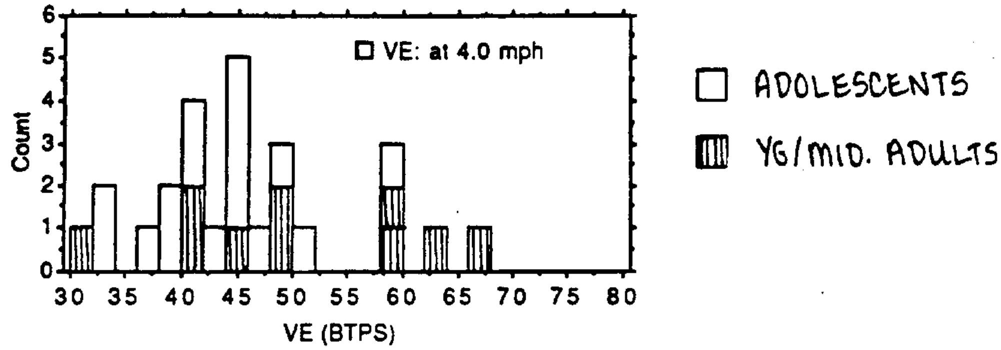


a: HR values for female adoles. (x = 109), yg/mid. adults (x = 97), and older adults (x = 104) during 2.5 mph walking.

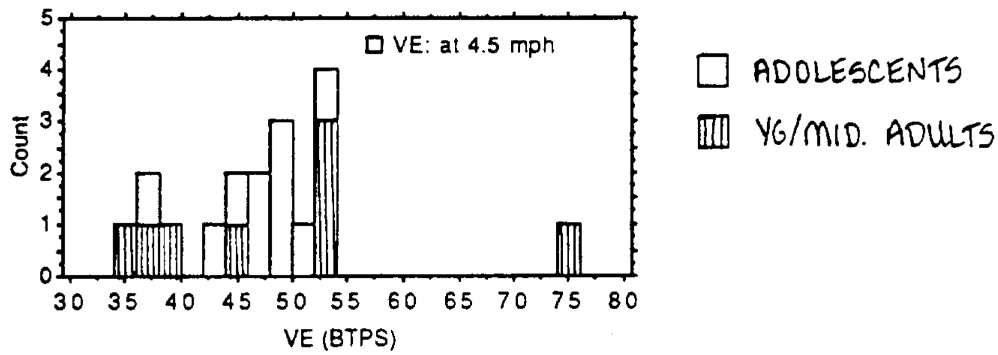


c: HR values for female adoles. (x = 111), yg/mid. adults (x = 107), and older adults (x = 111) during 3.0 mph walking.

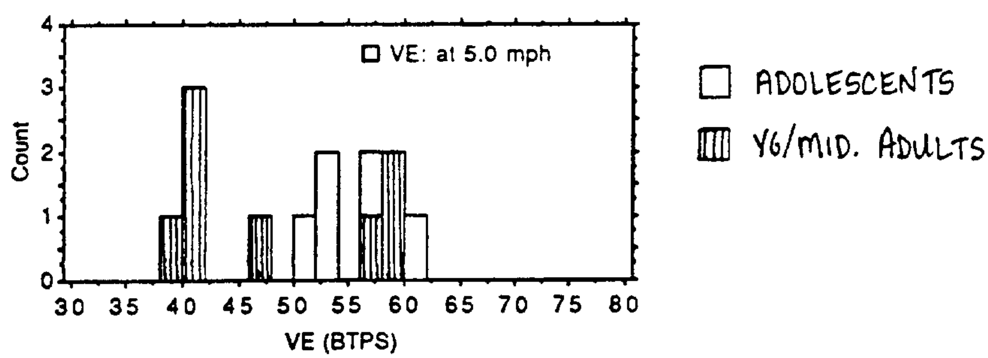
APPENDIX FIGURE 21. Adolescent and young/middle-aged adult female group frequency distribution for V_E during running at 4.0 (a), 4.5 (b) and 5.0 mph (c).



a: V_E values for female adolescents (x = 43.27) and young/ middle-aged adults (x = 50.44) during 4.0 mph running.

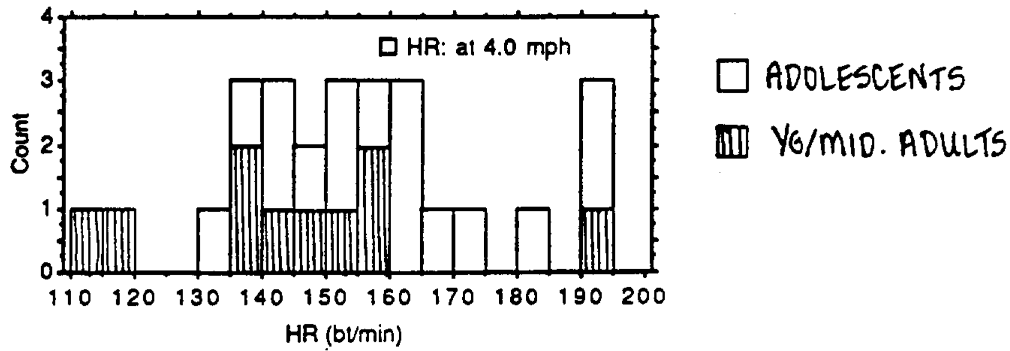


b: V_E values for female adolescents (x = 47.04) and young/ middle-aged adults (x = 48.89) during 4.5 mph running.

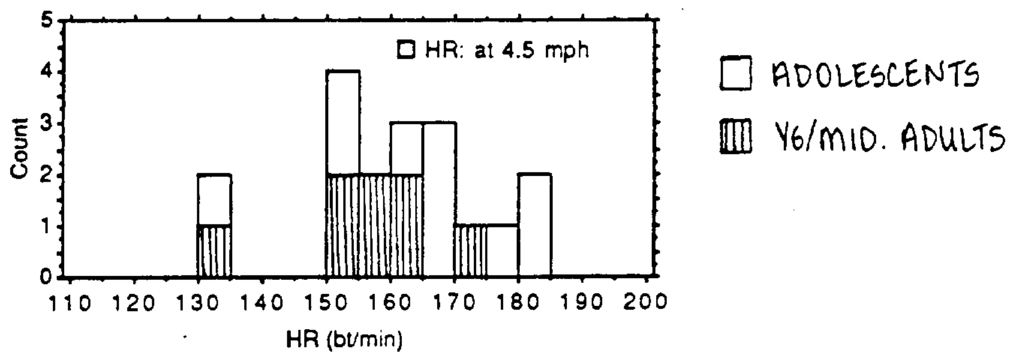


c: V_E values for female adolescents (x = 54.81) and young/ middle-aged adults (x = 48.26) during 5.0 mph running.

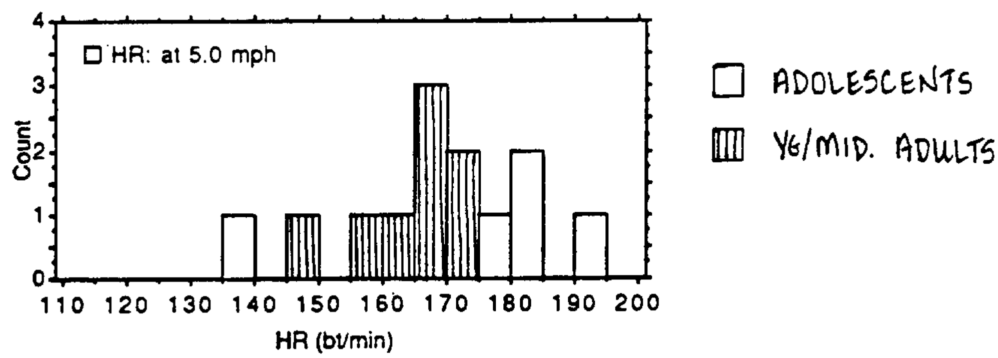
APPENDIX FIGURE 22. Adolescent and young/middle-aged adult female group frequency distribution for HR during <u>running</u> at 4.0 (a), 4.5 (b) and 5.0 mph (c).



a: HR values for female adolescents (x = 160) and young/ middle-aged adults (x = 145) during 4.0 mph running.

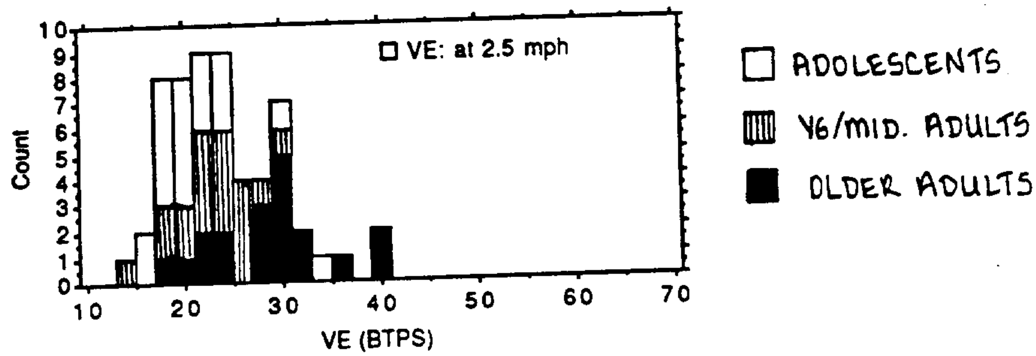


b: HR values for female adolescents (x = 164) and young/ middle-aged adults (x = 156) during 4.5 mph running.

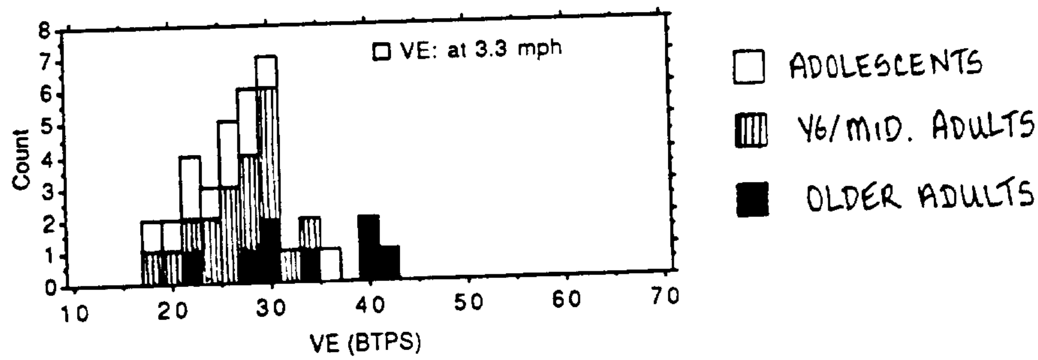


c: HR values for female adolescents (x = 174) and young/ middle-aged adults (x = 163) during 5.0 mph running.

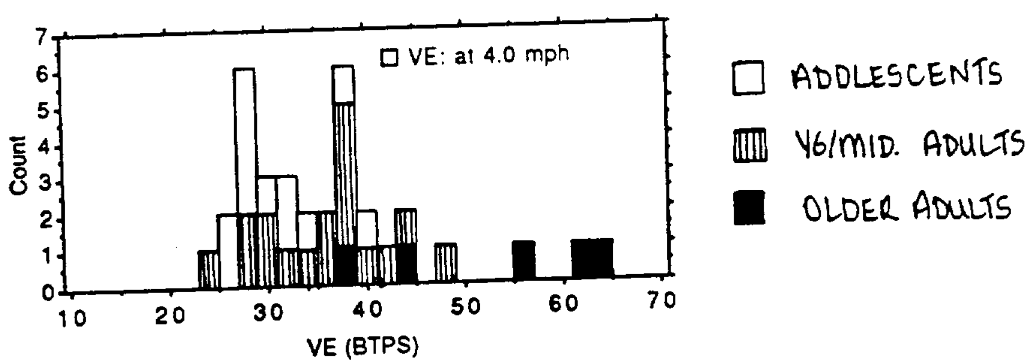
APPENDIX FIGURE 23. Adolescent, young/middle-aged adult and older adult male group frequency distribution for V_E during walking at 2.5 (a), 3.3 (b) and 4.0 mph (c).



a: V_E values for male adoles. (x = 20.90), yg/mid adults (x = 22.79), and older adults (x = 28.89) during 2.5 mph walking.

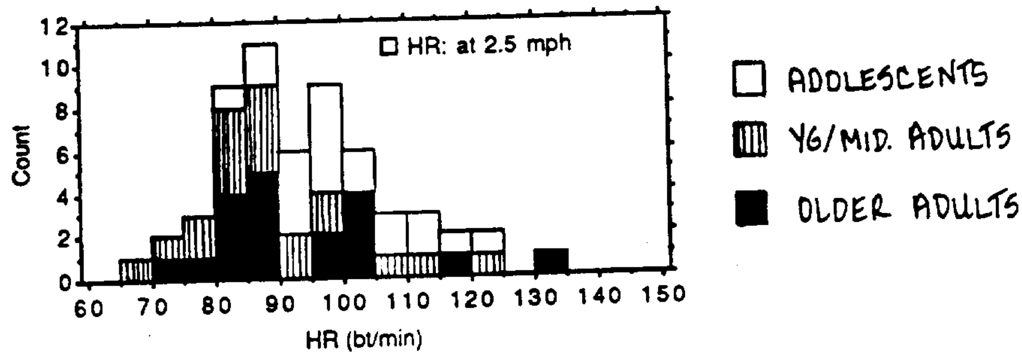


b: V_E values for male adoles. (x = 25.64), yg/mid adults (x = 26.78), and older adults (x = 33.39) during 3.3 mph walking.

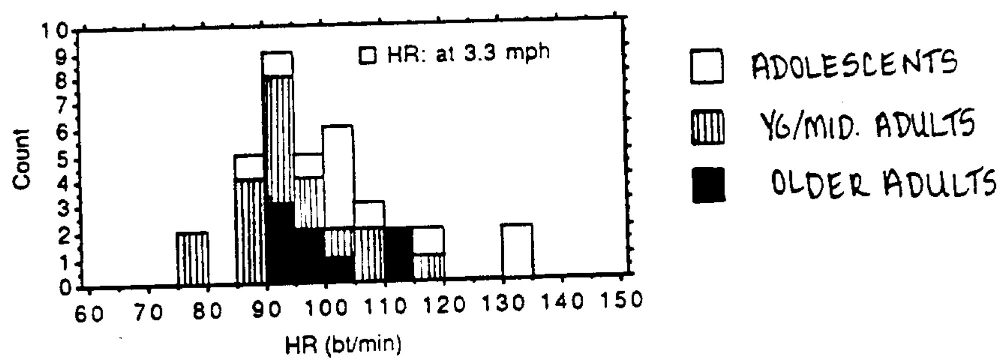


c: V_E values for male adoles. (x = 31.10), yg/mid adults (x = 35.56), and older adults (x = 52.86) during 4.0 mph walking.

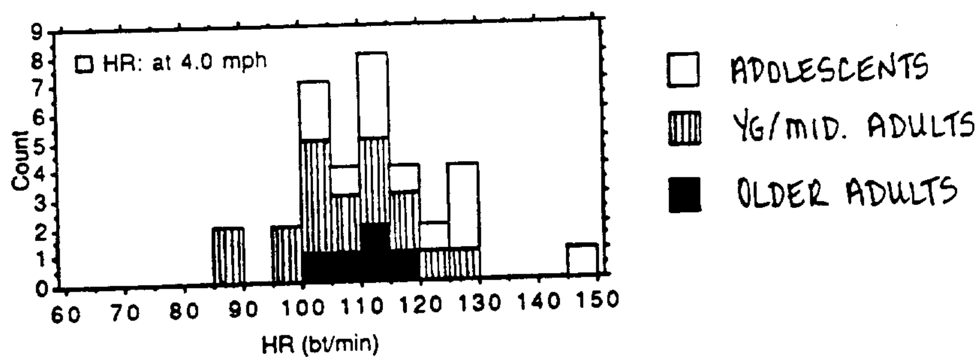
APPENDIX FIGURE 24. Adolescent, young/middle-aged adult and older adult male group frequency distribution for HR during walking at 2.5 (a), 3.3 (b) and 4.0 mph (c).



a: HR values for male adoles. (x = 99), yg/mid. adults (x = 89), and older adults (x = 93) during 2.5 mph walking.

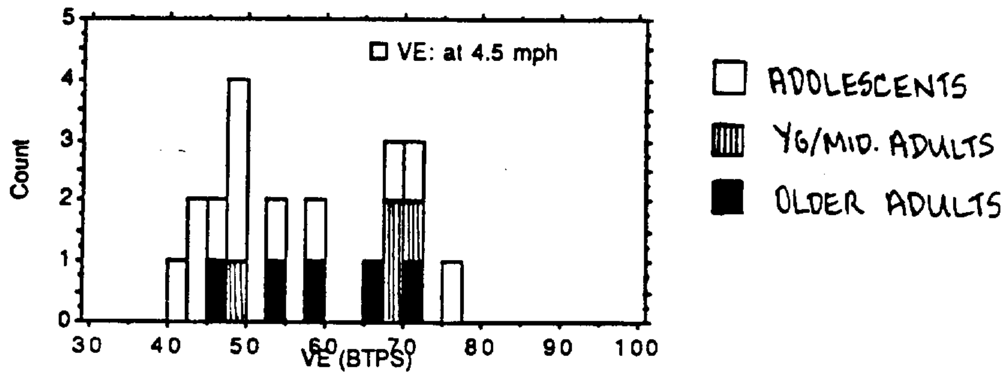


b: HR values for male adoles. (x = 107), yg/mid. adults (x = 94), and older adults (x = 99) during 3.3 mph walking.

