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7. INHALATION ROUTE

7.1 INTRODUCTION

This chapter presents data and recommendations for inhalation rates that can be used to assess children's exposure to contaminants in air. Inhalation rates vary with both size and activity level, both of which influence oxygen consumption. Infants and young children have a higher resting metabolic rate and rate of oxygen consumption per unit body weight than do adults because they have a larger cooling surface per unit body weight and because they are growing rapidly. The oxygen consumption of a resting infant aged between one week and one year is 7 mL/kg body weight per minute. The rate for an adult under the same conditions is 3-5 mL/kg per minute (WHO, 1986). Thus, while on an absolute basis, greater amounts of air and pollutants are inhaled by adults than children per similar time periods, on a body-weight basis, the volume of air passing through the lungs of a resting infant is twice that of a resting adult under the same conditions. The recommended inhalation rates for children are summarized in Section 7.3.

7.2 INHALATION RATE STUDIES

7.2.1 Linn et al., 1992

Linn et al. (1992) conducted a study that estimated the inhalation rates for "high-risk" subpopulation groups exposed to ozone in their daily activities in the Los Angeles area. The population surveyed consisted of several panels of both adults and children. The panels consisting of children included *Panel 2*: 17 healthy elementary school students (5 males and 12 females, ages 10-12 years); *Panel 3*: 19 healthy high school students (7 males and 12 females, ages 13-17 years); *Panel 6*: 13 young asthmatics (7 males and 6 females, ages 11-16 years).

An initial calibration test was conducted, followed by a training session. Finally, a field study that involved the subjects collecting their own heart rate and diary data was conducted. During the calibration tests, ventilation rate (VR), breathing rate, and heart rate (HR) were measured simultaneously at each exercise level. From the calibration data an equation was developed using linear regression analysis to predict VR from measured HR.

In the field study, each subject recorded in diaries their daily activities, change in locations (indoors, outdoors, or in a vehicle), self-estimated breathing rates during each

activity/location, and time spent at each activity/location. Healthy subjects recorded their HR once every 60 seconds using a Heart Watch, an automated system consisting of a transmitter and receiver worn on the body. Asthmatic subjects recorded their diary information once every hour. Subjective breathing rates were defined as slow (walking at their normal pace), medium (faster than normal walking), and fast (running or similarly strenuous exercise). Table 7-1 presents the calibration and field protocols for self-monitoring of activities for each subject panel.

Table 7-2 presents the mean, 99th percentile, and mean VR at each subjective activity level (slow, medium, fast). The mean and 99th percentile VR were derived from all HR recordings that appeared to be valid, without considering the diary data. Each of the three activity levels was determined from both the concurrent diary data and HR recordings by direct calculation or regression. The authors reported that the diary data showed that on a typical day, most individuals spent most of their time indoors at slow activity level. During slow activity, asthmatic subjects had higher VRs than healthy subjects (Table 7-2). The authors also reported that in every panel the predicted VR correlated significantly with the subjective estimates of activity levels.

A limitation of this study is that calibration data may overestimate the predictive power of HR during actual field monitoring. The wide variety of exercises in everyday activities may result in greater variation of the VR-HR relationship than was calibrated. Another limitation is the small sample size of each subpopulation surveyed. An advantage of this study is that diary data can provide rough estimates of ventilation patterns which are useful in exposure assessments. Another advantage is that inhalation rates were presented for both healthy and asthmatic children.

7.2.2 Spier et al., 1992

Spier et al. (1992) investigated the activity patterns of 17 elementary school students (10-12 years old) and 19 high school students (13-17 years old) in suburban Los Angeles from late September to October (oxidant pollution season). Calibration tests were conducted in supervised outdoor exercise sessions. The exercise sessions consisted of 5 minutes each of rest, slow walking, jogging, and fast walking. HR and VR were measured during the last 2 minutes of each exercise. Individual VR and HR relationships for each individual were determined by fitting a regression line to HR values and log VR values. Each subject recorded their daily activities,

change in location, and breathing rates in diaries for 3 consecutive days. Self-estimated breathing rates were recorded as slow (slow walking), medium (walking faster than normal), and fast (running). HR was recorded once per minute during the 3 days using a Heart Watch. VR values for each self-estimated breathing rate and activity type were estimated from the HR recordings by employing the VR and HR equation obtained from the calibration tests.

The data presented in Table 7-3 represent HR distribution patterns and corresponding predicted VR for each age group during hours spent awake. At the same self-reported activity levels for both age groups, inhalation rates were higher for outdoor activities than for indoor activities. The total number of hours spent indoors was higher for high school students (21.2 hours) than for elementary school students (19.6 hours). The converse was true for outdoor activities: 2.7 hours for high school students and 4.4 hours for elementary school students (Table 7-4). Based on the data presented in Tables 7-3 and 7-4, the average activity-specific inhalation rates for elementary school students (10-12 years old) and high school students (13-17 years old) were calculated and are presented in Table 7-5. For elementary school students, the average daily inhalation rates (based on indoor and outdoor locations) are 15.8 m^3/day for light activities, 4.6 m^3/day for moderate activities, and 1.0 m^3/day for heavy activities. For high school students the daily inhalation rates for light, moderate, and heavy activities are estimated to be 16.4 m^3/day, 3.0 m^3/day, and 0.6 m^3/day, respectively (Table 7-5).

A limitation of this study is the small sample size. The results may not be representative of all children in these age groups. Another limitation is that the accuracy of the self-estimated breathing rates reported by younger age groups is uncertain. This may affect the validity of the data set generated. An advantage of this study is that inhalation rates were determined for children and adolescents. These data are useful in estimating exposure for the younger population.

7.2.3 Adams, 1993

Adams (1993) conducted research to accomplish two main objectives: (1) identification of mean and ranges of inhalation rates for various age/gender cohorts and specific activities, and (2) derivation of simple linear and multiple regression equations that could be used to predict inhalation rates through other measured variables: breathing frequency and oxygen consumption. A total of 160 subjects participated in the primary study. For children, there were two age-

dependent groups: children 6 to 12.9 years old and adolescents 13 to18.9 years old. An additional 40 children from 6 to 12 years old and 12 young children from 3 to 5 years old were identified as subjects for pilot testing purposes.

Resting protocols conducted in the laboratory for all age groups consisted of three phases (25 minutes each) of lying, sitting, and standing. The phases were categorized as resting and sedentary activities. Two active protocols— moderate (walking) and heavy (jogging/ running) phases— were performed on a treadmill over a progressive continuum of intensity levels made up of 6-minute intervals at three speeds ranging from slow to moderately fast. All protocols involved measuring ventilation rate (VR), heart rate (HR), breathing frequency, and oxygen consumption. Measurements were taken in the last 5 minutes of each phase of the resting protocol and the last 3 minutes of the 6-minute intervals at each speed designated in the active protocols.

In the field, all children completed spontaneous play protocols; the older adolescent population (16-18 years) completed car driving and riding, car maintenance (males), and housework (females) protocols.

During all activities in either the laboratory or field protocols, VR for the children's group revealed no significant gender differences. Therefore, VR data presented in Appendix Tables 7A-1 and 7A-2 were categorized by activity type (lying, sitting, standing, walking, and running) for young children and children without regard to gender. These categorized data from the appendix tables are summarized as inhalation rates in Tables 7-6 and 7-7. The laboratory protocols are shown in Table 7-6. Table 7-7 presents the mean inhalation rates by group and for moderate activity levels in field protocols. Data were not provided for the light and sedentary activities because the group did not perform for this protocol or the number of subjects was too small for appropriate comparisons. Accurate predictions of inhalation rates across all population groups and activity types were obtained by including body surface area (BSA), HR, and breathing frequency in multiple regression analysis (Adams, 1993). Adams (1993) calculated BSA from measured height and weight using the equation:

$$BSA = Height^{(0.425)} \times Weight^{(0.425)} \times 71.84 \qquad (7\text{-}1)$$

A limitation associated with this study is that the population does not represent the general U.S. population. Also, the classification of activity types (i.e., laboratory and field protocols) into activity levels may bias the inhalation rates obtained for various age/gender cohorts. The estimated rates were based on short-term data and may not reflect long-term patterns.