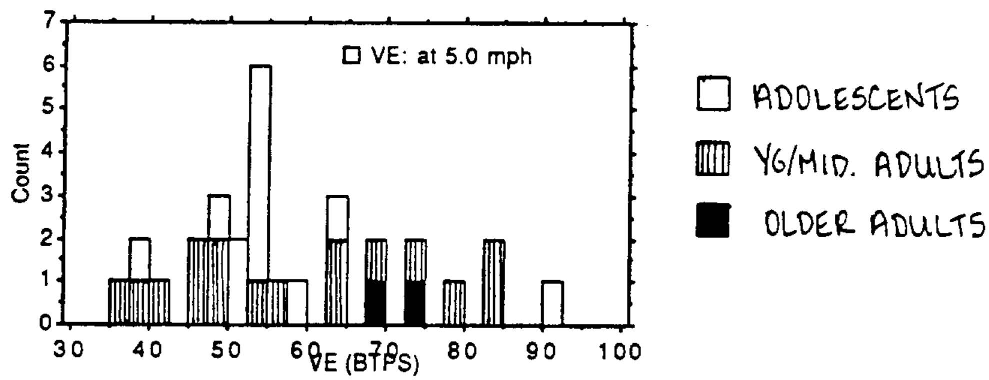


c: HR values for male adoles. (x = 118), yg/mid. adults (x = 107), and older adults (x = 111) during 4.0 mph walking.

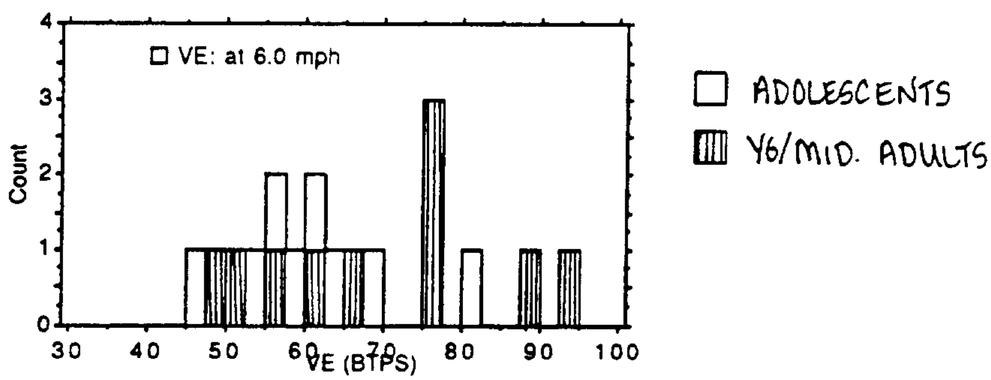
APPENDIX FIGURE 25. Adolescent, young/middle-aged adult and older adult male group frequency distribution for V_E during running at 4.5 (a), 5.0 (b) and 5.5 mph (c).



a: V_E values for male adoles. (x = 53.96), yg/mid adults (x = 64.82), and older adults (x = 59.30) during 4.5 mph running.

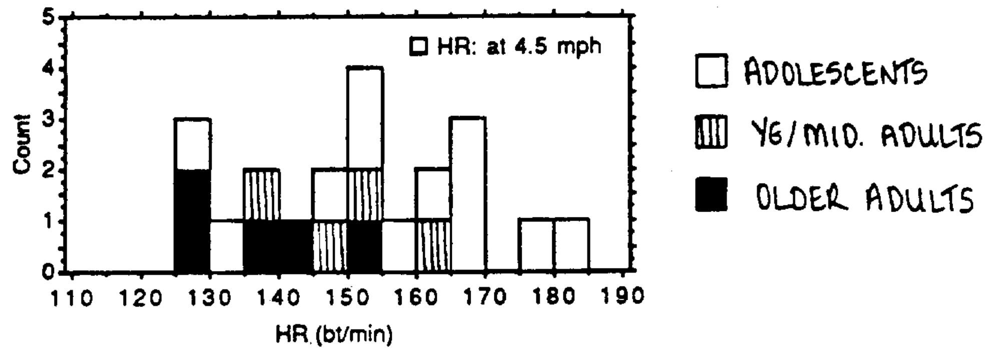


b: V_E values for male adoles. (x = 55.89), yg/mid. adults (x = 58.74) and older adults during 5.0 mph running.

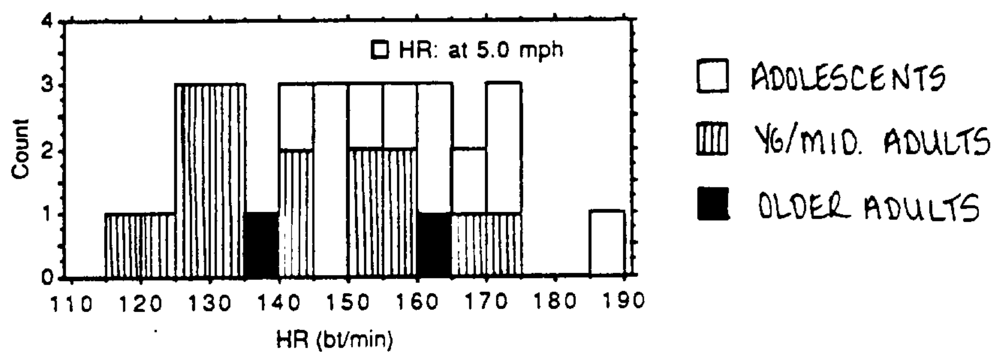


c: V_E values for male adoles. (x = 61.21) and yg/mid. adults (x = 69.22) during 6.0 mph running.

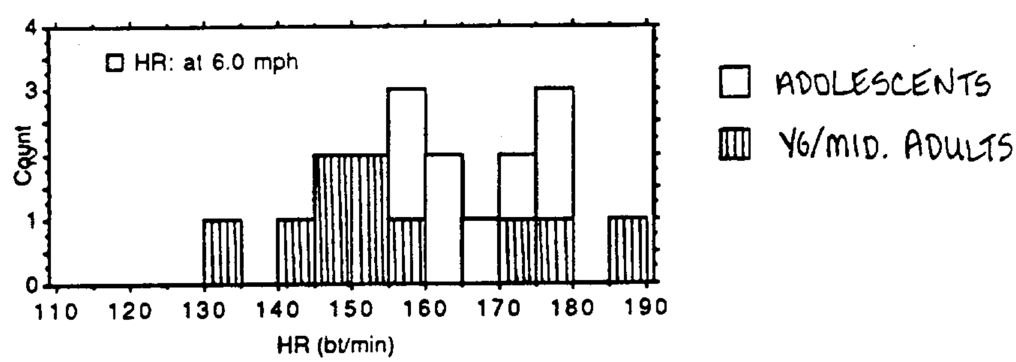
APPENDIX FIGURE 26. Adolescent, young/middle-aged adult and older adult male group frequency distribution for HR during running at 4.5 (a), 5.0 (b) and 5.5 mph (c).



a: HR values for male adoles. (x = 158), yg/mid. adults (x = 150), and older adults (x = 137) during 4.5 mph running.

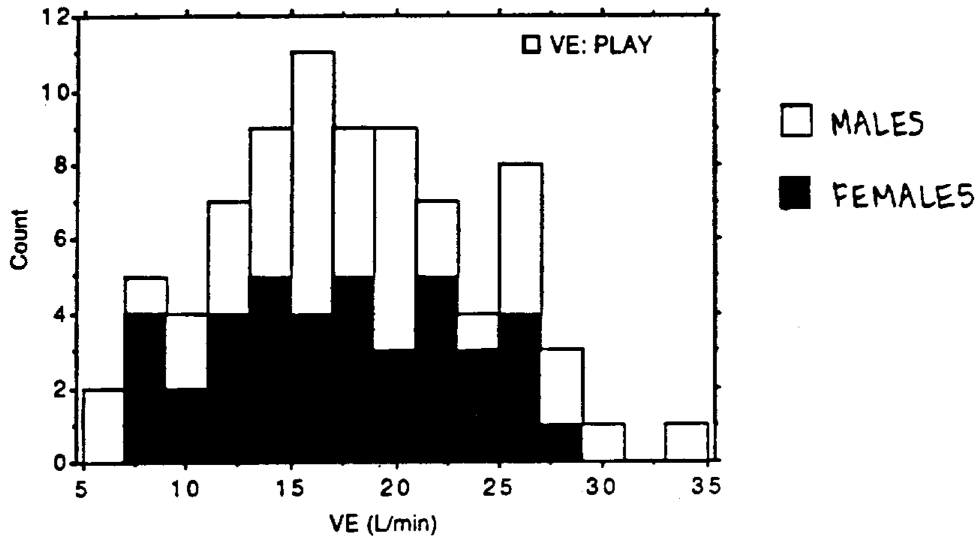


b: HR values for male adoles. (x = 159), yg/mid. adults (x = 141), and older adults during 5.0 mph running.

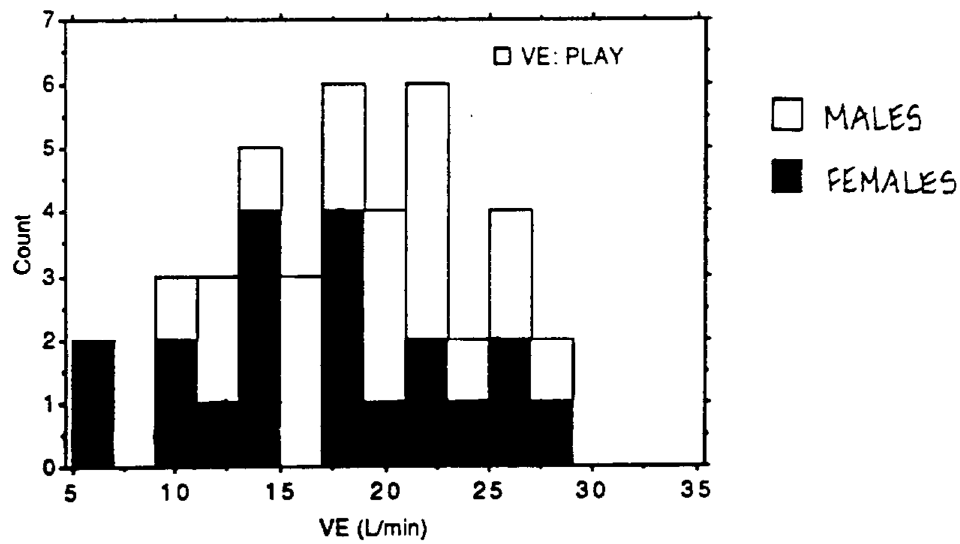


c: HR values for male adoles. (x = 166) and yg/mid. adults (x = 157) during 6.0 mph running.

APPENDIX FIGURE 27. Original group of children (a) and cross-validation children (b) group frequency distribution for V_E for play.

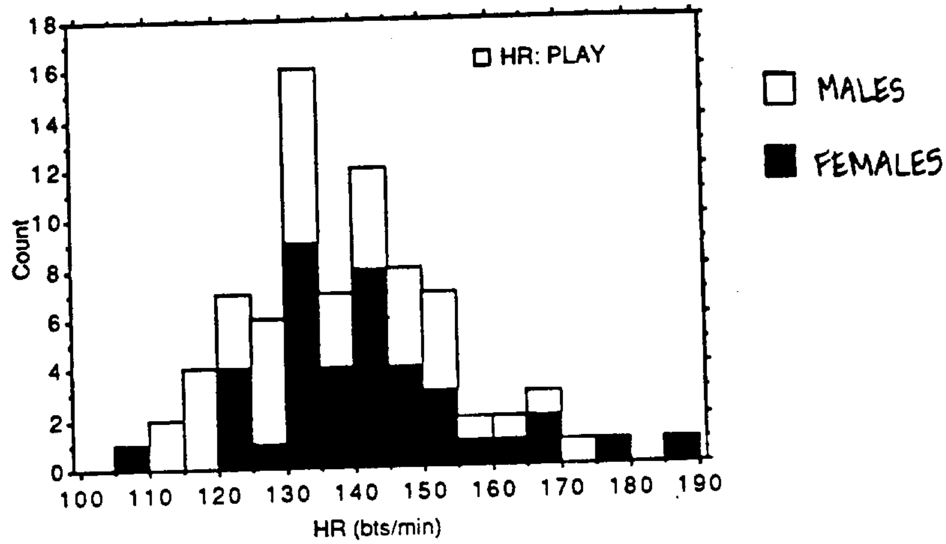


a: V_E values for original group of male (x = 18.32, N = 20 x 2) and female (x = 17.46, N = 20 x 2) children for play (protocols 1 and 2 combined).

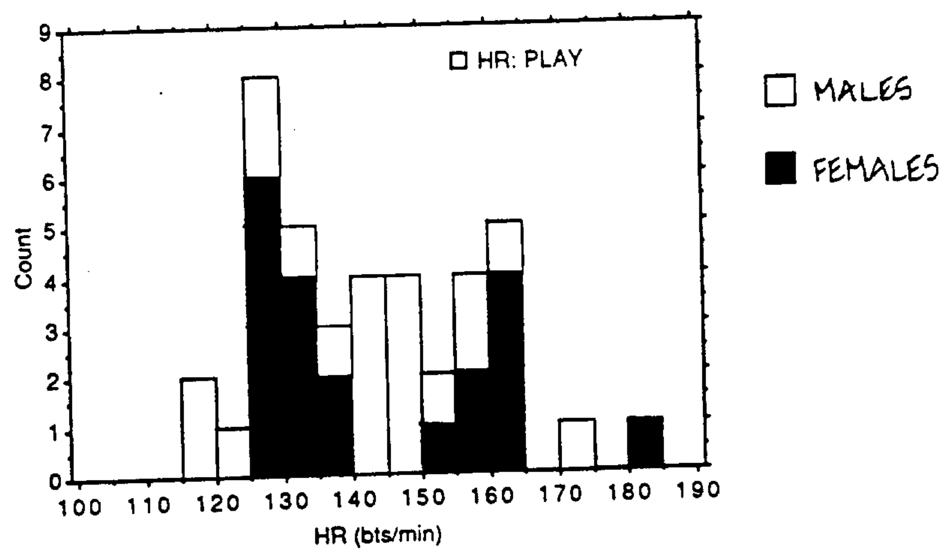


b: V_E values for male (x = 19.13, N = 20) and female (x = 17.32, N = 20) cross-validation children for play.

APPENDIX FIGURE 28. Original group of children (a) and cross-validation children (b) group frequency distribution for HR for play.

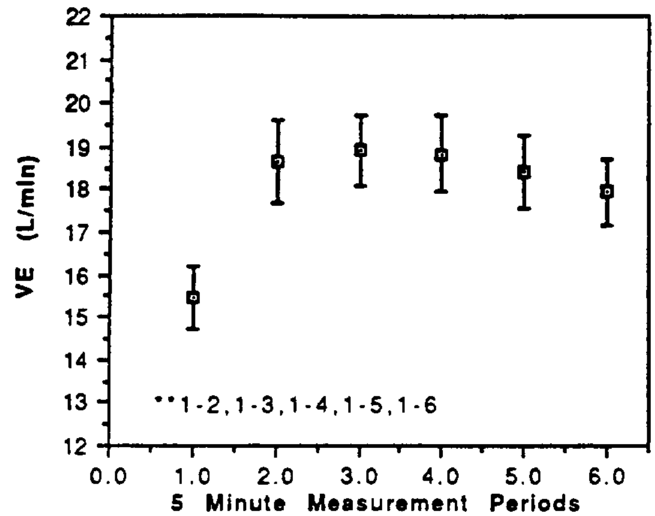


a: HR values for original group of male (x = 136, N = 20 x 2) and female (x = 142, N = 20 x 2) children for play (protocols 1 and 2 combined).

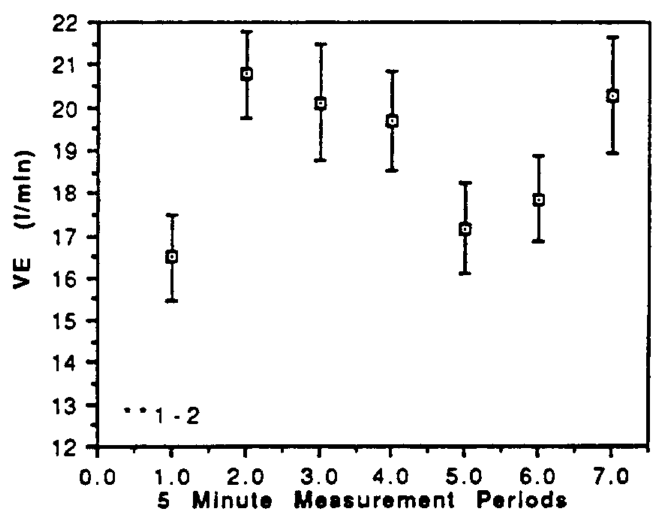


b: HR values for male (x = 142, N = 20) and female (x = 144, N =20) cross-validation children for play.

APPENDIX FIGURE 29. Original group of children (a) and cross-validation children (b) 5 minute means for V_E for play.

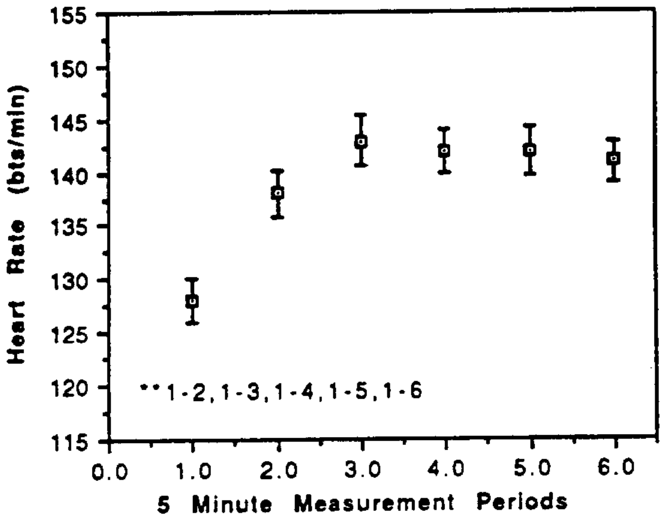


a: 5 minute V_E means (x = 15.44, 18.65, 18.91, 18.84, 18.43, 17.94) for original group of children for play (protocols 1 and 2 combined).

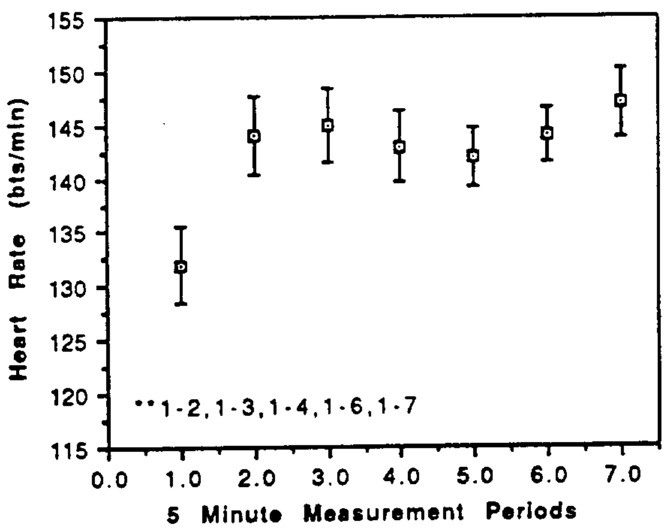


b: 5 minute V_E means (x = 16.49, 20.76, 20.12, 19.69, 17.16, 17.86, 20.29) for cross-validation children for play.

APPENDIX FIGURE 30. Original group of children (a) and cross-validation children (b) 5 minute means for HR for play.

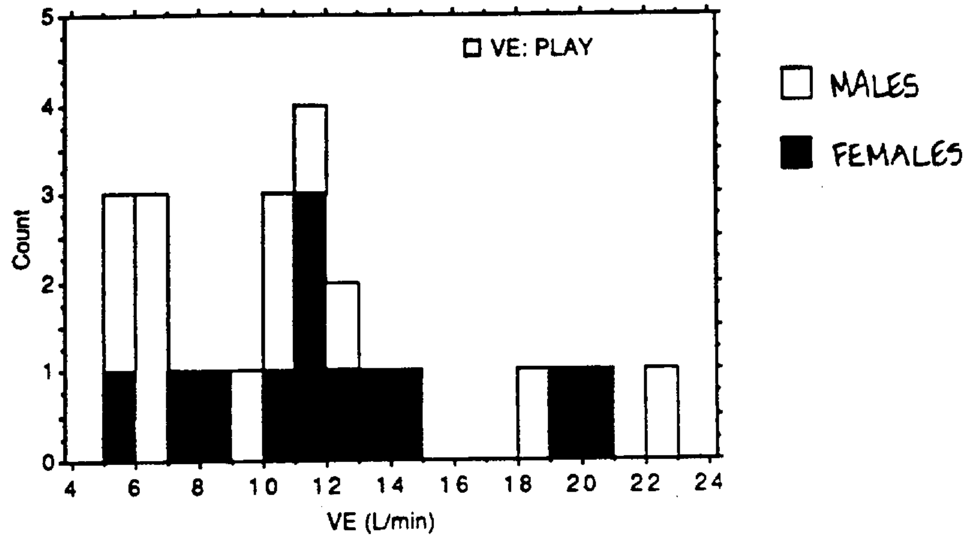


a: 5 minute HR means (x = 128, 138, 143, 142, 142, 141) for original group of children for play (protocols 1 and 2 combined).

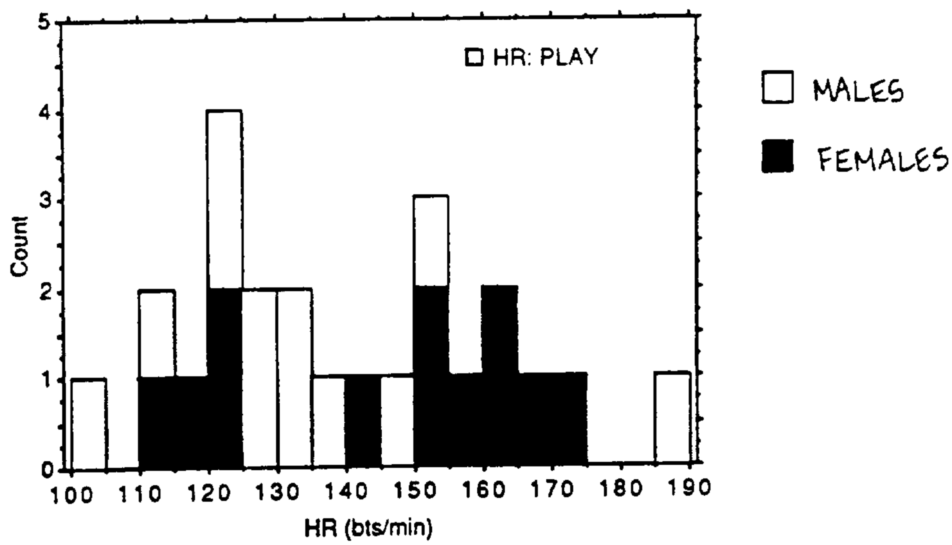


b: 5 minute HR means (x = 132, 144, 145, 143, 142, 144, 147) for cross-validation children for play.

APPENDIX FIGURE 31. Young children group frequency distribution for V_E (a) and HR (b) for play (protocols 1 and 2 combined).

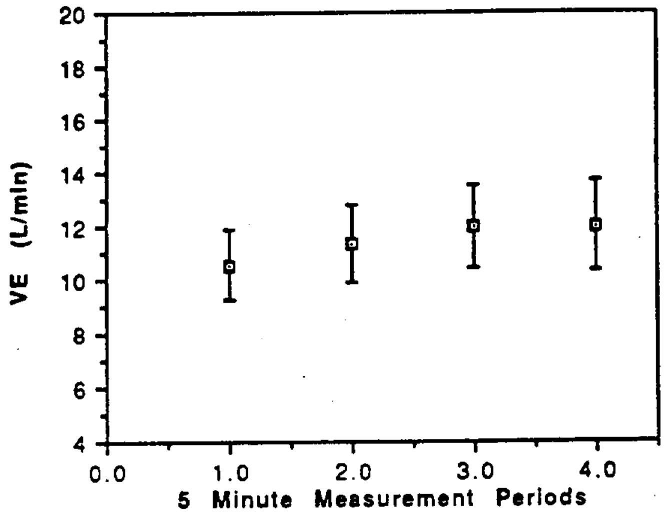


a: V_E values for young male (x = 10.44, N = 6 x 2) and female (x = 12.18, N = 6 x 2) children for play (protocols 1 and 2 combined).

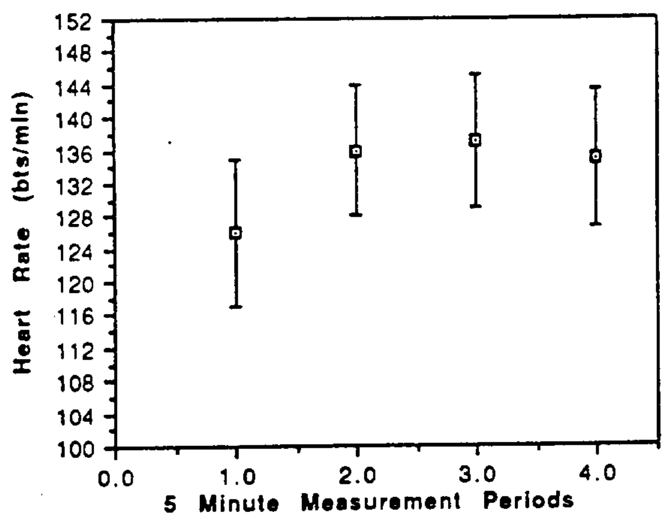


b: HR values for young male (x = 133, N = 6 x 2) and female (x = 145, N = 6 x 2) children for play (protocols 1 and 2 combined).

APPENDIX FIGURE 32. Young children 5 minute means for V_E and HR for play (protocols 1 and 2 combined).

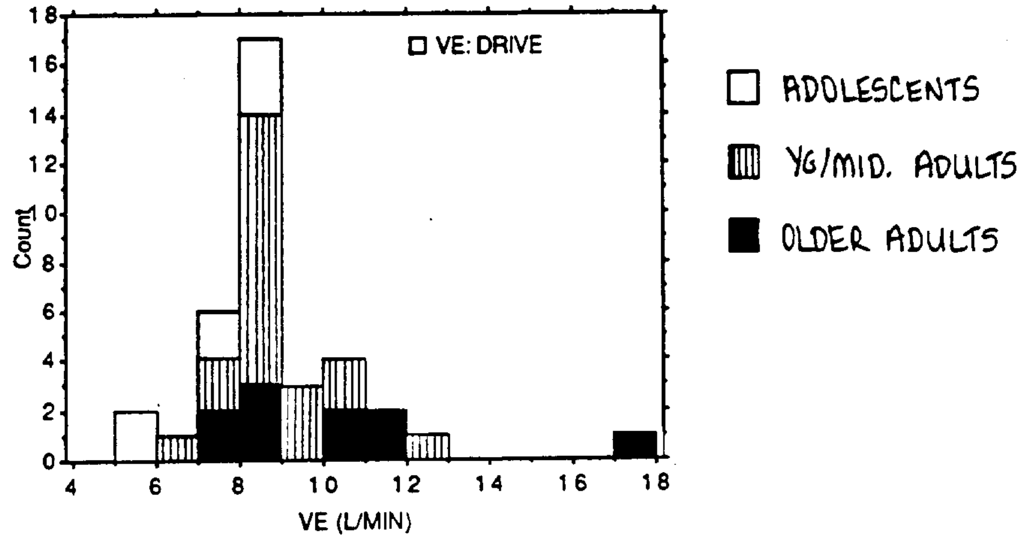


a: 5 minute V_E means (x = 10.57, 11.40, 12.00, 12.04) for young children for play (protocols 1 and 2 combined).

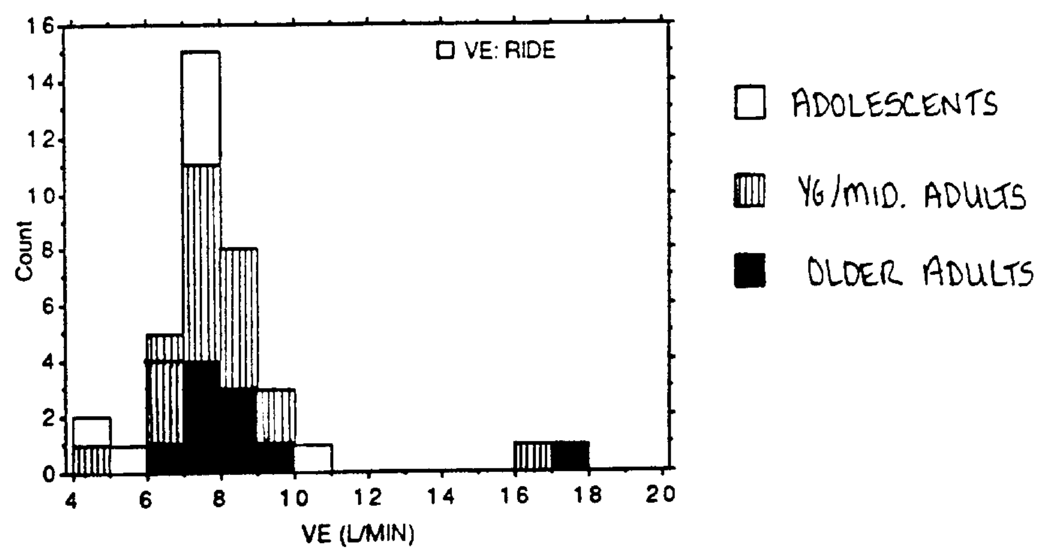


b: 5 minute HR means (x = 126, 136, 137, 135) for young children for play (protocols 1 and 2 combined).

APPENDIX FIGURE 33. Adolescent, young/middle-aged adult and older adult female group frequency distribution for V_E for car driving (a) and riding (b).

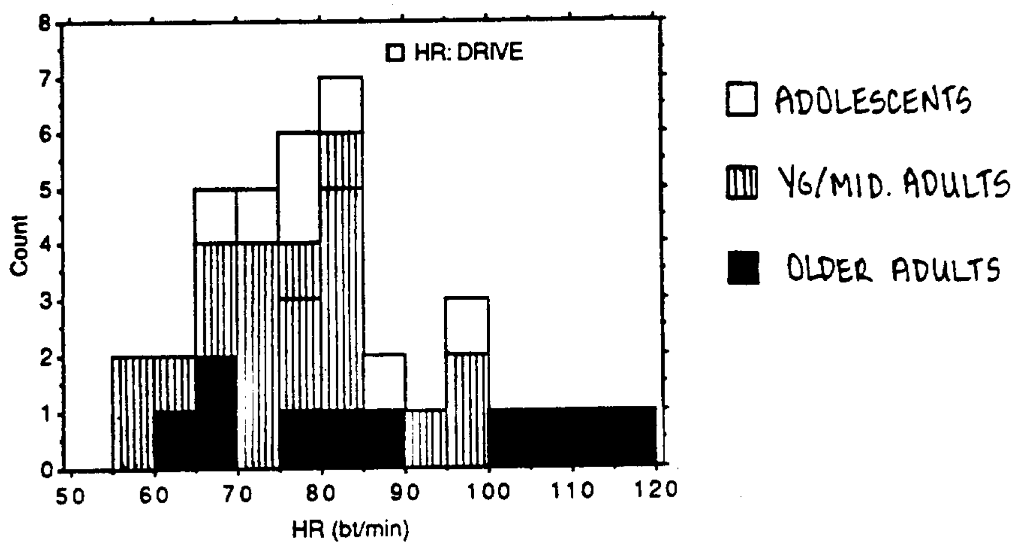


a: V_E values for female adolescents (x = 7.27), young/ middle-aged adults (x = 8.95), and older adults (x = 10.13) for driving.

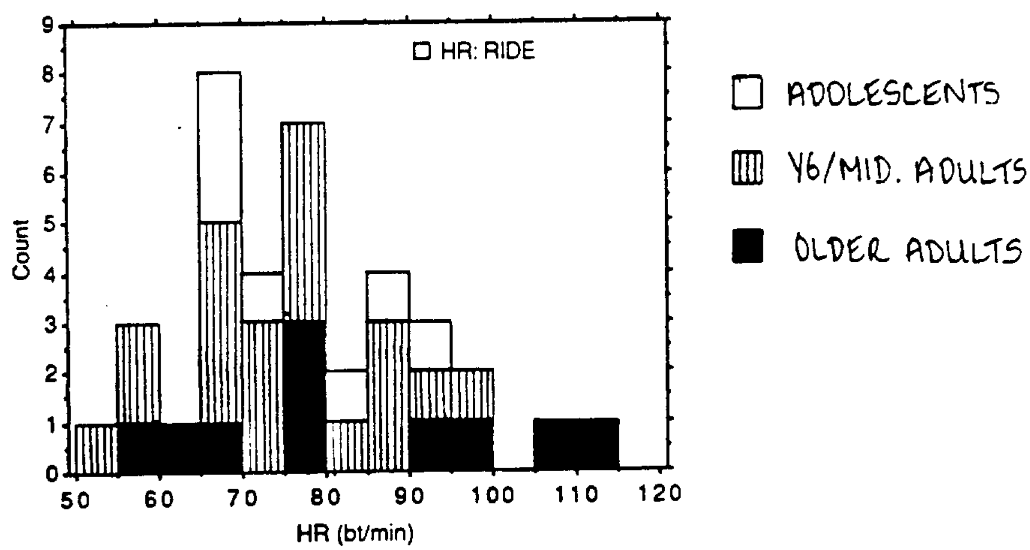


b: V_E values for female adolescents (x = 7.33), young/ middle-aged adults (x = 8.16), and older adults (x = 8.88) for riding.