7.2.4 Layton, 1993

Layton (1993) presented a new method for estimating metabolically consistent inhalation rates for use in quantitative dose assessments of airborne radionuclides. Generally, the approach for estimating the breathing rate for a specified time frame was to calculate a time-weighted-average of ventilation rates associated with physical activities of varying durations. However, in this study, breathing rates were calculated on the basis of oxygen consumption associated with energy expenditures for short (hours) and long (weeks and months) periods of time, using the following general equation to calculate energy-dependent inhalation rates:

$$V_E = E \times H \times VQ \qquad (7\text{-}2)$$

where:

V_E = ventilation rate (L/min or m^3/hr);

E = energy expenditure rate; [kilojoules/minute (KJ/min) or megajoules/hour (MJ/hr)];

H = volume of oxygen [at standard temperature and pressure, dry air consumed in the production of 1 KJ of energy expended (L/KJ or m^3/MJ)]; and

VQ = ventilatory equivalent (ratio of minute volume (L/min) to oxygen uptake (L/min)); unitless.

Layton used two alternative approaches to estimate daily chronic (long term) inhalation rates for different age/gender cohorts of the U.S. population using this methodology.

7.2.4.1. *First Approach*

Inhalation rates were estimated by multiplying average daily food energy intakes for different age/gender cohorts, volume of oxygen (H), and ventilatory equivalent (VQ), as shown in the equation above. The average food energy intake data (Table 7-8) are based on approximately 30,000 individuals and were obtained from the USDA 1977-78 Nationwide Food Consumption Survey (USDA-NFCS). The food energy intakes were adjusted upwards by a constant factor of 1.2 for all individuals 9 years and older. This factor compensated for a consistent bias in USDA-NFCS that was attributed to under-reporting of the foods consumed or the methods used to ascertain dietary intakes. Layton used a weighted average oxygen uptake of 0.05 L O_2/KJ which was determined from data reported in the 1977-78 USDA-NFCS and the second National Health and Nutrition Examination Survey (NHANES II). The survey sample for NHANES II was approximately 20,000 participants. A VQ of 27 used in the calculations was calculated as the geometric mean of VQ data that were obtained from several studies.

The inhalation rate estimation techniques are shown in footnote (a) of Table 7-9. Table 7-9 presents the daily inhalation rate for each age/gender cohort. The highest daily inhalation rates were 10 m^3/day for children between the ages of 6 and 8 years, 17 m^3/day for males between 15 and 18 years, and 13 m^3/day for females between 9 and 11 years. Inhalation rates were also calculated for active and inactive periods for the various age/gender cohorts.

The inhalation rate for inactive periods was estimated by multiplying the basal metabolic rate (BMR) times H times VQ. BMR was defined as "the minimum amount of energy required to support basic cellular respiration while at rest and not actively digesting food" (Layton, 1993). The inhalation rate for active periods was calculated by multiplying the inactive inhalation rate by the ratio of the rate of energy expenditure during active hours to the estimated BMR. This ratio is presented as F in Table 7-9. These data for active and inactive inhalation rates are also presented in Table 7-9. For children, inactive and active inhalation rates ranged between 2.35 and 5.95 m^3/day and 6.35 to 13.09 m^3/day, respectively.

7.2.4.2. *Second Approach*

Inhalation rates were calculated as the product of the BMR of the population cohorts, the ratio of total daily energy expenditure to daily BMR, H, and VQ. The BMR data obtained from the literature were statistically analyzed, and regression equations were developed to predict

BMR from body weights of various age/gender cohorts. The statistical data used to develop the regression equations are presented in Appendix Table 7A-3. The data obtained from the second approach are presented in Table 7-10. Inhalation rates for children (6 months - 10 years) ranged from 7.3 to 9.3 m^3/day for male and 5.6 to 8.6 m^3/day for female children; for older children (10 to 18 years), inhalation rates were 15 m^3/day for males and 12 m^3/day for females. These rates are similar to the daily inhalation rates obtained using the first approach. Also, the inactive inhalation rates obtained from the first approach are lower than the inhalation rates obtained using the second approach. This may be attributed to the BMR multiplier employed in the equation of the second approach to calculate inhalation rates.

Inhalation rates were also obtained for short-term exposures for various age/gender cohorts and five energy-expenditure categories (rest, sedentary, light, moderate, and heavy). BMRs were multiplied by the product of the metabolic equivalent, H, and VQ. The data obtained for short term exposures are presented in Table 7-11.

This study obtains similar results using three different approaches. The major strengths of this study are that it estimates inhalation rates in different age groups and that the populations are large. Explanations for differences in results due to metabolic measurements, reported diet, or activity patterns are supported by observations reported by other investigators in other studies. Major limitations of this study are (1) the estimated activity pattern levels are somewhat subjective; (2) the explanation that activity pattern differences are responsible for the lower level obtained with the metabolic approach (25 %) compared to the activity pattern approach is not well supported by the data; and (3) different populations were used in each approach, which may have introduced error.

7.2.5 Rusconi et al., 1994

Rusconi et al. (1994) examined a large number of infants and children in order to determine the reference values for respiratory rate in children aged 15 days to 3 years. Previous discrepancies in methodologies and results, and lack of age-related reference values for the first years of life prompted the investigators to obtain normal reference values for respiratory rate from a sufficient number of subjects. They assessed 618 infants and children (336 males and 282 females) aged 15 days to 3 years old who did not have respiratory infections or any severe

disease. Of the 618, a total of 309 were in good health and in day care centers, while the remaining 309 were seen in hospitals or outpatients.

Respiratory rates were recorded twice, 30 to 60 minutes apart, listening to breath sounds for 60 seconds with a stethoscope, when the child was awake and calm and when the child was sleeping quietly (sleep not associated with any spontaneous movement, including eye movements or vocalizations) (Table 7-12). The children were assessed for one year in order to determine the repeatability of the recordings, to compare respiratory rate counts obtained by stethoscope and by observation, and to construct reference percentile curves by age in a large number of subjects.

The authors plotted the differences between respiratory rate counts determined by stethoscope at 30- to 60-minute intervals against their mean count in waking and sleeping subjects. The standard deviation of the differences between the two counts was 2.5 and 1.7 breaths/minute, respectively, for waking and sleeping children. This standard deviation yielded 95% repeatability coefficients of 4.9 breaths when the infants and children were awake and 3.3 breaths when they were asleep.

In both waking and sleeping states, the respiratory rate counts determined by stethoscope were found to be higher than those obtained by observation. The mean difference was 2.6 and 1.8 breaths per minute, respectively, in waking and sleeping states. The mean respiratory rate counts were significantly higher in infants and children at all ages when awake and calm than when asleep. A decrease in respiratory rate with increasing age was seen in waking and sleeping infants and children. A scatter diagram of respiratory rate counts by age in waking and sleeping subjects showed that the pattern of respiratory rate decline with age was similar in both states, but it was much faster in the first few months of life. The authors constructed centile curves by first log-transforming the data and then applying a second degree polynormal curve, which allowed excellent fitting to observed data. Figures 7-1 and 7-2 show smoothed percentiles by age in waking and sleeping subjects, respectively.