APPENDIX FIGURE 34. Adolescent, young/middle-aged adult and older adult female group frequency distribution for HR for car driving (a) and riding (b).

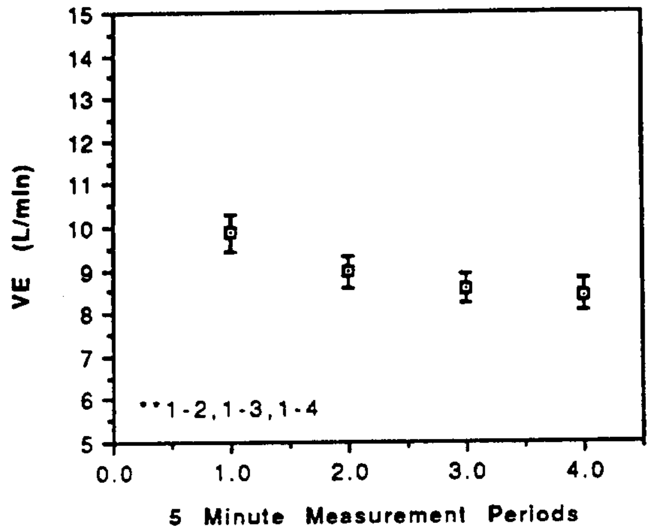


a: HR values for female adolescents (x = 80), young/ middle-aged adults (x = 76), and older adults (x = 89) for driving.

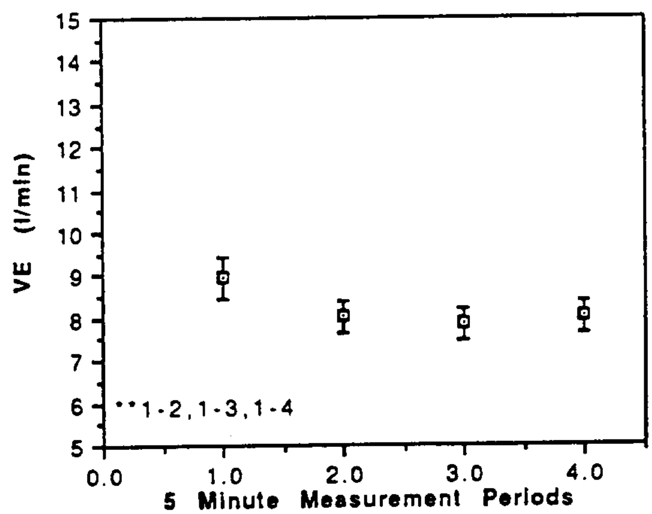


b: HR values for female adolescents (x = 77), young/ middle-aged adults (x = 75), and older adults (x = 83) for riding.

APPENDIX FIGURE 35. Adolescent, young/middle-aged adult and older adult female combined group 5 minute means for V_E for car driving (a) and riding (b).

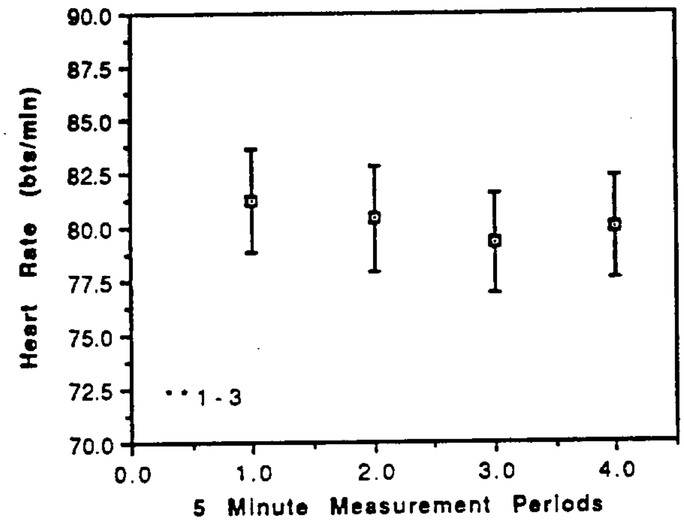


a: 5 minute V_E means (x = 9.88, 8.96, 8.58, 8.43) for combined group of female adolescents, young/middle-aged adults, and older adults for driving.

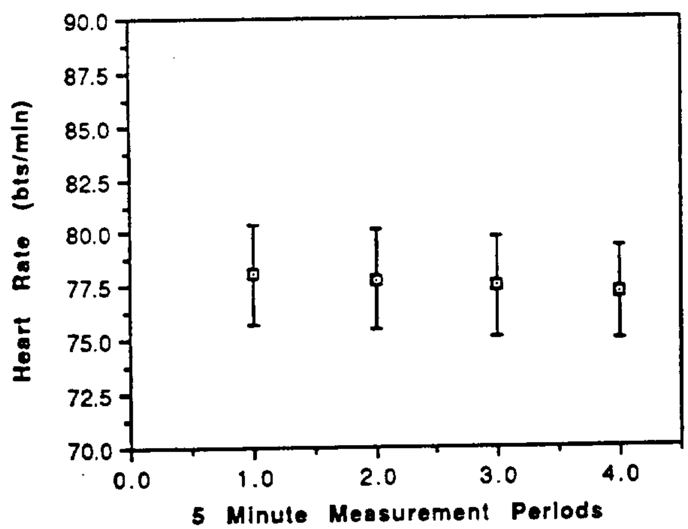


b: 5 minute V_E means (x = 8.94, 8.04, 7.85, 8.02) for combined group of female adolescents, young/middle-aged adults, and older adults for riding.

APPENDIX FIGURE 36. Adolescent, young/middle-aged adult and older adult female combined 5 minute means for HR for car driving (a) and riding (b).

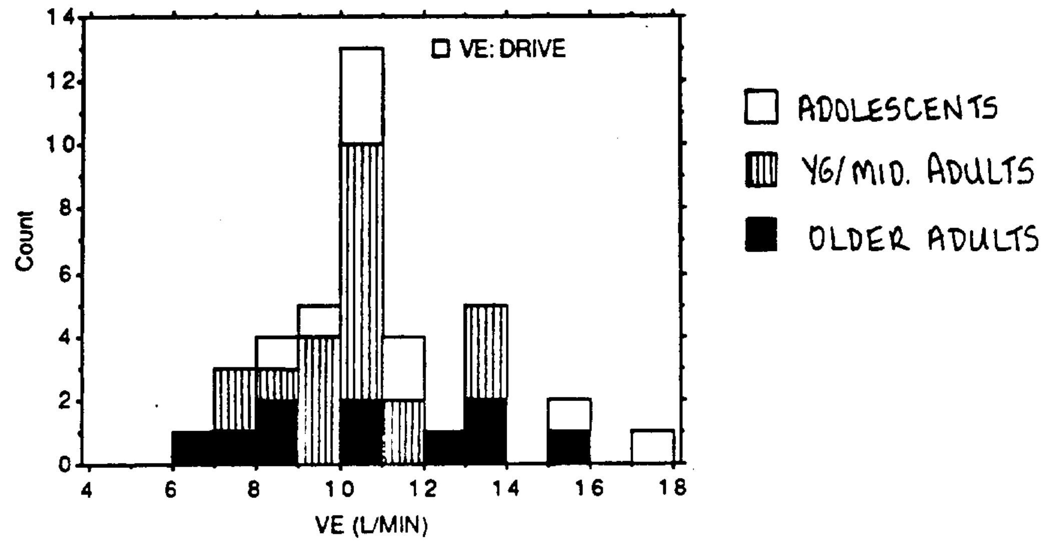


a: 5 minute HR means (x = 81.2, 80.4, 79.3, 80.0) for combined group of female adolescents, young/middle-aged adults, and older adults for driving.

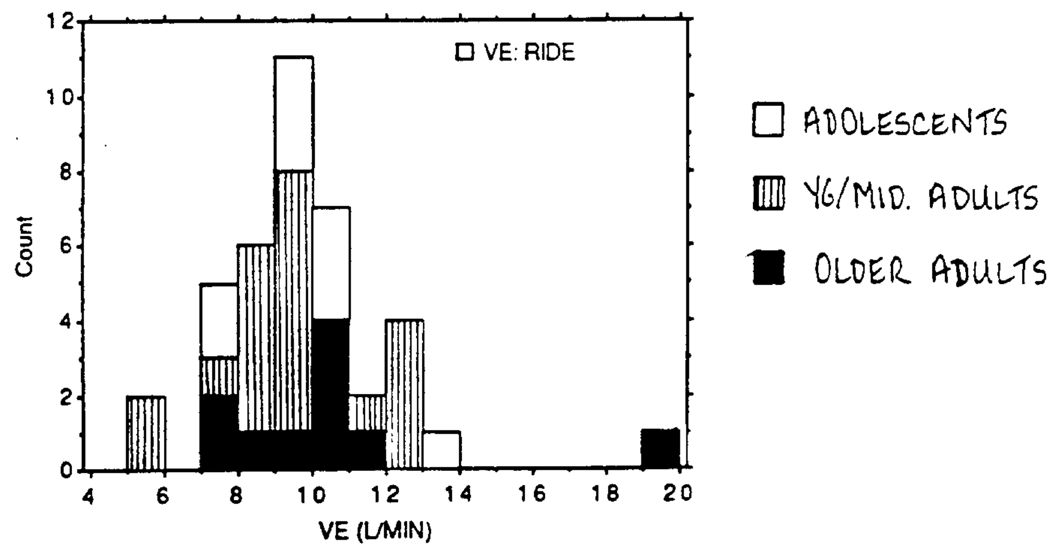


b: 5 minute HR means (x = 78.1, 77.8, 77.5, 77.2) for combined group of female adolescents, young/middle-aged adults, and older adults for riding.

APPENDIX FIGURE 37. Adolescent, young/middle-aged adult and older adult male group frequency distribution for V_E for car driving (a) and riding (b).

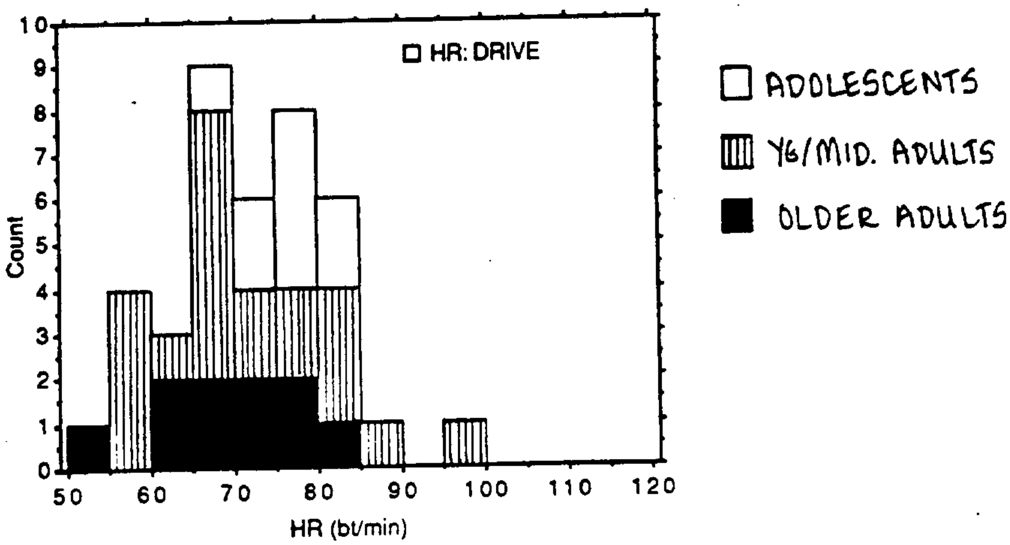


a: V_E values for male adolescents (x = 11.52), young/ middle-aged adults (x = 10.52), and older adults (x = 10.67) for driving.

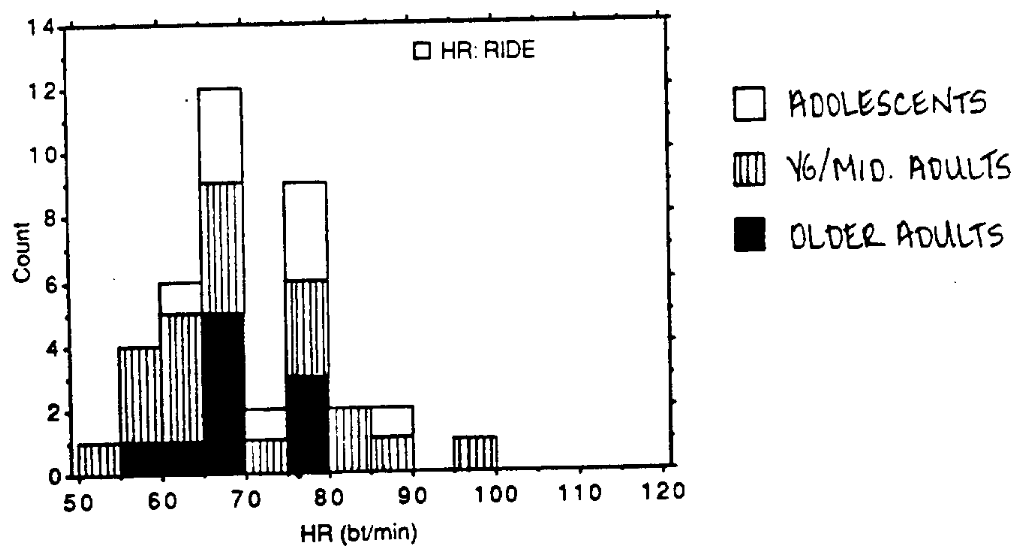


b: V_E values for male adolescents (x = 9.88), young/ middle-aged adults (x = 9.42), and older adults (x = 10.58) for riding.

APPENDIX FIGURE 38. Adolescent, young/middle-aged adult and older adult male group frequency distribution for HR for car driving (a) and riding (b).

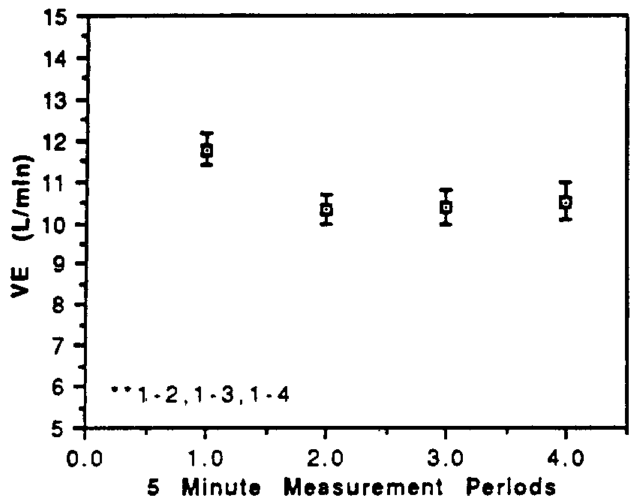


a: HR values for male adolescents (x = 76), young/middle-aged adults (x = 72), and older adults (x = 70) for driving.

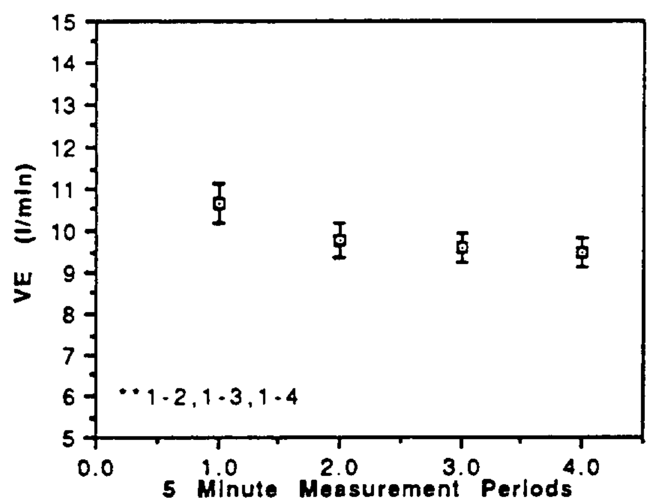


b: HR values for male adolescents (x = 73), young/middle-aged adults (x = 70), and older adults (x = 69) for riding.

APPENDIX FIGURE 39. Adolescent, young/middle-aged adult and older adult male combined group 5 minute means for V_E for car driving (a) and riding (b).

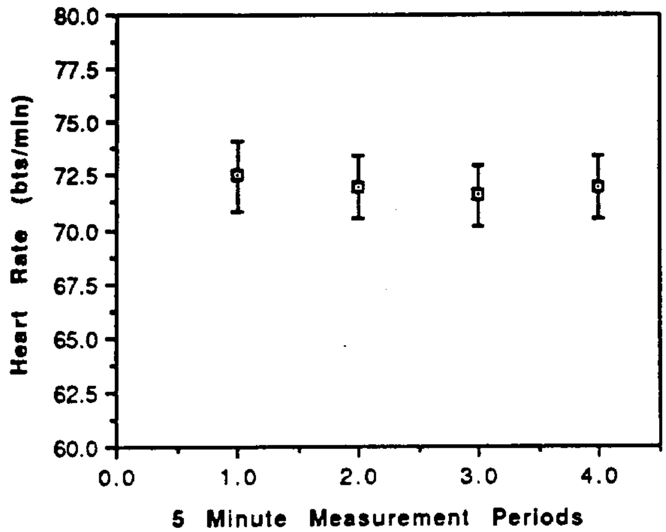


a: 5 minute V_E means (x = 11.77, 10.32, 10.40, 10.52) for combined group of male adolescents, young/middle-aged adults, and older adults for driving.

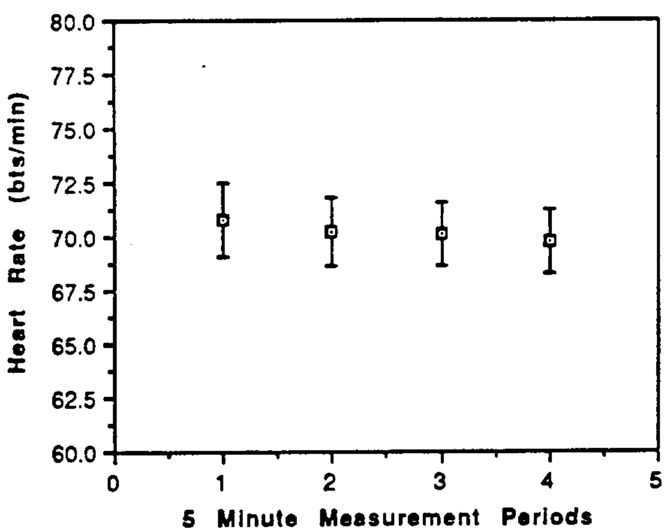


b: 5 minute V_E means (x = 10.66, 9.75, 9.60, 9.47) for combined group of male adolescents, young/middle-aged adults, and older adults for riding.

APPENDIX FIGURE 40. Adolescent, young/middle-aged adult and older adult male combined group 5 minute means for HR for car driving (a) and riding (b).

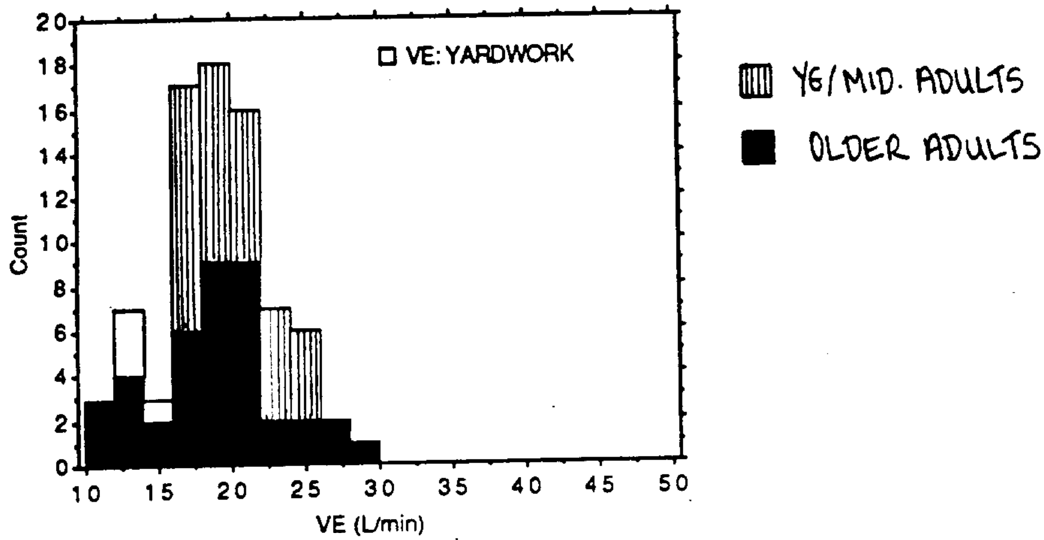


a: 5 minute HR means (x = 72.5, 72.0, 71.6, 72.0) for combined group of male adolescents, young/middle-aged adults, and older adults for driving.

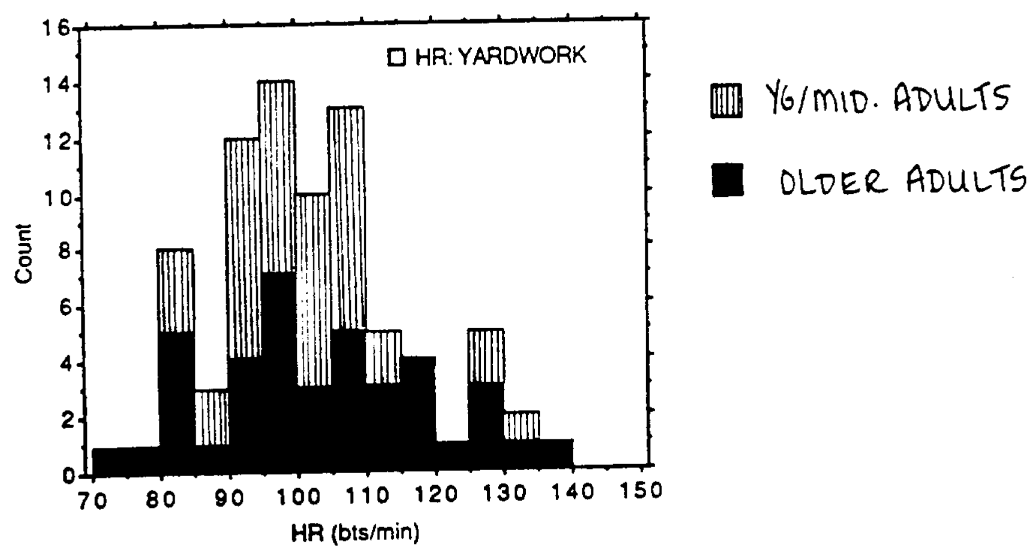


b: 5 minute HR means (x = 70.8, 70.2, 70.1, 69.8) for combined group of male adolescents, youngmiddle-aged adults, and older adults for riding.

APPENDIX FIGURE 41. Young/middle-aged and older adult females group frequency distribution for V_E (a) and HR (b) for yardwork (protocols 1 and 2 combined).

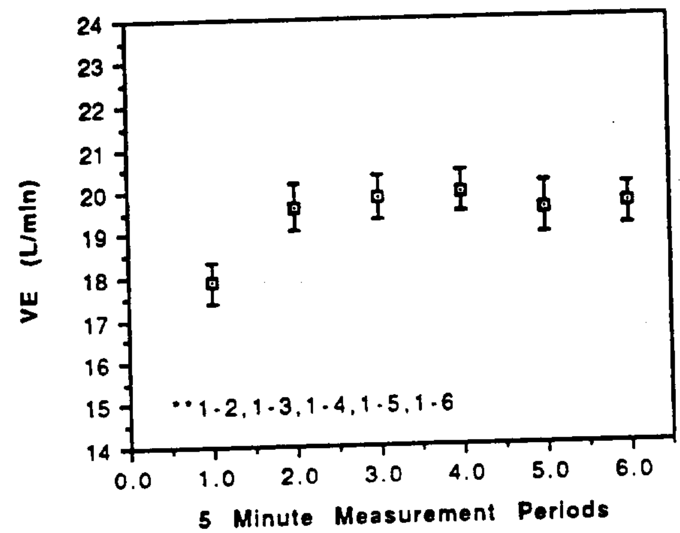


a: V_E values for young/middle-aged adult (x = 19.40, N = 20 x 2) and older adult females (x = 19.07, N = 20 x 2) for yardwork (protocols 1 and 2 combined).

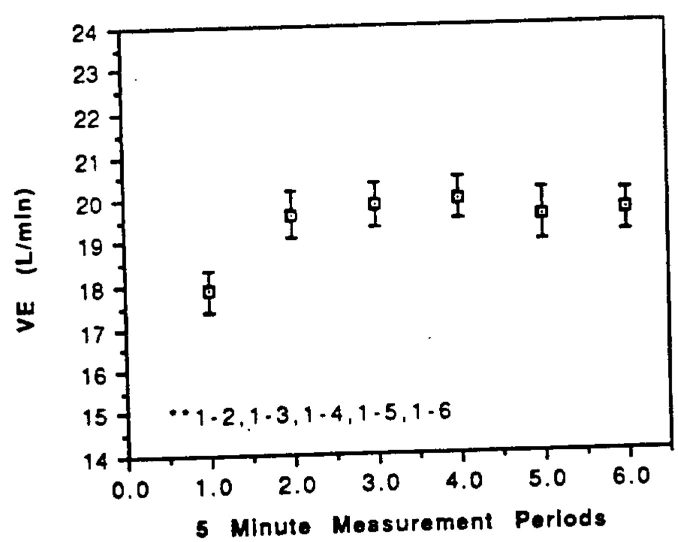


b: HR values for young/middle-aged adults (x = 101, N = 20 x 2) and older adult females (x = 103, N = 20 x 2) for yardwork (protocols 1 and 2 combined).

APPENDIX FIGURE 42. Young/middle-aged adult and older adult female groups combined 5 minute means for V_E (a) and HR (b) for yardwork (protocols 1 and 2 combined).

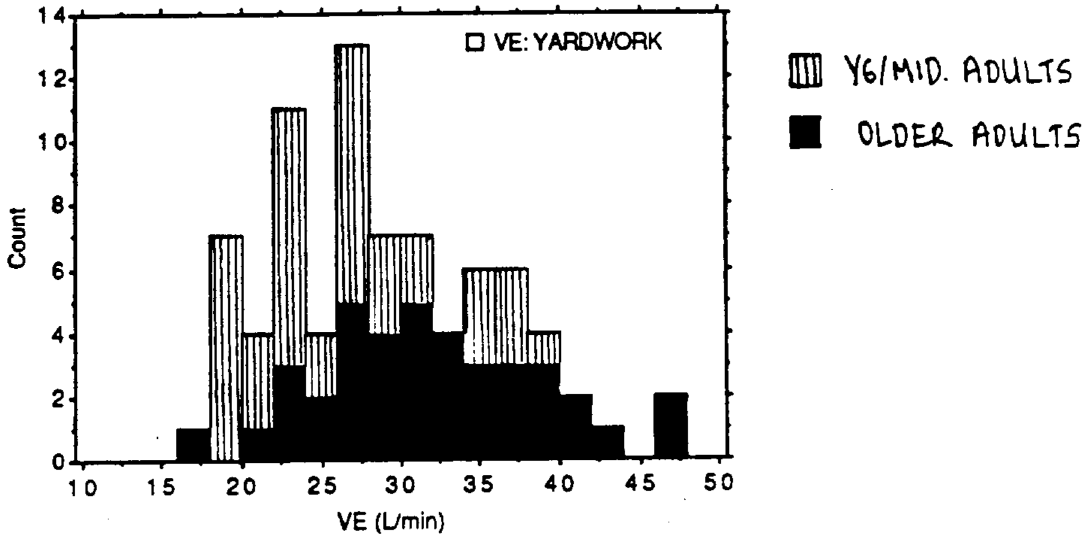


a: 5 minute V_E means (x = 17.86, 19.62, 19.81, 19.97, 19.57, 19.63) for young/middle-aged adult and older adult females for yardwork (protocols 1 and 2 combined).

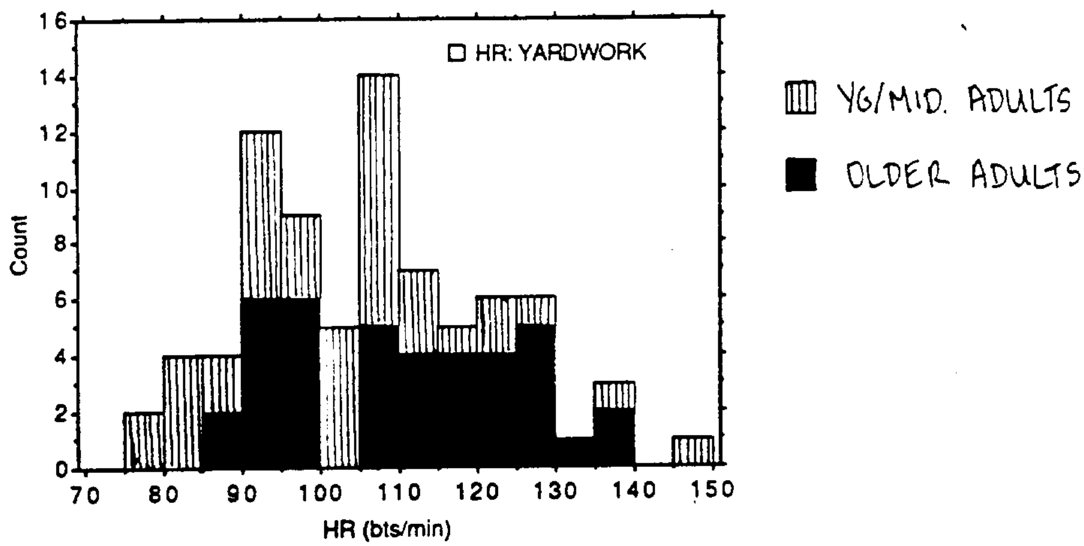


b: 5 minute HR means (x = 98, 102, 103, 103, 102, 103) for young/middle-aged adult and older adult females for yardwork (protocols 1 and 2 combined).

APPENDIX FIGURE 43. Young/middle-aged and older adult males group frequency distribution for V_E (a) and HR (b) for yardwork (protocols 1 and 2 combined).

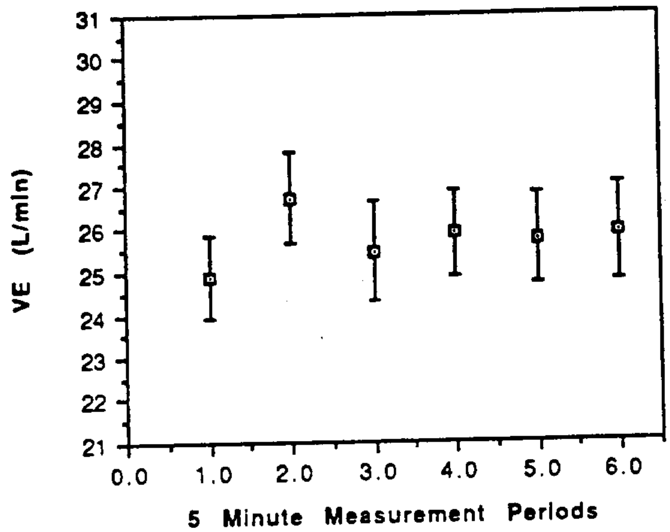


a: V_E values for young/middle-aged adult (x = 26.07, N = 20 x 2) and older adult males (x = 31.89, N = 19 x 2 + 1) for yardwork (protocols 1 and 2 combined).

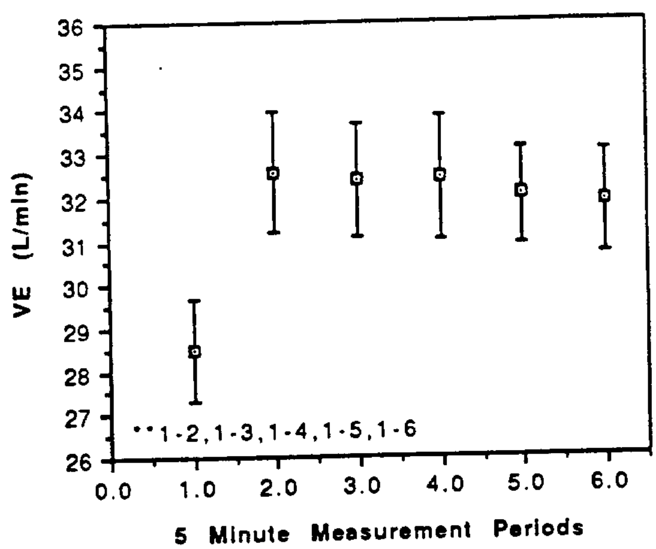


b: HR values for young/middle-aged adults (x = 102, N = 20 x 2) and older adult males (x = 110, N = 19 x 2 + 1) for yardwork (protocols 1 and 2 combined).

APPENDIX FIGURE 44. Young/middle-aged adult male group (a) and older adult male group (b) 5 minute means for V_E for yardwork (protocols 1 and 2 combined).