The authors suggested that the differences between the reported respiratory rates in healthy infants and children might be due to various factors, including the number of infants studied, the period of time of counting, the method of counting, and the state of the infant. The variability of respiratory rate among subjects was higher in the first few months of life, which may be attributable to biological events that occur during these months, such as maturation of the

neurologic control of breathing and changes in lung and chest wall compliance and lung volumes.

An advantage of this study is that it provides distribution data for respiratory rate for children from infancy (less than 2 months) to 36 months old. These data are not U.S. data; however, U.S. distributions were not available.

7.2.6 Lordo et al., 2006

Lordo et al. (2006), under direction from EPA's National Center for Environmental Assessment (NCEA), conducted a study to ascertain ventilation rates for children and adults. Specifically, they sought to improve upon the methodology used by Layton (1993) and other studies that relied upon the ventilatory equivalent (VQ) and a linear relationship between oxygen consumption and fitness rate. The authors used a revised approach, developed by EPA's National Exposure Research Laboratory (NERL), in which an individual's ventilation rate is derived from his or her oxygen consumption rate. Lordo et al. apply this revised approach using weight data from the 1999-2002 NHANES and metabolic equivalents (METS) data from EPA's Consolidated Human Activity Database (CHAD).

NHANES provided age, gender, and body weight data for 19,022 individuals from throughout the United States. From these data, basal metabolic rate (BMR) was estimated using an age-specific linear equation used in Appendix 5A the *Exposure Factors Handbook* (EPA, 1997), and in several other studies and reference works.

The CHAD database is a compilation of several databases of human activity patterns. Lordo et al. used one of these studies, the National Human Activity Pattern Survey (NHAPS), as its source for METS values because it was more representative of the entire United States population than the other studies in the database. The NHAPS data set included activity data for 9,196 individuals, each of which provided 24 hours of activity pattern data using a diary-based questionnaire. While NHAPS was identified as the best available data source for activity patterns, there were some shortcomings in the quality of the data. Study respondents did not provide body weights; instead, body weights are simulated using statistical sampling. Also, the NHAPS data extracted from CHAD could not be corrected to account for non-random sampling of study participants and survey days.

NHANES and NHAPS data were grouped into age categories using the standardized age categories presented elsewhere in this Handbook, with the exception that children under the age of one year were placed into a single category to preserve an adequate sample size within the category. For each NHANES participant, a "simulated" 24-hour activity pattern was generated by randomly sampling activity patterns from the set of NHAPS participants with the same gender and age category as the NHANES participant. Twenty such patterns were selected at random for each NHANES participant, resulting in 480 hours of simulated activity data for each NHANES participant. The data were then scaled down to a 24-hour time frame to yield an average 24-hour activity pattern for each of the 19,022 NHANES individuals.

Each activity was assigned a METS value based on statistical sampling of the statistical distribution assigned by CHAD to each activity code. For most codes, these distributions were not age-dependent, but age was a factor for some activities for which intensity level varies strongly with age. Using statistical software, equations for METS based on normal, lognormal, exponential, triangular, and uniform distributions were generated as needed for the various activity codes. The METS values were then translated into energy expenditure (*EE*) by multiplying the METS by the basal metabolic rate (BMR), which was calculated as a linear function of body weight. The oxygen consumption rate VO_2 was calculated by multiplying *EE* by *H*, the volume of oxygen consumed per unit of energy. VO_2 was calculated both as volume per time and as volume per time per unit body weight.

The ventilation rate for each activity within the 24-hour simulated activity pattern for each individual was estimated as a function of VO_2, body weight, age, and gender. Following this, average ventilation rate was calculated for each individual for the entire 24-hour period, as well as for four separate classes of activities based on METS value (sedentary/passive (METS less than or equal to 1.5), light intensity (METS greater than 1.5 and less than or equal to 3.0), moderate intensity (METS greater than 3.0 and less than or equal to 6.0), and high intensity (METS greater than 6.0)). Data for individuals were then used to generate summary tables based on gender and age categories.

Data from this study are presented in Tables 7-13 through 7-19. Tables 7-13 and 7-14 present, for male and female subjects respectively, summary statistics for daily average ventilation rate by age category on a volumetric (L/min) and weight adjusted (L/min-kg) basis. Tables 7-15 and 7-16 present, for male and female subjects respectively, mean ventilation rates

by age category on a volumetric (L/min) and weight adjusted (L/min-kg) basis for the five different activity level ranges described above. They also present the *daily* ventilation rates (L/day and L/day-kg) for each activity level and age group and the mean number of hours spent engaged in each of these activities by subjects in each age group.

Tables 7-17 and 7-18 present the same data as Tables 7-13 and 7-14, respectively, but in units of m^3/day and m^3/day-kg rather than L/min and L/min-kg. Table 7-19 presents the number of hours spent at each activity level by males and females; the data are similar to the activity data presented in Tables 7-15 and 7-16 but offer percentile data in addition to the mean.

7.3 RECOMMENDATIONS

The recommended inhalation rates for children are based on the EPA-sponsored research of Lordo et al. (2006), which is the most recent and geographically broad of the studies described in this chapter. The study represents an improvement upon studies previously used for recommended inhalation rates in this Handbook in that it uses a large data set that is representative of the United States as a whole and considers the correlation between body weight and inhalation rate. The confidence level for the studies considered in this chapter are presented in Table 7-20.

Table 7-21 summarizes the short-and long-term inhalation rates for the standard age categories used in this Handbook.

7.4 REFERENCES FOR CHAPTER 7

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Table 7-1. Calibration And Field Protocols For Self-monitoring of Activities Grouped by Subject Panels

Panel	Calibration Protocol	Field Protocol
Panel 2 - Healthy Elementary School Students - 5 male, 12 female, age 10-12	Outdoor exercises each consisted of 20 minute rest, slow walking, jogging and fast walking	Saturday, Sunday and Monday (school day) in early autumn; HR recordings and activity diary during waking hours and during sleep.
Panel 3 - Healthy High School Students - 7 male, 12 female, age 13-17	Outdoor exercises each consisted of 20 minute rest, slow walking, jogging and fast walking	Same as Panel 2, however, no HR recordings during sleep for most subjects.
Panel 6 - Young Asthmatics - 7 male, 6 female, age 11-16	Laboratory exercise tests on bicycles and treadmills	Summer monitoring for 2 successive weeks, including 2 controlled exposure studies with few or no observable respiratory effects.

Source: Linn et al., 1992

Table 7-2. Subject Panel Inhalation Rates by Mean VR, Upper Percentiles, And Self-estimated Breathing Rates

		Inhalation Rates (m^3/hr)				
	N[a]	Mean VR (m^3/hr)	99th Percentile VR	Mean VR at Activity Levels (m^3/hr)[b]		
Panel				Slow	Medium	Fast
Healthy						
2 - Elementary School Students	17	0.90	1.98	0.84	0.96	1.14
3 - High School Students	19	0.84	2.22	0.78	1.14	1.62
Asthmatics						
6 - Elementary and High School Students	13	1.20	2.40	1.20	1.20	1.50

[a]Number of individuals in each survey panel.
[b]Some subjects did not report medium and/or fast activity. Group means were calculated from individual means (i.e., give equal weight to each individual who recorded any time at the indicated activity level).

Source: Linn et al., 1992

Table 7-3. Distribution of Predicted Intake Rates by Location And Activity Levels For Elementary And High School Students

Age (yrs)	Student	Location	Activity Level	% Recorded Time[a]	Inhalation Rates (m^3/hr)			
					Mean ± SD	Percentile Rankings[b]		
						1st	50th	99.9th
10-12	ELc (n^d=17)	Indoors	slow	49.6	0.84 ± 0.36	0.18	0.78	2.34
			medium	23.6	0.96 ± 0.36	0.24	0.84	2.58
			fast	2.4	1.02 ± 0.60	0.24	0.84	3.42
		Outdoors	slow	8.9	0.96 ± 0.54	0.36	0.78	4.32
			medium	11.2	1.08 ± 0.48	0.24	0.96	3.36
			fast	4.3	1.14 ± 0.60	0.48	0.96	3.60
13-17	HS[c] (n^d=19)	Indoors	slow	70.7	0.78 ± 0.36	0.30	0.72	3.24
			medium	10.9	0.96 ± 0.42	0.42	0.84	4.02
			fast	1.4	1.26 ± 0.66	0.54	1.08	6.84[c]
		Outdoors	slow	8.2	0.96 ± 0.48	0.42	0.90	5.28
			medium	7.4	1.26 ± 0.78	0.48	1.08	5.70
			fast	1.4	1.44 ± 1.08	0.48	1.02	5.94

[a]Recorded time averaged about 23 hr per elementary school student and 33 hr. per high school student, over 72-hr. periods.
[b]Geometric means closely approximated 50th percentiles; geometric standard deviations were 1.2-1.3 for HR, 1.5-1.8 for VR.
[c]EL = elementary school student; HS = high school student.
[d]N = number of students that participated in survey.
[e]Highest single value.

Source: Spier et al., 1992

Table 7-4. Average Hours Spent Per Day in a Given Location and Activity Level For Elementary and High School Students

Students	Location	Activity Level			Total Time Spent (hrs/day)
		Slow	Medium	Fast	
Elementary school, ages 10-12 years (N=17)	Indoors	16.3	2.9	0.4	19.6
	Outdoors	2.2	1.7	0.5	4.4
High school, ages 13-17 years (N=19)	Indoors	19.5	1.5	0.2	21.2
	Outdoors	1.2	1.3	0.2	2.7

Source: Spier et al., 1992

Table 7-5. Distribution Patterns of Daily Inhalation Rates For Elementary (EL) And High School (HS) Students Grouped by Activity Level[a]

Students	Location	Activity type[b]	Mean IR[c] (m^3/day)	Percentile Rankings		
				1st	50th	99.9th
Elementary school, ages 10-12 years (N=17)	Indoors	Light	13.7	2.9	12.7	38.1
		Moderate	2.8	0.7	2.4	7.5
		Heavy	0.4	0.1	0.3	1.4
	Outdoors	Light	2.1	0.8	1.7	9.5
		Moderate	1.8	0.4	1.6	5.7
		Heavy	0.6	0.2	0.5	1.8
High school, ages 13-17 years (N=19)	Indoors	Light	15.2	5.9	14.0	63.2
		Moderate	1.4	0.6	1.3	6.0
		Heavy	0.3	0.1	0.2	1.4
	Outdoors	Light	1.2	0.5	1.1	6.3
		Moderate	1.6	0.6	1.4	7.4
		Heavy	0.3	0.1	0.2	1.2

[a] Generated using data from Tables 7-3 and 7-4

[b] For this report, activity type presented in Table 7-2 was redefined as light activity for slow, moderate activity for medium, and heavy activity for fast.

[c] Daily inhalation rate (IR) was calculated by multiplying the hours spent at each activity level (Table 7-4) by the corresponding inhalation rate (Table 7-3).

Source: Adapted from Spier et al., 1992

Table 7-6. Summary of Average Inhalation Rates (m^3/hr) by Age Group And Activity Levels for Laboratory Protocols

Age Group	Activity Level				
	Resting[a]	**Sedentary[b]**	**Light[c]**	**Moderate[d]**	**Heavy[e]**
Young Children (3-5.9 years) Average inhalation rate (m^3/hr) (N=12, gender not specified)	0.37	0.40	0.65	DNP[f]	DNP[f]
Children (6-12.9 years) Average inhalation rate (m^3/hr) (N=40, 20 male and 20 female)	0.45	0.47	0.95	1.74	2.23

[a]Resting defined as lying (see Appendix Table 7A-1 for original data).
[b]Sedentary defined as sitting and standing (see Appendix Table 7A-1 for original data).
[c]Light defined as walking at speed level 1.5 - 3.0 mph (see Appendix Table 7A-1 for original data).
[d]Moderate defined as fast walking (3.3 - 4.0 mph) and slow running (3.5 - 4.0 mph) (see Appendix Table 7A-1 for original data).
[e]Heavy defined as fast running (4.5 - 6.0 mph) (see Appendix Table 7A-1 for original data).
[f]DNP. Group did not perform this protocol or N was too small for appropriate mean comparisons. All young children did not run.

Source: Adapted from Adams, 1993

Table 7-7. Summary of Average Inhalation Rates (m^3/hr) by Age Group And Activity Levels in Field Protocols

Age Group	Moderate Activity[a]
Young Children (3-5.9 years) Average inhalation rate (m^3/hr) (N=12, gender not specified)	0.68
Children (6-12.9 years) Average inhalation rate (m^3/hr) (N=40, 20 male and 20 female)	1.07

[a] Moderate activity was defined as mowing (males); wood working (males); yard work (males); and play (children) (see Appendix Table 7A-2 for original data).

Source: Adams, 1993.

Table 7-8. Comparisons of Estimated Basal Metabolic Rates (BMR) With Average Food-energy Intakes (EFD) For Individuals Sampled in The 1977-78 NFCS

Cohort/Age (years)	Body Weight kg	BMR[a]		Energy Intake (EFD)		Ratio EFD/BMR
		MJ d^{-1}	kcal d^{-1}	MJ d^{-1}	kcal d^{-1}	
Children						
< 1	7.6	1.74	416	3.32	793	1.90
1 to 2	13	3.08	734	5.07	1209	1.65
3 to 5	18	3.69	881	6.14	1466	1.66
6 to 8	26	4.41	1053	7.43	1774	1.68
Males						
9 to 11	36	5.42	1293	8.55	2040	1.58
12 to 14	50	6.45	1540	9.54	2276	1.48
15 to 18	66	7.64	1823	10.8	2568	1.41
Females						
9 to 11	36	4.91	1173	7.75	1849	1.58
12 to 14	49	5.64	1347	7.72	1842	1.37
15 to 18	56	6.03	1440	7.32	1748	1.21

[a]Calculated from the appropriate age and gender-based BMR equations given in Appendix Table 7A-3.
MJ d^{-1} - mega joules/day
kcal d^{-1} - kilo calories/day
EFD= Food energy intake (Kcal/day) or (MJ/day)

Source: Layton, 1993

Table 7-9. Daily Inhalation Rates Calculated From Food-energy Intakes

Cohort/Age (years)	L	Daily Inhalation Rate[a] (m^3/day)	Sleep (hours)	MET Value		Inhalation Rates	
				A[b]	F[c]	Inactive[d] (m^3/day)	Active[e] (m^3/day)
Children							
<1	1	4.5	11	1.9	2.7	2.35	6.35
1 - 2	2	6.8	11	1.6	2.2	4.16	9.15
3 - 5	3	8.3	10	1.7	2.2	4.98	10.96
6 - 8	3	10	10	1.7	2.2	5.95	13.09
Males							
9 - 11	3	14	9	1.9	2.5	7.32	18.3
12 - 14	3	15	9	1.8	2.2	8.71	19.16
15 - 18	4	17	8	1.7	2.1	10.31	21.65
Females							
9 - 11	3	13	9	1.9	2.5	6.63	16.58
12 - 14	3	12	9	1.6	2.0	7.61	15.22
15 - 18	4	12	8	1.5	1.7	8.14	13.84

[a]Daily inhalation rate was calculated by multiplying the EFD values (see Table 7-8) by H × VQ for subjects under 9 years of age and by 1.2 × H × VQ (for subjects 9 years of age and older (see text for explanation), where EFD = Food energy intake (Kcal/day) or (MJ/day), H = Oxygen uptake = 0.05 LO_2/KJ or 0.21 LO_2/Kcal, and VQ = Ventilation equivalent = 27 = geometric mean of VQs (unitless).