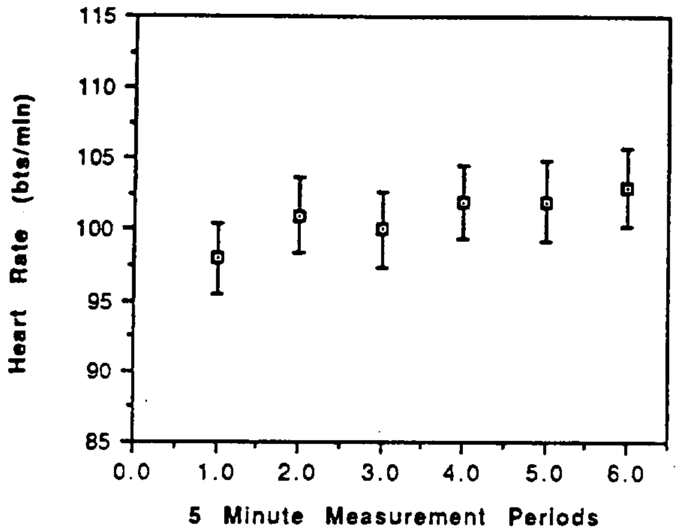


a: 5 minute V_E means (x = 24.89, 26.74, 25.48, 25.89, 25.86, 25.90) for young/middle-aged adult males for yardwork (protocols 1 and 2 combined).

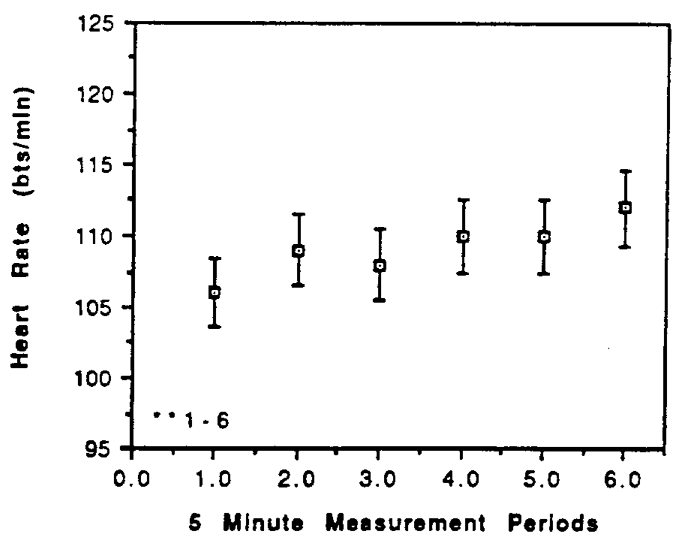


b: 5 minute V_E means (x = 28.48, 32.58, 32.36, 32.44, 32.03, 31.88) for older adult males for yardwork (protocols 1 and 2 combined).

APPENDIX FIGURE 45. Young/middle-aged adult male group (a) and older adult male group (b) 5 minute means for HR for yardwork (protocols 1 and 2 combined).

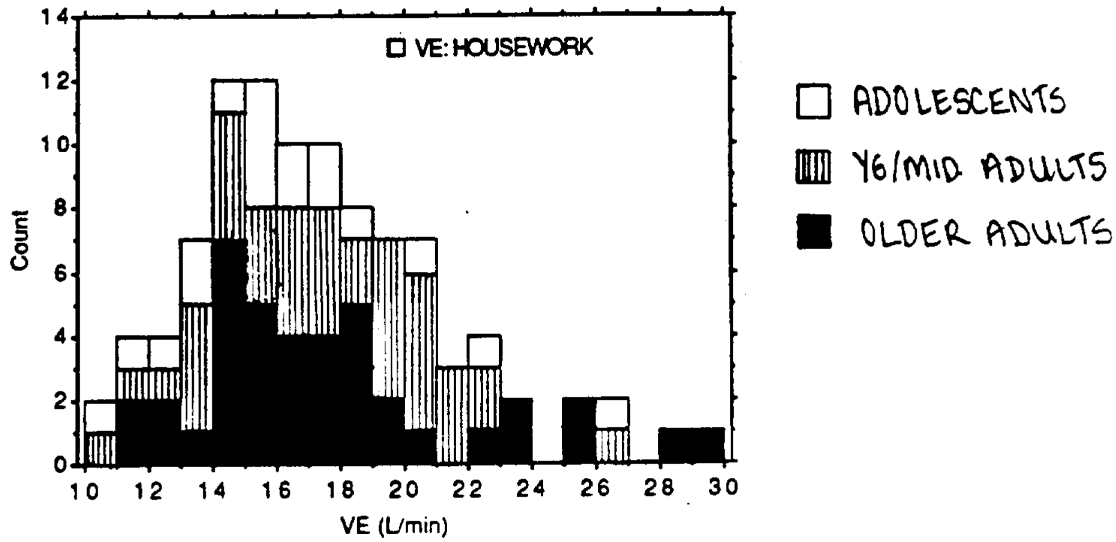


a: 5 minute HR means (x = 98, 101, 100, 102, 102, 103) for young/middle-aged adult males for yardwork (protocols 1 and 2 combined).

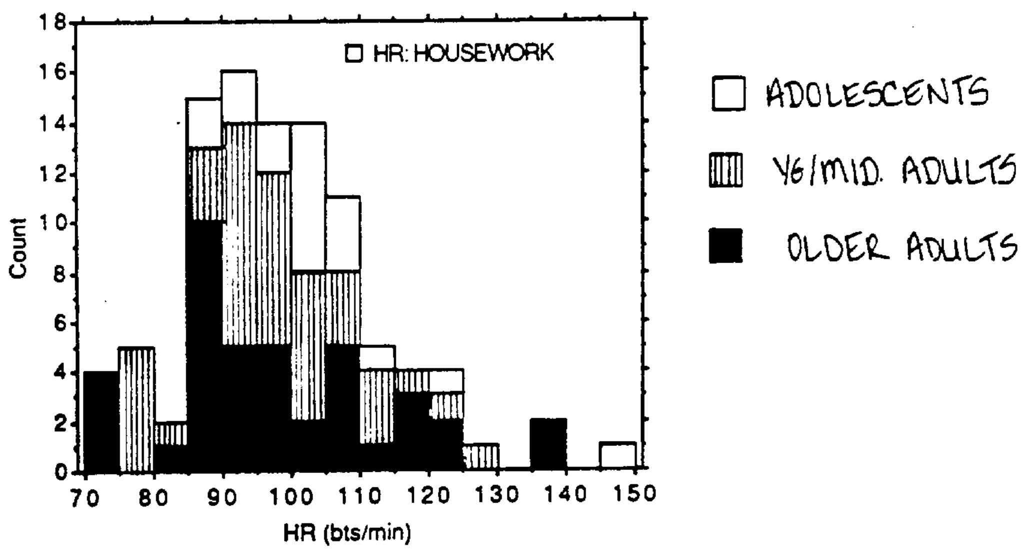


b: 5 minute HR means (x = 106, 109, 108, 110, 110, 112) for older adult males for yardwork (protocols 1 and 2 combined).

APPENDIX FIGURE 46. Adolescent, young/middle-aged adult and older adult females group frequency distribution for V_E (a) and HR (b) for housework (protocols 1 and 2 combined).

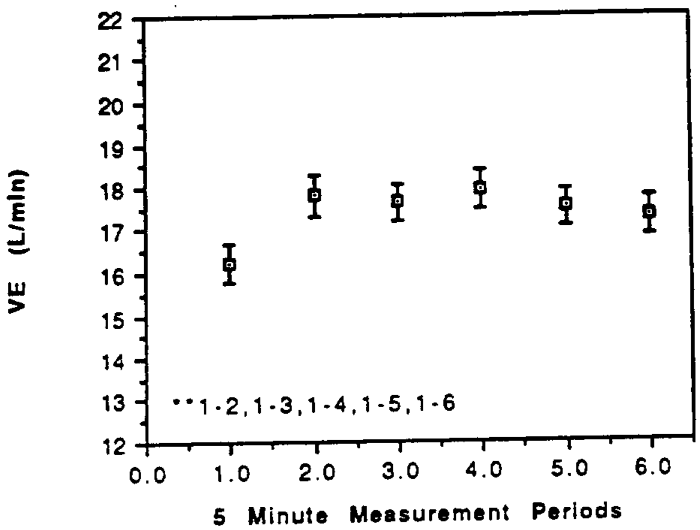


a: V_E values for female adolescents (x = 16.34, N = 9 x 2), young/middle-aged adults (x = 17.47, N = 20 x 2) and older adults (x = 17.76, N = 20 x 2) for housework (protocols 1 and 2 combined).

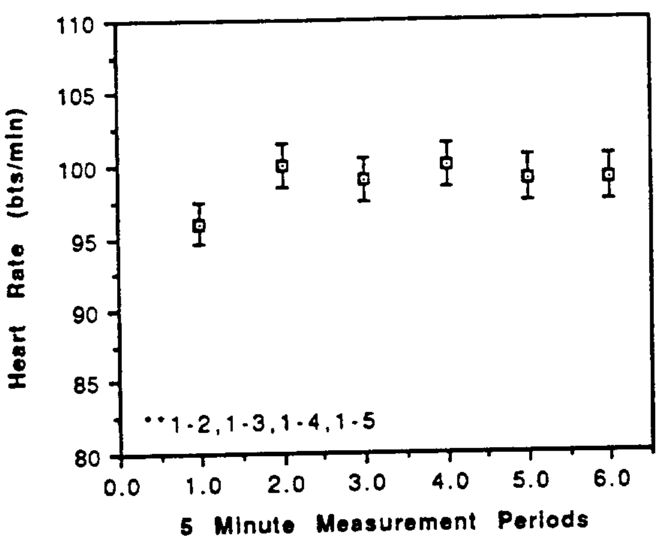


b: HR values for female adolescents (x = 104, N = 9 x 2), young/middle-aged adults (x = 97, N = 20 x 2) and older adults (x = 98, N = 20 x 2) for housework (protocols 1 and 2 combined).

APPENDIX FIGURE 47. Adolescent, young/middle-aged adult and older adult female combined 5 minute means for V_E (a) and HR (b) for housework (protocols 1 and 2 combined).

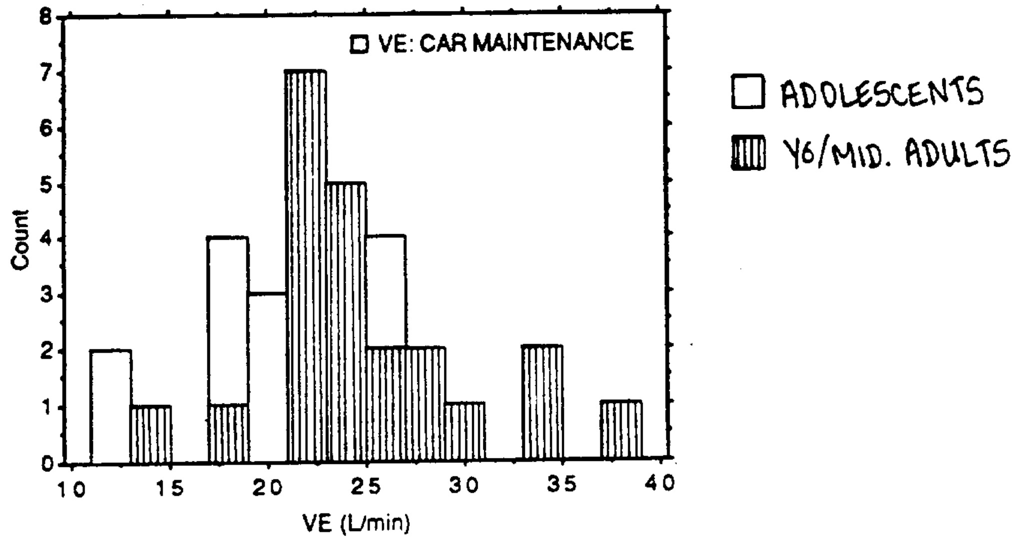


a: 5 minute V_E means (x = 16.23, 17.80, 17.63, 17.93, 17.52, 17.32) for adolescent, young/middle-aged adult and older adult females for housework (protocols 1 and 2 combined).

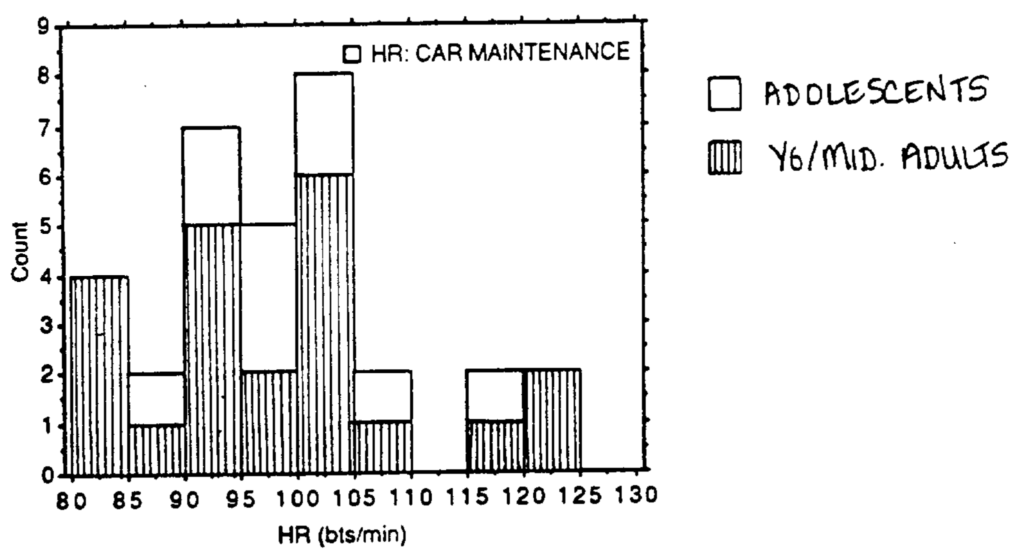


b: 5 minute HR means (x = 96, 100, 99, 100, 99, 99) for adolescent, young/middle-aged adult and older adult females for housework (protocols 1 and 2 combined).

APPENDIX FIGURE 48. Adolescent males and young/middle-aged adult males combined group frequency distribution for V_E (a) and HR (b) for car maintenance (protocols 1 and 2 combined).

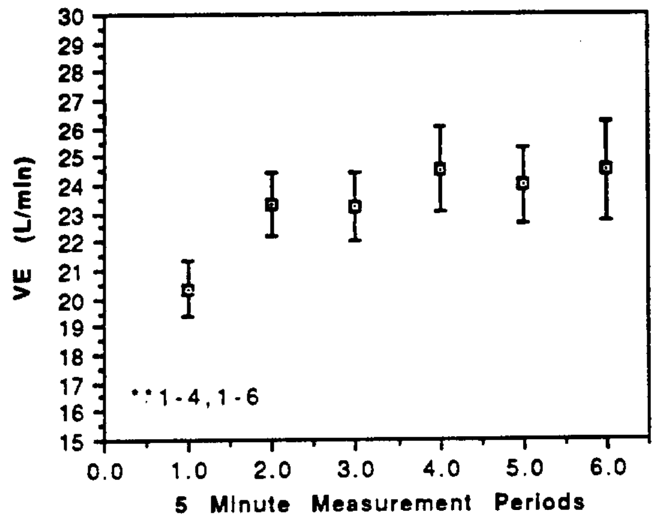


a: V_E values for adolescent and young/middle-aged adult males (x = 23.21, N = 16 x 2) for car maintenance (protocols 1 and 2 combined).

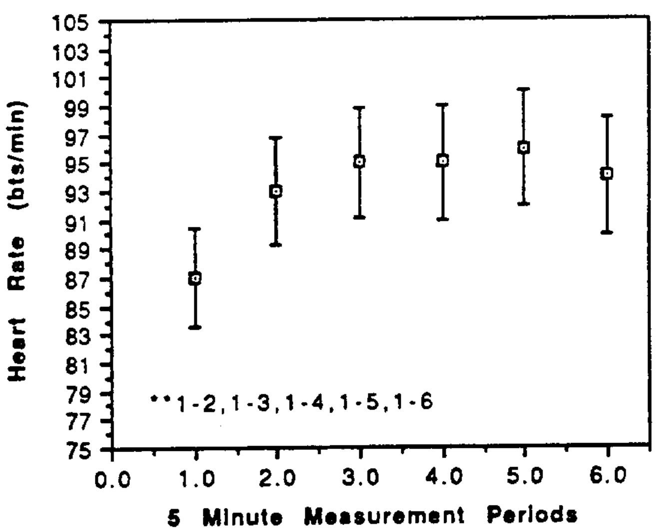


b: HR values for adolescent and young/middle-aged adult males (x = 99, N = 16 x 2) for car maintenance (protocols 1 and 2 combined).

APPENDIX FIGURE 49. Adolescent and young/middle-aged adult males combined 5 minute means for V_E (a) and HR (b) for car maintenance (protocols 1 and 2 combined).

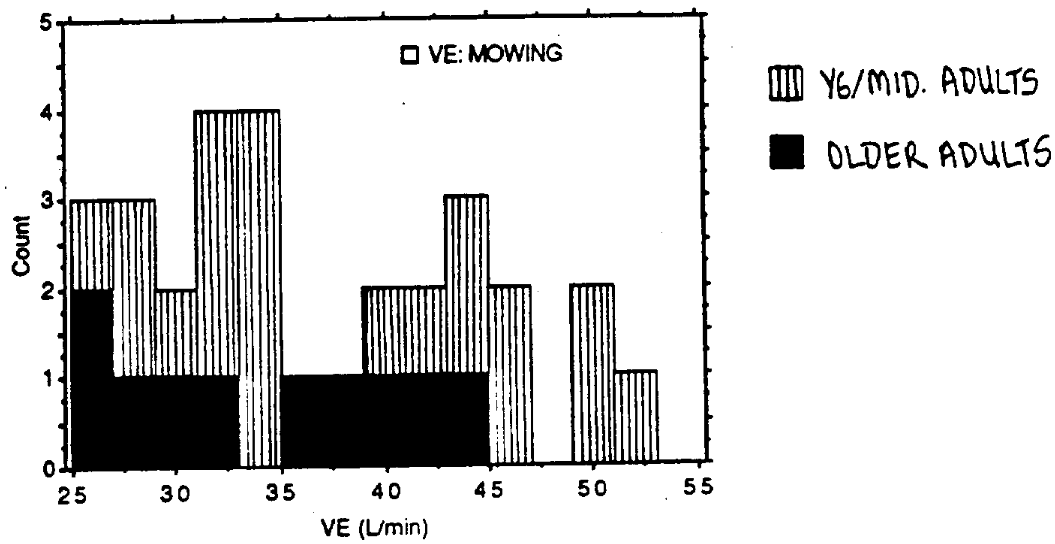


a: 5 minute V_E means (x = 20.34, 23.30, 23.25, 24.52, 23.96, 24.49) for adolescent and young/middle-aged adult males for car maintenance (protocols 1 and 2 combined).

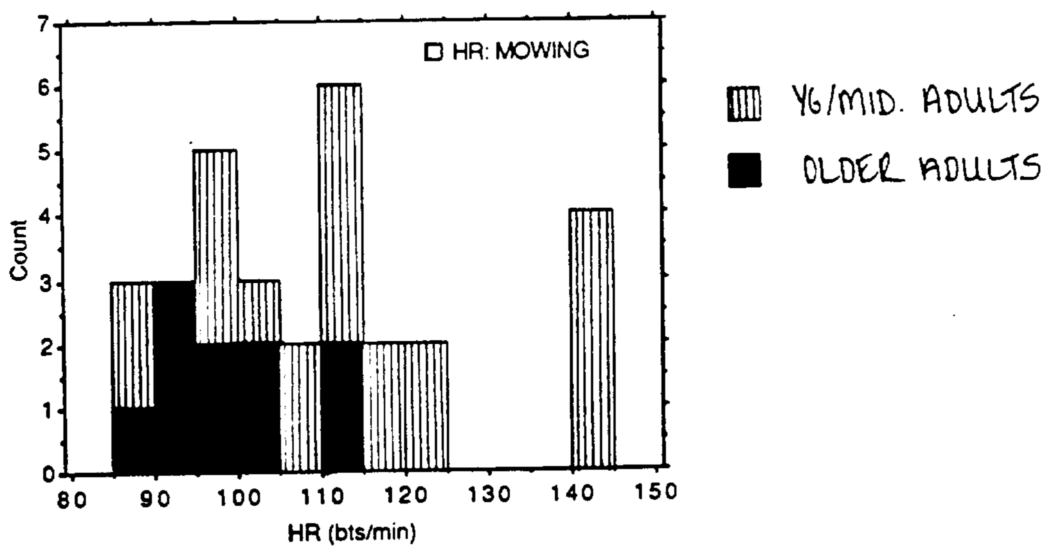


b: 5 minute HR means (x = 87, 93, 95, 95, 96, 94) for adolescent and young/middle-aged adult males for car maintenance (protocols 1 and 2 combined).

APPENDIX FIGURE 50. Young/middle-aged and older adult males combined group frequency distribution for V_E (a) and HR (b) for mowing (protocols 1 and 2 combined).

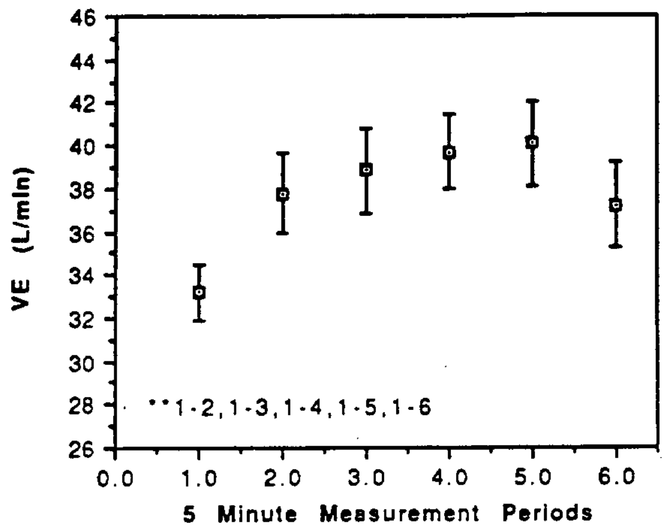


a: V_E values for young/middle-aged adult and older adult males (x = 36.55, N = 14 x 2 + 2) for mowing (protocols 1 and 2 combined).

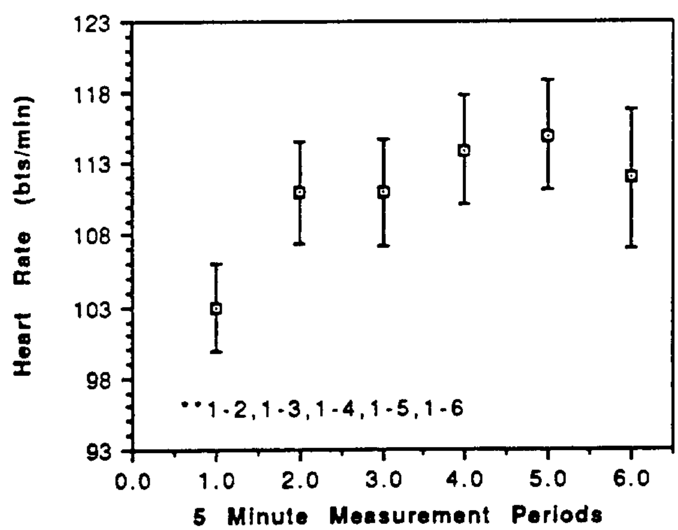


b: HR values for young/middle-aged and older adult males (x = 109, N = 14 x 2 + 2) for mowing (protocols 1 and 2 combined).

APPENDIX FIGURE 51. Young/middle-aged and older adult male group combined 5 minute means for V_E (a) and HR (b) for mowing (protocols 1 and 2 combined).

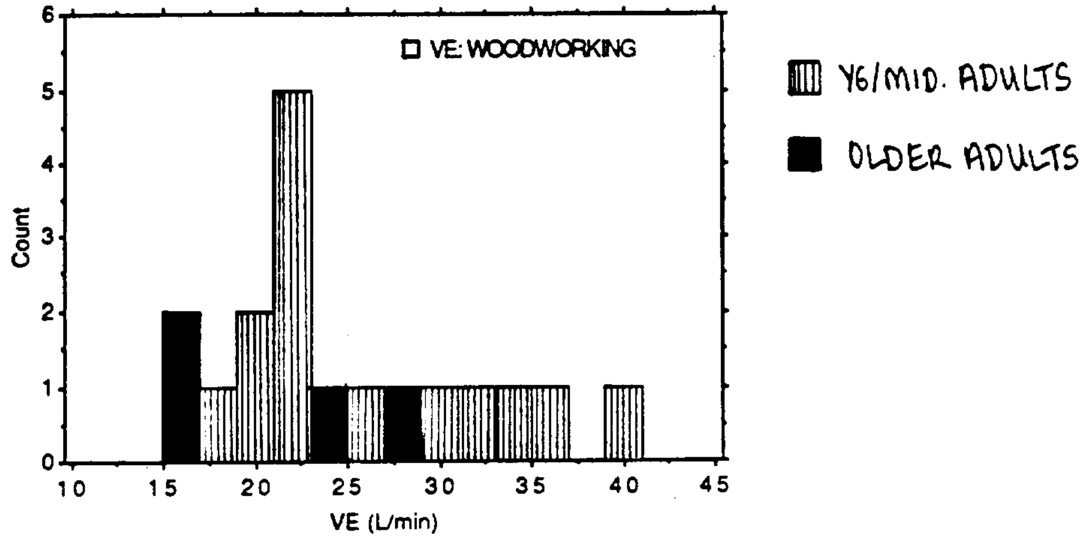


a: 5 minute V_E means (x = 33.18, 37.76, 38.84, 39.72, 40.08, 37.24) for young/middle-aged and older adult males for mowing (protocols 1 and 2 combined).

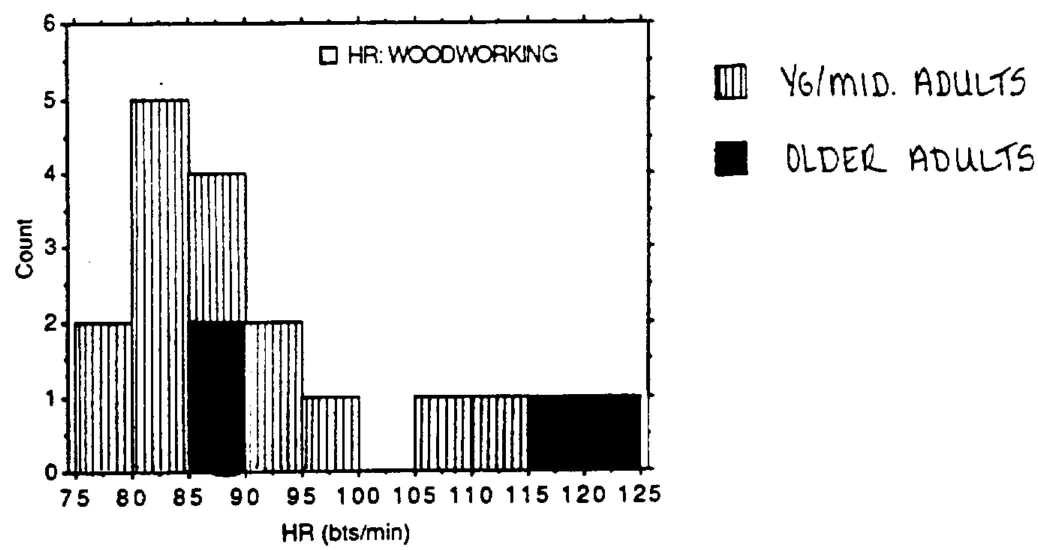


b: 5 minute HR means (x = 103, 111, 111, 114, 115, 112) for young/middle-aged and older adult males for mowing (protocols 1 and 2 combined).

APPENDIX FIGURE 52. Young/middle-aged and older adult males combined group frequency distribution for V_E (a) and HR (b) for woodworking (protocolS 1 and 2 combined).

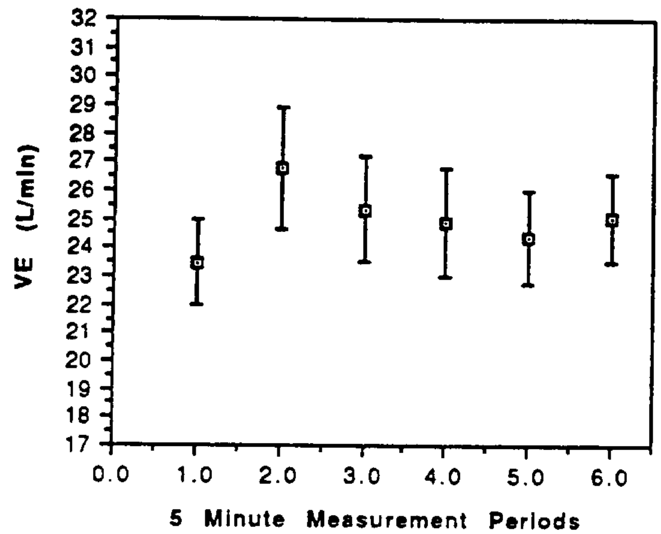


a: V_E values for young/middle-aged and older adult males (x = 24.42, N = 9 x 2) for woodworking (protocols 1 and 2 combined).

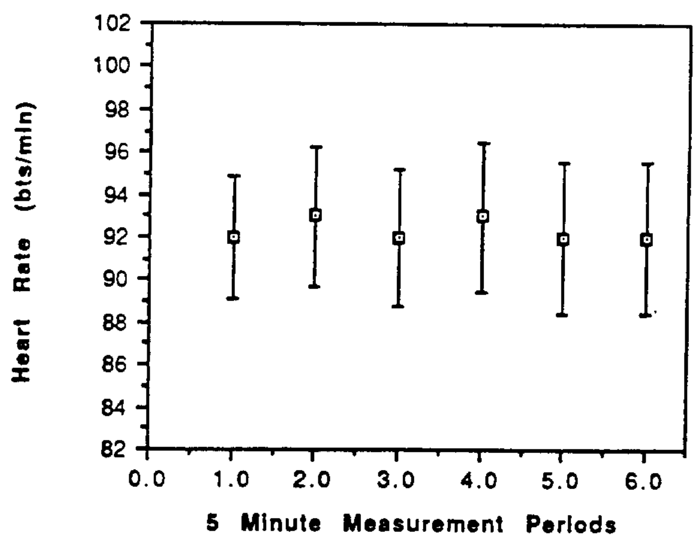


b: HR values for young/middle-aged and older adult males (x = 93, N = 9 x 2) for woodworking (protocols 1 and 2 combined).

APPENDIX FIGURE 53. Young/middle-aged and older adult male group combined 5 minute means for V_E (a) and HR (b) for woodworking (protocols 1 and 2 combined).



a: 5 minute V_E means (x = 23.44, 26.78, 25.34, 24.89, 24.35, 25.06) for young/middle-aged and older adult males for woodworking (protocols 1 and 2 combined).



b: 5 minute HR means (x = 92, 93, 92, 93, 92, 92) for young middle-aged and older adult males for woodworking (protocols 1 and 2 combined).

APPENDIX TABLE 1. Group mean response, (SD) and comparison of male and female children for lying, sitting and standing protocols.

	LYING		SITTING		STANDING	
	males	females	males	females	males	females
V_E	8.04	6.99	7.54	7.02	8.86	8.12
(L/min)	(2.69)	(1.20)	(1.53)	(1.09)	(1.81)	(1.31)
HR	81	85	88	88	95	98
(bts/min)	(10)	(10)	(10)	(9)	(10)	(11)
f_B	21.5	19.6	20.4	18.7	20.6	19.6
(br/min)	(7.3)	(5.0)	(4.9)	(5.2)	(4.6)	(3.7)
VO_2	0.208	0.181	0.210	0.186	0.224	0.202
(L/min)	(0.054)	(0.043)	(0.050)	(0.041)	(0.056)	(0.045)
VO_2/LBM	7.92	7.13	7.92	7.43	8.49	8.00
(ml/kg/min)	(3.16)	(1.00)	(2.55)	(1.30)	(2.88)	(1.04)
V_E/BSA	7.65	6.33	7.03	6.47	8.17	7.42
	(3.61)	(0.84)	(1.74)	(1.38)	(1.80)	(1.26)

No significant differences for these measures at $p < 0.05$. V_E, ventilation; HR, heart rate; f_B, breathing frequency; VO_2, volume of oxygen consumption; VO_2/LBM, volume of oxygen consumption/ lean body mass; V_E/BSA, ventilation/ body surface area.

APPENDIX TABLE 2. Group mean response, (SD) and comparison of male and female cross-validation children for sitting and standing protocols.

	SITTING males		SITTING females	STANDING males		STANDING females
V_E (L/min)	8.56 (1.65)		7.87 (1.44)	8.71 (1.68)		7.99 (1.54)
HR (bts/min)	88 (9)		88 (9)	94 (10)		96 (8)
f_B (br/min)	19.8 (4.5)	**	23.3 (5.9)	21.8 (3.7)		21.8 (5.2)
VO_2 (L/min)	0.208 (0.035)	**	0.184 (0.032)	0.221 (0.032)	**	0.196 (0.039)
VO_2/LBM (ml/kg/min)	7.80 (0.96)		7.40 (1.49)	8.34 (1.28)		7.84 (1.48)
V_E/BSA	7.93 (1.90)		7.36 (1.66)	7.97 (1.41)		7.44 (1.59)

** Denotes significant differences for these measures at $p < 0.05$. V_E, ventilation; HR, heart rate; f_B, breathing frequency; VO_2, volume of oxygen consumption; VO_2/LBM, volume of oxygen consumption/ lean body mass; V_E/BSA, ventilation/ body surface area.

APPENDIX TABLE 3. Group mean response, (SD) and comparison of young male and female children for lying, sitting and standing protocols.