[b]For individuals 9 years of age and older, A was calculated by multiplying the ratio for EFD/BMR (unitless) (Table 7-8) by the factor 1.2 (see text for explanation).

[c]F = (24 × A - S)/(24 - S) (unitless), ratio of the rate of energy expenditure during active hours to the estimated BMR (unitless), where S = Number of hours spent sleeping each day.

[d]Inhalation rate for inactive periods was calculated as BMR × H × VQ, and for active periods by multiplying the inactive inhalation rate by F (see footnote c); BMR values are from Table 7-8, where BMR = basal metabolic rate (MJ/day) or (kg/hr).

L = number of years for each age cohort.
MET = metabolic equivalent.

Source: Layton, 1993

Table 7-10. Daily Inhalation Rates Obtained From The Ratios Of Total Energy Expenditure to Basal Metabolic Rate (BMR)

Gender/Age (yrs)	Body Weight[a] (kg)	BMR[b] (MJ/day)	VQ	A[c]	H (m^3O_2/MJ)	Inhalation Rate, V_E (m^3/day)[d]
Male						
0.5 - <3	14	3.4	27	1.6	0.05	7.3
3 - <10	23	4.3	27	1.6	0.05	9.3
10 - <18	53	6.7	27	1.7	0.05	15
Female						
0.5 - <3	11	2.6	27	1.6	0.05	5.6
3 - <10	23	4.0	27	1.6	0.05	8.6
10 - <18	50	5.7	27	1.5	0.05	12

[a]Body weight was based on the average weights for age/gender cohorts in the U.S. population.
[b]The BMRs (basal metabolic rate) are calculated using the respective body weights and BMR equations (see Appendix Table 7A-3).
[c]The values of the BMR multiplier (EFD/BMR) for those 18 years and older were derived from the Basiotis et al. (1989) study: Male = 1.59, Female = 1.38. For males and females under 10 years old, the mean BMR multiplier used was 1.6. For males and females aged 10 to < 18 years, the mean values for A given in Table 7-9 for 12-14 years and 15-18 years, age brackets for males and females were used: male = 1.7 and female = 1.5.
[d]Inhalation rate = BMR x A x H x VQ; VQ = ventilation equivalent and H = oxygen uptake.

Source: Layton, 1993

Table 7-11. Inhalation Rates For Short-term Exposures

Gender/Age (yrs)	Weight (kg)[a]	BMR[b] (MJ/day)	Activity Type				
			Rest	Sedentary	Light	Moderate	Heavy
			MET (BMR Multiplier)				
			1	1.2	2[c]	4[d]	10[e]
			Inhalation Rate (m^3/hr)[f,g]				
Male							
0.5 - <3	14	3.40	0.19	0.23	0.38	0.78	1.92
3 - <10	23	4.30	0.24	0.29	0.49	0.96	2.40
10 - <18	53	6.70	0.38	0.45	0.78	1.50	3.78
Female							
0.5 - <3	11	2.60	0.14	0.17	0.29	0.60	1.44
3 - <10	23	4.00	0.23	0.27	0.45	0.90	2.28
10 - <18	50	5.70	0.32	0.38	0.66	1.26	3.18

[a]Body weights were based on average weights for age/gender cohorts of the U.S. population
[b]The BMRs for the age/gender cohorts were calculated using the respective body weights and the BMR equations (Appendix Table 7A-3).
[c]Range = 1.5 - 2.5.
[d]Range = 3 - 5.
[e]Range = >5 - 20.
[f]The inhalation rate was calculated as IR = BMR (MJ/day) × H (0.05 L/KJ) × MET × VQ (27) × (d/24 hrs)
[g]Original data were presented in L/min. Conversion to m^3/hr was obtained as follows: $\frac{60\ \text{min}}{\text{hr}} \times \frac{\text{m}^3}{1000\text{L}} \times \frac{\text{L}}{\text{min}}$

Source: Layton, 1993

Table 7-12. Mean, Median, and SD of Respiratory Rate According to Waking or Sleeping in 618 Infants and Children Grouped in Classes of Age

Age (months)	N	Respiratory Rate (breaths/min)			
		Waking		Sleeping	
		Mean ± SD	Median	Mean ± SD	Median
<2	104	48.0 ± 9.1	47	39.8 ± 8.7	39
2 to <6	106	44.1 ± 9.9	42	33.4 ± 7.0	32
6 to <12	126	39.1 ± 8.5	38	29.6 ± 7.0	28
12 to <18	77	34.5 ± 5.8	34	27.2 ± 5.6	26
18 to <24	65	32.0 ± 4.8	32	25.3 ± 4.6	24
24 to <30	79	30.0 ± 6.2	30	23.1 ± 4.6	23
30 to 36	61	27.1 ± 4.1	28	21.5 ± 3.7	21

Source: Rusconi et al., 1994

Figure 7-1. 5th, 10th, 25th, 50th, 75th, 90th, and 95th Smoothed Centiles by Age in Awake Subjects (RR = respiratory rate). Source: Rusconi et al., 1994

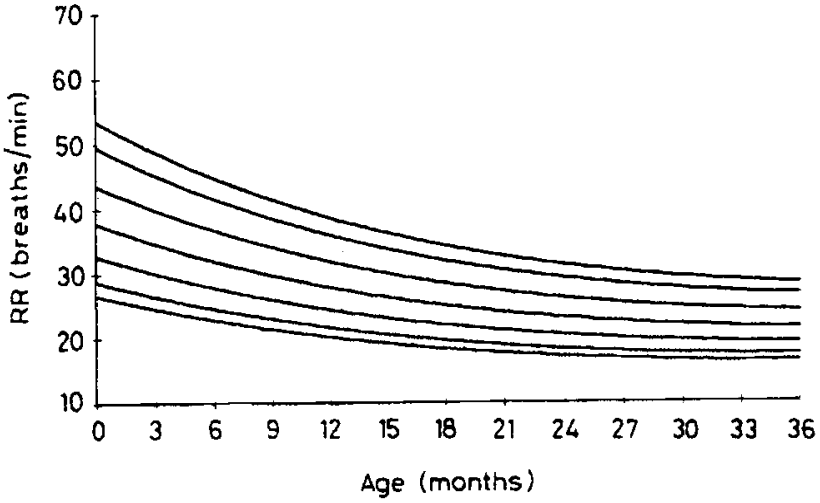

Figure 7-2. 5th, 10th, 25th, 50th, 75th, 90th, and 95th Smoothed Centiles by Age in Asleep Subjects (RR = respiratory rate). Source: Rusconi et al., 1994

Table 7-13. Descriptive Statistics for Daily Average Ventilation Rate (L/min) in Males, by Age Category

Age Category	N	Daily Average Ventilation Rate, Unadjusted for Body Weight ($\dot{V}_E$; L/min)									Daily Average Ventilation Rate, Adjusted for Body Weight ($\dot{V}_E$/*BW*: L/min-kg)								
		Mean	Percentiles							Maximum	Mean	Percentiles							Maximum
			5th	10th	25th	50th	75th	90th	95th			5th	10th	25th	50th	75th	90th	95th	
Birth to <1 year	419	6.08	3.32	3.96	4.97	6.04	7.24	8.28	8.81	11.84	0.759	0.634	0.655	0.696	0.754	0.808	0.872	0.898	1.025
1 year	308	9.37	6.76	7.23	8.09	9.11	10.43	11.82	12.43	16.83	0.823	0.669	0.706	0.756	0.813	0.876	0.949	1.027	1.201
2 years	261	9.19	6.56	7.09	7.94	9.16	10.07	11.30	12.30	19.56	0.658	0.542	0.567	0.606	0.655	0.704	0.757	0.782	0.944
3 to <6 years	540	8.78	7.24	7.55	7.91	8.74	9.47	10.16	10.70	13.56	0.488	0.363	0.386	0.426	0.481	0.540	0.606	0.639	0.753
6 to <11 years	940	9.32	7.00	7.42	8.15	9.09	10.23	11.50	12.31	17.34	0.307	0.221	0.238	0.261	0.302	0.346	0.381	0.403	0.559
11 to <16 years	1337	10.64	7.92	8.41	9.22	10.27	11.68	13.57	14.73	19.82	0.198	0.144	0.153	0.171	0.192	0.220	0.252	0.267	0.351
16 to <21 years	1241	11.95	8.75	9.31	10.06	11.55	13.31	15.23	16.23	27.23	0.159	0.116	0.126	0.140	0.158	0.176	0.194	0.206	0.274

Individual daily averages are weighted by their 4-year sampling weights as assigned within NHANES 1999-2002 when calculating the statistics in this table. Ventilation rate was estimated using a multiple linear regression model.

Source: Lordo et al., 2006

Table 7-14. Descriptive Statistics for Daily Average Ventilation Rate (L/min) in Females, by Age Category

Age Category	N	Daily Average Ventilation Rate, Unadjusted for Body Weight ($\dot{V}_E$; L/min)									Daily Average Ventilation Rate, Adjusted for Body Weight ($\dot{V}_E/BW$: L/min-kg)								
		Mean	Percentiles							Maximum	Mean	Percentiles							Maximum
			5th	10th	25th	50th	75th	90th	95th			5th	10th	25th	50th	75th	90th	95th	
Birth to <1 year	415	5.92	3.36	3.81	4.75	5.84	6.79	8.09	8.79	18.23	0.793	0.634	0.673	0.720	0.782	0.863	0.922	0.961	1.112
1 year	245	9.24	6.31	7.03	7.81	9.05	10.17	12.12	12.93	17.20	0.831	0.677	0.703	0.765	0.818	0.901	0.976	1.017	1.200
2 years	255	8.85	6.19	6.99	7.90	8.75	9.69	10.82	11.36	15.98	0.663	0.569	0.583	0.618	0.664	0.703	0.740	0.767	0.857
3 to <6 years	543	8.45	6.86	7.21	7.78	8.35	9.04	9.74	10.37	13.71	0.480	0.335	0.372	0.414	0.475	0.533	0.614	0.636	0.775
6 to <11 years	894	8.62	6.94	7.19	7.65	8.30	9.32	10.51	11.35	14.46	0.297	0.194	0.214	0.248	0.296	0.339	0.381	0.404	0.519
11 to <16 years	1451	9.33	7.27	7.72	8.36	9.08	10.10	11.29	12.09	18.46	0.174	0.131	0.138	0.153	0.170	0.194	0.217	0.236	0.327
16 to <21 years	1182	9.44	6.85	7.37	8.18	9.17	10.43	11.89	12.70	20.91	0.148	0.110	0.117	0.132	0.144	0.163	0.186	0.197	0.248

Individual daily averages are weighted by their 4-year sampling weights as assigned within NHANES 1999-2002 when calculating the statistics in this table. Ventilation rate was estimated using a multiple linear regression model.

Source: Lordo et al., 2006

Table 7-15. Average Time Spent Per Day Performing Activities Within Specified Intensity Categories, and Average Ventilation Rates Associated With These Activity Categories, for Males According to Age Category

Age Category	# NHANES Participants Reporting Activity	Average Duration (hr/day) Spent at Activity	Ventilation Rate During This Activity[1]		Daily Ventilation Rate Associated With This Activity[2]	
			Unadjusted for Body Weight (L/min)	Adjusted for Body Weight (L/min-kg)	Unadjusted for Body Weight (L/day)	Adjusted for Body Weight (L/day-kg)
Sleep or nap (Activity ID = 14500)						
Birth to <1 year	419	13.5	3.08	0.385	2,499	311.8
1 year	308	12.6	4.50	0.395	3,405	298.9
2 years	261	12.1	4.61	0.330	3,334	239.1
3 to <6 years	540	11.2	4.36	0.243	2,928	162.9
6 to <11 years	940	10.2	4.61	0.151	2,814	92.5
11 to <16 years	1,337	9.4	5.26	0.098	2,958	54.9
16 to <21 years	1,241	8.7	5.31	0.071	2,769	36.9
21 to <31 years	701	8.4	4.73	0.058	2,368	29.0
31 to <41 years	728	8.1	5.16	0.061	2,496	29.4
41 to <51 years	753	7.9	5.65	0.065	2,676	30.9
51 to <61 years	627	8.0	5.78	0.066	2,757	31.7
61 to <71 years	678	8.3	5.98	0.069	2,979	34.5
71 to <81 years	496	8.5	6.07	0.075	3,098	38.1
81 years and older	255	9.2	5.97	0.080	3,309	44.3
Sedentary & Passive Activities (METS # 1.5 -- Includes Sleep or Nap)						
Birth to <1 year	419	15.0	3.18	0.397	2,858	355.9
1 year	308	14.3	4.62	0.406	3,958	347.5
2 years	261	14.6	4.79	0.343	4,206	301.7
3 to <6 years	540	14.1	4.58	0.255	3,886	216.0
6 to <11 years	940	13.5	4.87	0.160	3,949	130.2
11 to <16 years	1,337	13.8	5.64	0.105	4,692	87.1
16 to <21 years	1,241	13.2	5.76	0.077	4,575	61.1
21 to <31 years	701	12.4	5.11	0.062	3,807	46.6
31 to <41 years	728	12.3	5.57	0.066	4,117	48.6
41 to <51 years	753	12.3	6.11	0.071	4,522	52.2
51 to <61 years	627	13.1	6.27	0.072	4,918	56.5
61 to <71 years	678	14.5	6.54	0.076	5,693	66.1
71 to <81 years	496	15.9	6.65	0.082	6,345	78.1
81 years and older	255	16.6	6.44	0.086	6,411	85.9

Age Category	# NHANES Participants Reporting Activity	Average Duration (hr/day) Spent at Activity	Ventilation Rate During This Activity[1]		Daily Ventilation Rate Associated With This Activity[2]	
			Unadjusted for Body Weight (L/min)	Adjusted for Body Weight (L/min-kg)	Unadjusted for Body Weight (L/day)	Adjusted for Body Weight (L/day-kg)
Light Intensity Activities (1.5 < METS # 3.0)						
Birth to <1 year	419	5.3	7.94	0.988	2,603	322.7
1 year	308	5.5	11.56	1.019	3,959	350.7
2 years	261	5.5	11.67	0.837	3,917	281.9
3 to <6 years	540	6.6	11.36	0.633	4,561	255.2
6 to <11 years	940	7.6	11.64	0.384	5,345	177.5
11 to <16 years	1,337	7.5	13.22	0.246	5,943	110.9
16 to <21 years	1,241	7.1	13.41	0.179	5,745	76.9
21 to <31 years	701	6.1	12.97	0.158	4,821	58.5
31 to <41 years	728	5.7	13.64	0.161	4,714	55.5
41 to <51 years	753	6.1	14.38	0.166	5,271	60.8
51 to <61 years	627	5.6	14.56	0.167	5,005	57.0
61 to <71 years	678	5.5	14.12	0.164	4,669	54.0
71 to <81 years	496	5.0	13.87	0.171	4,131	50.8
81 years and older	255	4.9	13.76	0.185	4,014	53.9
Moderate Intensity Activities (3.0 < METS # 6.0)						
Birth to <1 year	419	3.7	14.49	1.804	3,157	396.5
1 year	308	4.0	21.35	1.878	5,141	451.0
2 years	261	3.8	21.54	1.546	4,958	353.4
3 to <6 years	540	3.2	21.03	1.173	3,890	214.5
6 to <11 years	940	2.7	22.28	0.736	3,567	115.1
11 to <16 years	1,337	2.3	26.40	0.491	3,733	68.8
16 to <21 years	1,241	3.3	29.02	0.387	5,904	78.3
21 to <31 years	701	5.2	29.19	0.357	9,369	115.2
31 to <41 years	728	5.7	30.30	0.357	10,560	124.1
41 to <51 years	753	5.4	31.58	0.366	10,438	121.3
51 to <61 years	627	5.0	32.71	0.376	9,953	115.1
61 to <71 years	678	3.7	29.76	0.344	6,705	77.4
71 to <81 years	496	2.9	29.29	0.360	5,058	62.0
81 years and older	255	2.3	28.53	0.383	4,036	54.1