	LYING		SITTING		STANDING	
	males	females	males	females	males	females
V_E (L/min)	6.28 (1.85)	6.09 (1.19)	6.84 (2.01)	6.12 (0.48)	6.96 (1.76)	6.56 (0.53)
HR (bts/min)	100 (9)	102 (6)	102 (10)	105 (8)	102 (13)	110 (6)
f_B (br/min)	26.2 (6.0)	26.3 (3.4)	23.8 (6.0)	25.2 (3.2)	24.5 (3.3)	26.0 (2.3)
VO_2 (L/min)	0.137 (0.022)	0.134 (0.027)	0.154 (0.033)	0.141 (0.023)	0.164 (0.029)	0.149 (0.015)
VO_2/LBM (ml/kg/min)	9.73 (1.56)	8.85 (1.79)	10.86 (1.73)	9.35 (1.73)	11.60 (1.59)	9.87 (1.42)
V_E/BSA	8.92 (2.36)	8.02 (1.55)	9.71 (2.57)	8.06 (0.64)	9.87 (2.15)	8.63 (0.66)

No significant differences for these measures at $p < 0.05$. V_E, ventilation; HR, heart rate; f_B, breathing frequency; VO_2, volume of oxygen consumption; VO_2/LBM, volume of oxygen consumption/ lean body mass; V_E/BSA, ventilation/ body surface area.

APPENDIX TABLE 4. Group mean response, (SD) and comparison of female adolescents, young/middle-aged adults and older adults for lying, sitting and standing protocols.

	V_E (L/min)	HR (bts/min)	f_B (br/min)	VO_2 (L/min)	VO_2/LBM (ml/kg/min)	V_E/BSA
LYING:						
Adoles: (1)	6.90 (1.24)	70 (10)	14.5 (5.3)	0.198 (0.014)	4.61 (0.50)	4.35 (0.85)
Yg/Mid. Adults: (2)	7.53 (1.95)	64 (9)	15.4 (4.2)	0.205 (0.036)	4.45 (0.79)	4.52 (0.93)
Older Adults: (3)	6.93 (1.14)	71 (13)	13.3 (4.3)	0.183 (0.026)	4.04 (0.59)	4.15 (0.72)
SIGNIFICANT DIFFERENCES:				**2-3	**1-3	
SITTING:						
Adoles: (1)	7.76 (1.29)	75 (10)	15.2 (3.6)	0.220 (0.030)	5.12 (0.76)	4.87 (0.83)
Yg/Mid. Adults: (2)	7.87 (1.90)	67 (11)	15.6 (4.2)	0.206 (0.034)	4.45 (0.55)	4.71 (0.85)
Older Adults: (3)	7.53 (2.39)	71 (12)	14.8 (5.5)	0.193 (0.029)	4.29 (0.70)	4.50 (1.40)
SIGNIFICANT DIFFERENCES:				**1-3	**1-2,1-3	
STANDING:						
Adoles: (1)	8.33 (1.65)	86 (11)	15.1 (3.5)	0.225 (0.039)	5.21 (0.96)	5.22 (0.97)
Yg/Mid. Adults: (2)	8.50 (1.96)	75 (15)	15.9 (4.2)	0.218 (0.032)	4.73 (0.62)	5.11 (1.00)
Older Adults: (3)	8.23 (2.69)	76 (12)	14.0 (5.0)	0.211 (0.031)	4.67 (0.66)	4.91 (1.54)
SIGNIFICANT DIFFERENCES:		**1-2				

** Denotes significant differences for these measures at $p < 0.05$. Adoles, adolescents; Yg/Mid. Adults, young/middle-aged adults; V_E, ventilation; HR, heart rate; f_B, breathing frequency; VO_2, volume of oxygen consumption; VO_2/LBM, volume of oxygen consumption/ lean body mass; V_E/BSA, ventilation/ body surface area.

APPENDIX TABLE 5. Group mean response, (SD) and comparison of male adolescents, young/middle-aged adults and older adults for lying, sitting and standing protocols.

	V_E (L/min)	HR (bts/min)	f_B (br/min)	VO_2 (L/min)	VO_2/LBM (ml/kg/min)	V_E/BSA
LYING:						
Adoles: (1)	8.22 (1.61)	67 (7)	14.0 (4.7)	0.270 (0.052)	4.85 (0.89)	4.62 (0.85)
Yg/Mid. Adults: (2)	8.62 (1.53)	63 (13)	11.9 (2.7)	0.281 (0.040)	4.19 (0.58)	4.37 (0.65)
Older Adults: (3)	9.96 (2.32)	67 (12)	13.8 (3.6)	0.257 (0.038)	4.17 (0.61)	4.94 (0.91)
SIGNIFICANT DIFFERENCES:	**1-3				**1-2,1-3	
SITTING:						
Adoles: (1)	8.33 (1.45)	71 (7)	14.0 (3.3)	0.272 (0.059)	4.87 (0.93)	4.68 (0.71)
Yg/Mid. Adults: (2)	9.22 (1.56)	66 (13)	12.8 (3.6)	0.297 (0.040)	4.43 (0.59)	4.69 (0.73)
Older Adults: (3)	10.37 (2.03)	68 (11)	14.7 (4.4)	0.272 (0.033)	4.40 (0.37)	5.15 (0.76)
SIGNIFICANT DIFFERENCES:	**1-3					
STANDING:						
Adoles: (1)	9.64 (2.05)	81 (9)	13.6 (3.9)	0.303 (0.066)	5.42 (0.97)	5.43 (1.13)
Yg/Mid. Adults: (2)	9.90 (1.71)	73 (12)	13.2 (3.9)	0.315 (0.035)	4.71 (0.59)	5.04 (0.82)
Older Adults: (3)	12.41 (3.70)	76 (13)	16.2 (4.6)	0.301 (0.041)	4.88 (0.57)	6.14 (1.49)
SIGNIFICANT DIFFERENCES:	**1-3,2-3				**1-2	**2-3

** Denotes significant differences for these measures at $p < 0.05$. Adoles, adolescents; Yg/Mid. Adults, young to middle-aged adults; V_E, ventilation; HR, heart rate; f_B, breathing frequency; VO_2, volume of oxygen consumption; VO_2/LBM, volume of oxygen consumption/ lean body mass; V_E/BSA, ventilation/ body surface area.

APPENDIX TABLE 6. Group mean response, (SD) and comparison of male and female children during walking at different velocities.

Velocity: (mph)	2.0 males N = 18		2.0 females N = 20	2.5 males N = 20	2.5 females N = 20	3.0 males N = 18	3.0 females N = 20
V_E (L/min)	14.56 (2.77)		13.74 (2.41)	16.19 (3.30)	15.21 (2.74)	17.98 (3.42)	17.61 (3.80)
HR (bts/min)	111 (8)		113 (8)	116 (11)	119 (9)	124 (10)	128 (10)
f_B (br/min)	30.1 (5.1)		28.5 (5.1)	31.3 (5.2)	30.6 (4.5)	33.7 (6.2)	32.8 (5.6)
VO_2 (L/min)	0.430 (0.148)		0.418 (0.131)	0.522 (0.167)	0.490 (0.142)	0.595 (0.178)	0.582 (0.177)
VO_2 (ml/kg/min)	13.7 (2.0)		12.8 (1.6)	16.1 (2.3)	15.2 (2.2)	19.3 (2.9)	17.9 (2.3)
V_E/BSA	13.66 (2.11)	**	12.44 (1.52)	14.73 (1.94)	13.76 (1.79)	16.88 (2.47)	15.86 (2.28)

** Denotes significant differences for these measures at $p < 0.05$. V_E, ventilation; HR, heart rate; f_B, breathing frequency; VO_2, volume of oxygen consumption; VO_2 (ml/kg/min), volume of oxygen consumption/ body weight; V_E/BSA, ventilation/ body surface area.

APPENDIX TABLE 7. Group mean response, (SD) and comparison of male and female cross-validation children during walking at different velocities.

Velocity: (mph)	2.0 males N = 16		2.0 females N = 16	2.5 males N = 20	2.5 females N = 20	3.0 males N = 19		3.0 females N = 19
V_E (L/min)	13.55 (2.21)		13.51 (2.44)	15.56 (2.89)	15.17 (2.81)	18.04 (2.86)		17.75 (3.05)
HR (bts/min)	111 (8)	**	119 (11)	114 (9)	120 (11)	121 (10)	**	129 (11)
f_B (br/min)	31.8 (6.7)		32.4 (6.5)	33.2 (8.1)	33.6 (7.3)	34.7 (7.2)		36.6 (8.9)
VO_2 (L/min)	0.403 (0.066)		0.363 (0.088)	0.503 (0.100)	0.452 (0.089)	0.616 (0.117)		0.548 (0.116)
VO_2 (ml/kg/min)	13.6 (1.9)		12.4 (1.8)	15.7 (2.4)	14.5 (2.0)	19.0 (2.9)		17.9 (2.1)
V_E/BSA	12.98 (1.82)		12.92 (1.49)	14.21 (2.11)	13.98 (1.89)	16.35 (2.06)		16.54 (1.95)

** Denotes significant differences for these measures at $p < 0.05$. V_E, ventilation; HR, heart rate; f_B, breathing frequency; VO_2, volume of oxygen consumption; VO_2 (ml/kg/min), volume of oxygen consumption/ body weight; V_E/BSA, ventilation/ body surface area.

APPENDIX TABLE 8. Group mean response, (SD) and comparison of young male and female children during walking at different velocities.

Velocity: (mph)	1.5 males N = 6	1.5 females N = 6	1.875 males N = 6	1.875 females N = 5	2.25 males N = 6		2.25 females N = 5
V_E (L/min)	10.41 (1.36)	10.09 (1.29)	10.54 (1.14)	10.52 (2.66)	11.15 (1.64)		12.31 (1.76)
HR (bts/min)	129 (6)	126 (9)	131 (5)	130 (8)	134 (6)		133 (9)
f_B (br/min)	32.8 (8.6)	36.7 (6.9)	34.8 (5.3)	36.8 (5.8)	35.5 (8.4)		40.2 (3.9)
VO_2 (L/min)	0.259 (0.051)	0.243 (0.060)	0.272 (0.045)	0.274 (0.060)	0.309 (0.046)		0.317 (0.035)
VO_2 (ml/kg/min)	15.2 (2.0)	12.7 (1.6)	16.0 (1.2)	13.5 (2.6)	18.2 (1.1)	**	15.7 (1.5)
V_E/BSA	14.79 (1.41)	13.40 (2.60)	14.97 (0.90)	13.39 (3.28)	15.86 (1.88)		15.72 (2.22)

** Denotes significant differences for these measures at $p < 0.05$. V_E, ventilation; HR, heart rate; f_B, breathing frequency; VO_2, volume of oxygen consumption; VO_2 (ml/kg/min), volume of oxygen consumption/ body weight; V_E/BSA, ventilation/ body surface area.

APPENDIX TABLE 9. Adolescent, young/middle-aged adult and older adult male group r, r^2 and SEM for predicting V_E using simple linear and multiple regression analysis during walking (includes velocity).

V_E:	Adolescents r r^2 (SEM)	Yg/Mid. Adults r r^2 (SEM)	Older Adults r r^2 (SEM)	Groups Combined r r^2 (SEM)
BSA	0.41 0.166 (5.09)	0.30 0.091 (6.90)	0.47 0.223 (8.57)	0.49 0.242 (7.30)
HR (bts/min)	0.53 0.280 (4.73)	0.57 0.320 (5.97)	0.46 0.213 (8.63)	0.32 0.104 (7.93)
f_B (br/min)	0.58 0.335 (4.54)	0.60 0.356 (5.81)	0.63 0.392 (7.59)	**0.51 0.257** (7.22)
Vel (mph)	**0.60 0.360** (4.46)	**0.68 0.464** (5.30)	**0.65 0.418** (7.42)	0.48 0.229 (7.36)

SIMPLE EQUATIONS:

Equation	Group	r	SEM
$V_E = 5.427\ vel + 8.349$	adolescents	0.60	4.46
$V_E = 7.582\ vel + 4.451$	yg/mid. adults	0.68	5.30
$V_E = 10.217\ vel + 4.494$	older adults	0.65	7.42
$V_E = 0.802\ f_B + 11.52$	groups comb.	0.51	7.22

MULTIPLE REGRESSION EQUATIONS:

Equation	Group	r	SEM
$V_E = 6.005\ vel + 14.18\ BSA + 0.379\ f_B - 27.44$	adolescents	0.90	2.44
$V_E = 6.827\ vel + 21.15\ BSA + 0.574\ f_B - 46.41$	yg/mid. adults	0.90	3.24
$V_E = 8.508\ vel + 23.65\ BSA + 0.702\ f_B - 54.25$	older adults	0.86	5.10
$V_E = 6.504\ vel + 23.94\ BSA + 0.587\ f_B - 49.56$	groups comb.	0.84	4.63

APPENDIX TABLE 10. Group mean response, (SD) and comparison of male and female children (original group) for play (protocols 1 and 2 combined).

	V_E (L/min)	HR (bts/min)	f_B (br/min)	V_E/BSA
MALES:				
N = 20 x 2	18.32	136	33.6	16.38
	(6.62)	(15)	(7.4)	(4.70)
FEMALES:				
N = 20 x 2	17.46	142	30.9	15.65
	(5.81)	(16)	(5.4)	(4.88)

SIGNIFICANT DIFFERENCES: NONE

No significant differences for these measures at $p < 0.05$. V_E, ventilation; HR, heart rate; f_B, breathing frequency; V_E/BSA, ventilation/ body surface area.

APPENDIX TABLE 11. Group mean response, (SD) and comparison of male and female cross-validation children for play.

	V_E (L/min)	HR (bts/min)	f_B (br/min)	V_E/BSA
CROSS-VALIDATION MALES:				
N = 20	19.13	142	32.4	17.41
	(4.97)	(15)	(4.9)	(4.38)
CROSS-VALIDATION FEMALES:				
N = 20	17.32	144	31.6	15.87
	(6.53)	(17)	(7.9)	(5.77)

SIGNIFICANT DIFFERENCES: NONE

No significant differences for these measures at $p < 0.05$. V_E, ventilation; HR, heart rate; f_B, breathing frequency; V_E/BSA, ventilation/ body surface area.

APPENDIX TABLE 12. Group mean response, (SD) and comparison of female adolescents, young/middle-aged adults and older adults for car driving and riding.

	V_E (L/min)	HR (bts/min)	f_B (br/min)	V_E/BSA
FEMALE DRIVING:				
Adoles: (1) N = 7	7.27 (1.32)	80 (9)	16.6 (4.8)	4.47 (0.71)
Young/Middle Adults: (2) N = 20	8.95 (1.36)	76 (11)	17.9 (4.1)	5.38 (0.81)
Older Adults: (3) N = 10	10.13 (2.97)	89 (20)	16.9 (2.5)	6.04 (1.74)
SIGNIFICANT DIFFERENCES: NONE				
FEMALE RIDING:				
Adoles: (1) N = 7	7.33 (1.87)	77 (11)	17.5 (3.8)	4.49 (1.00)
Young/Middle Adults: (2) N = 20	8.16 (2.15)	75 (12)	17.4 (3.9)	4.90 (1.19)
Older Adults: (3) N = 10	8.88 (2.97)	83 (19)	18.0 (4.0)	5.30 (1.75)
SIGNIFICANT DIFFERENCES: NONE				

No significant differences for these measures at $p < 0.05$. V_E, ventilation; HR, heart rate; f_B, breathing frequency; V_E/BSA, ventilation/ body surface area.

APPENDIX TABLE 13. Group mean response, (SD) and comparison of male adolescents, young/middle-aged adults and older adults for car driving and riding.

	V_E (L/min)	HR (bts/min)	f_B (br/min)	V_E/BSA
MALE DRIVING:				
Adoles: (1) N = 9	11.52 (2.93)	76 (5)	16.6 (2.1)	6.47 (1.67)
Young/Middle Adults: (2) N = 20	10.52 (1.68)	72 (11)	16.1 (3.4)	5.32 (0.75)
Older Adults: (3) N = 10	10.67 (3.16)	70 (9)	18.3 (3.9)	5.41 (1.36)
SIGNIFICANT DIFFERENCES: NONE				
MALE RIDING:				
Adoles: (1) N = 9	9.88 (1.90)	73 (7)	15.8 (2.4)	5.54 (1.07)
Young/Middle Adults: (2) N = 20	9.42 (2.02)	70 (11)	15.7 (4.4)	4.75 (0.87)
Older Adults: (3) N = 10	10.58 (3.30)	69 (7)	17.3 (3.4)	5.33 (1.23)
SIGNIFICANT DIFFERENCES: NONE				

No significant differences for these measures at $p < 0.05$. V_E, ventilation; HR, heart rate; f_B, breathing frequency; V_E/BSA, ventilation/ body surface area.

APPENDIX TABLE 14. Group mean response, (SD) and comparison of female young/middle-aged adults and older adults for yardwork (protocols 1 and 2 combined).

	V_E (L/min)	HR (bts/min)	f_B (br/min)	V_E/BSA
YARDWORK:				
Young/Middle Adults:	19.40	101	22.4	11.64
N = 20 x 2	(3.13)	(11)	(3.8)	(1.62)
Older Adults:	19.07	103	23.2	11.37
N = 20 x 2	(4.50)	(16)	(4.6)	(2.52)

SIGNIFICANT DIFFERENCES: NONE

No significant differences for these measures at $p < 0.05$. V_E, ventilation; HR, heart rate; f_B, breathing frequency; V_E/BSA, ventilation/ body surface area.