Age Category	# NHANES Participants Reporting Activity	Average Duration (hr/day) Spent at Activity	Ventilation Rate During This Activity[1]		Daily Ventilation Rate Associated With This Activity[2]	
			Unadjusted for Body Weight (L/min)	Adjusted for Body Weight (L/min-kg)	Unadjusted for Body Weight (L/day)	Adjusted for Body Weight (L/day-kg)
High Intensity (METS > 6.0)						
Birth to <1 year	183	0.2	27.47	3.477	325	41.2
1 year	164	0.3	40.25	3.523	799	68.3
2 years	162	0.1	40.45	2.889	242	17.4
3 to <6 years	263	0.3	39.04	2.167	639	34.3
6 to <11 years	637	0.3	43.62	1.410	851	28.2
11 to <16 years	1,111	0.4	50.82	0.950	1,154	21.9
16 to <21 years	968	0.4	53.17	0.711	1,275	16.9
21 to <31 years	546	0.3	53.91	0.660	1,041	12.8
31 to <41 years	567	0.4	54.27	0.644	1,183	14.1
41 to <51 years	487	0.3	57.31	0.655	1,124	12.7
51 to <61 years	452	0.4	58.42	0.675	1,441	16.5
61 to <71 years	490	0.4	54.13	0.624	1,158	13.3
71 to <81 years	343	0.4	52.46	0.646	1,181	14.6
81 years and older	168	0.3	53.31	0.716	1,052	13.9

[1] An individual's ventilation rate for the given activity category equals the weighted average of the individual's activity-specific ventilation rates for activities falling within the category, estimated using a multiple linear regression model, with weights corresponding to the number of minutes spent performing the activity. Numbers in these two columns represent averages, calculated across individuals in the specified age category, of these weighted averages. These are weighted averages, with the weights corresponding to the 4-year sampling weights assigned within NHANES 1999-2002.

[2] An individual's daily average ventilation rate equals the product of the individual's weighted average ventilation rate for the given activity category (L/min), estimated using a multiple linear regression model, and the number of minutes per day that the individual performs an activity within the category. Numbers in these two columns represent weighted averages across individuals in the specified age category, with the weights corresponding to the 4-year sampling weights assigned within NHANES 1999-2002.

Source: Lordo et al., 2006

Table 7-16. Average Time Spent Per Day Performing Activities Within Specified Intensity Categories, and Average Ventilation Rates Associated With These Activity Categories, for Females According to Age Category

Age Category	# NHANES Participants Reporting Activity	Average Duration (hr/day) Spent at Activity	Ventilation Rate During This Activity[1]		Daily Ventilation Rate Associated With This Activity[2]	
			Unadjusted for Body Weight (L/min)	Adjusted for Body Weight (L/min-kg)	Unadjusted for Body Weight (L/day)	Adjusted for Body Weight (L/day-kg)
Sleep or nap (Activity ID = 14500)						
Birth to <1 year	415	13.0	2.92	0.391	2,275	304.9
1 year	245	12.6	4.59	0.414	3,466	313.0
2 years	255	12.1	4.56	0.342	3,307	248.4
3 to <6 years	543	11.1	4.18	0.238	2,788	158.9
6 to <11 years	894	10.3	4.36	0.151	2,686	92.7
11 to <16 years	1,451	9.6	4.81	0.090	2,766	51.6
16 to <21 years	1,182	9.1	4.40	0.069	2,398	37.7
21 to <31 years	1,023	8.6	3.89	0.055	2,009	28.6
31 to <41 years	869	8.3	4.00	0.056	1,996	27.8
41 to <51 years	763	8.3	4.40	0.060	2,197	29.9
51 to <61 years	622	8.1	4.56	0.061	2,222	29.8
61 to <71 years	700	8.4	4.47	0.061	2,255	30.5
71 to <81 years	470	8.6	4.52	0.066	2,325	33.9
81 years and older	306	9.1	4.49	0.072	2,456	39.1
Sedentary & Passive Activities (METS # 1.5 -- Includes Sleep or Nap)						
Birth to <1 year	415	14.1	3.00	0.402	2,538	339.4
1 year	245	14.3	4.71	0.425	4,046	365.9
2 years	255	14.9	4.73	0.355	4,215	316.4
3 to <6 years	543	14.3	4.40	0.251	3,773	214.8
6 to <11 years	894	14.0	4.64	0.160	3,898	134.3
11 to <16 years	1,451	14.2	5.21	0.097	4,442	83.1
16 to <21 years	1,182	13.6	4.76	0.075	3,876	61.0
21 to <31 years	1,023	12.6	4.19	0.060	3,164	45.0
31 to <41 years	869	12.3	4.33	0.060	3,197	44.7
41 to <51 years	763	12.2	4.75	0.065	3,489	47.5
51 to <61 years	622	12.7	4.96	0.067	3,771	50.7
61 to <71 years	700	14.3	4.89	0.066	4,183	56.6
71 to <81 years	470	15.4	4.95	0.072	4,569	66.6
81 years and older	306	16.5	4.89	0.078	4,841	77.3

Table 7-16. Average Time Spent Per Day Performing Activities Within Specified Intensity Categories, and Average Ventilation Rates Associated With These Activity Categories, for Females According to Age Category (continued)

Age Category	# NHANES Participants Reporting Activity	Average Duration (hr/day) Spent at Activity	Ventilation Rate During This Activity[1]		Daily Ventilation Rate Associated With This Activity[2]	
			Unadjusted for Body Weight (L/min)	Adjusted for Body Weight (L/min-kg)	Unadjusted for Body Weight (L/day)	Adjusted for Body Weight (L/day-kg)
Light Intensity Activities (1.5 < METS # 3.0)						
Birth to <1 year	415	6.0	7.32	0.978	2,727	362.7
1 year	245	5.6	11.62	1.050	4,019	366.8
2 years	255	5.8	11.99	0.897	4,255	318.5
3 to <6 years	543	6.3	10.92	0.619	4,148	235.6
6 to <11 years	894	7.3	11.07	0.382	4,845	167.0
11 to <16 years	1,451	7.6	12.02	0.225	5,454	101.9
16 to <21 years	1,182	7.0	11.08	0.174	4,660	73.2
21 to <31 years	1,023	6.4	10.55	0.149	4,075	57.7
31 to <41 years	869	6.5	11.07	0.154	4,338	60.5
41 to <51 years	763	6.6	11.78	0.161	4,656	63.8
51 to <61 years	622	6.5	12.02	0.161	4,714	63.2
61 to <71 years	700	6.2	10.82	0.147	4,046	55.1
71 to <81 years	470	6.0	10.83	0.158	3,873	56.6
81 years and older	306	5.3	10.40	0.167	3,308	52.9
Moderate Intensity Activities (3.0 < METS # 6.0)						
Birth to <1 year	415	3.9	13.98	1.866	3,222	434.0
1 year	245	4.0	20.98	1.896	5,118	452.5
2 years	255	3.3	21.34	1.600	4,076	306.0
3 to <6 years	543	3.4	20.01	1.135	3,986	226.0
6 to <11 years	894	2.6	21.00	0.723	3,220	111.0
11 to <16 years	1,451	2.0	23.55	0.441	2,852	53.3
16 to <21 years	1,182	3.3	23.22	0.365	4,586	72.0
21 to <31 years	1,023	4.8	22.93	0.325	6,769	95.9
31 to <41 years	869	5.0	22.70	0.316	6,927	96.4
41 to <51 years	763	5.0	24.49	0.333	7,559	102.1
51 to <61 years	622	4.6	25.24	0.339	7,026	94.6
61 to <71 years	700	3.3	21.42	0.292	4,255	58.0
71 to <81 years	470	2.5	21.09	0.308	3,140	45.8
81 years and older	306	2.1	20.87	0.335	2,580	41.4

Table 7-16. Average Time Spent Per Day Performing Activities Within Specified Intensity Categories, and Average Ventilation Rates Associated With These Activity Categories, for Females According to Age Category (continued)

Age Category	# NHANES Participants Reporting Activity	Average Duration (hr/day) Spent at Activity	Ventilation Rate During This Activity[1]		Daily Ventilation Rate Associated With This Activity[2]	
			Unadjusted for Body Weight (L/min)	Adjusted for Body Weight (L/min-kg)	Unadjusted for Body Weight (L/day)	Adjusted for Body Weight (L/day-kg)
High Intensity (METS > 6.0)						
Birth to <1 year	79	0.2	24.19	3.263	244	32.3
1 year	55	0.2	36.48	3.376	471	44.3
2 years	130	0.2	37.58	2.800	355	25.6
3 to <6 years	347	0.2	34.53	1.979	407	23.4
6 to <11 years	707	0.2	39.39	1.331	568	18.7
11 to <16 years	1,170	0.3	46.56	0.879	840	15.8
16 to <21 years	887	0.2	44.09	0.696	621	9.8
21 to <31 years	796	0.3	45.68	0.650	725	10.2
31 to <41 years	687	0.2	44.44	0.613	646	8.9
41 to <51 years	515	0.3	46.98	0.653	725	10.1
51 to <61 years	424	0.3	47.35	0.634	965	13.0
61 to <71 years	465	0.3	40.02	0.544	777	10.5
71 to <81 years	304	0.3	40.64	0.594	718	10.5
81 years and older	188	0.3	41.88	0.666	654	10.7

[1] An individual's ventilation rate for the given activity category equals the weighted average of the individual's activity-specific ventilation rates for activities falling within the category, estimated using a multiple linear regression model, with weights corresponding to the number of minutes spent performing the activity. Numbers in these two columns represent averages, calculated across individuals in the specified age category, of these weighted averages. These are weighted averages, with the weights corresponding to the 4-year sampling weights assigned within NHANES 1999-2002.

[2] An individual's daily average ventilation rate equals the product of the individual's weighted average ventilation rate for the given activity category (L/min), estimated using a multiple linear regression model, and the number of minutes per day that the individual performs an activity within the category. Numbers in these two columns represent weighted averages across individuals in the specified age category, with the weights corresponding to the 4-year sampling weights assigned within NHANES 1999-2002.

Source: Lordo et al., 2006

Table 7-17. Descriptive Statistics for Daily Average Ventilation Rate (m^3/day) in Males, by Age Category

Age Category	N	Daily Average Ventilation Rate, Unadjusted for Body Weight ($\dot{V}_E$; m^3/day)									Daily Average Ventilation Rate, Adjusted for Body Weight ($\dot{V}_E/BW$: m^3/day-kg)								
		Mean	Percentiles							Maxi-mum	Mean	Percentiles							Maxi-mum
			5th	10th	25th	50th	75th	90th	95th			5th	10th	25th	50th	75th	90th	95th	
Birth to <1 year	419	8.76	4.77	5.70	7.16	8.70	10.43	11.93	12.69	17.05	1.093	0.913	0.943	1.002	1.085	1.163	1.256	1.293	1.476
1 year	308	13.49	9.73	10.41	11.65	13.11	15.02	17.03	17.89	24.24	1.186	0.964	1.017	1.088	1.171	1.261	1.367	1.479	1.730
2 years	261	13.23	9.45	10.20	11.43	13.19	14.49	16.27	17.71	28.17	0.948	0.781	0.816	0.873	0.943	1.014	1.090	1.127	1.360
3 to <6 years	540	12.65	10.42	10.87	11.40	12.58	13.64	14.63	15.41	19.52	0.703	0.523	0.555	0.613	0.693	0.778	0.873	0.920	1.084
6 to <11 years	940	13.42	10.08	10.69	11.73	13.09	14.73	16.56	17.72	24.97	0.441	0.318	0.343	0.376	0.434	0.499	0.549	0.581	0.805
11 to <16 years	1337	15.32	11.41	12.11	13.27	14.79	16.81	19.54	21.21	28.54	0.285	0.208	0.221	0.246	0.276	0.317	0.362	0.384	0.505
16 to <21 years	1241	17.22	12.60	13.41	14.48	16.63	19.16	21.94	23.38	39.21	0.229	0.168	0.181	0.202	0.228	0.253	0.279	0.296	0.395

Individual daily averages are weighted by their 4-year sampling weights as assigned within NHANES 1999-2002 when calculating the statistics in this table. Ventilation rate was estimated using a multiple linear regression model.

Source: Lordo et al., 2006

Table 7-18. Descriptive Statistics for Daily Average Ventilation Rate (m^3/day) in Females, by Age Category

Age Category	N	Daily Average Ventilation Rate, Unadjusted for Body Weight ($\dot{V}_E$; m^3/day)									Daily Average Ventilation Rate, Adjusted for Body Weight ($\dot{V}_E/BW$: m^3/day-kg)								
		Mean	Percentiles							Maxi-mum	Mean	Percentiles							Maxi-mum
			5th	10th	25th	50th	75th	90th	95th			5th	10th	25th	50th	75th	90th	95th	
Birth to <1 year	415	8.53	4.84	5.48	6.83	8.41	9.78	11.65	12.66	26.26	1.142	0.913	0.969	1.037	1.127	1.243	1.327	1.384	1.601
1 year	245	13.31	9.08	10.12	11.24	13.03	14.64	17.45	18.62	24.77	1.197	0.975	1.013	1.102	1.178	1.297	1.405	1.465	1.728
2 years	255	12.74	8.91	10.07	11.38	12.60	13.96	15.58	16.37	23.01	0.955	0.820	0.840	0.890	0.956	1.012	1.065	1.105	1.234
3 to <6 years	543	12.16	9.87	10.38	11.20	12.02	13.01	14.03	14.93	19.74	0.691	0.482	0.536	0.596	0.684	0.768	0.884	0.916	1.116
6 to <11 years	894	12.41	9.99	10.35	11.01	11.95	13.42	15.13	16.34	20.82	0.427	0.279	0.307	0.357	0.427	0.489	0.548	0.582	0.748
11 to <16 years	1451	13.44	10.47	11.11	12.04	13.08	14.54	16.25	17.41	26.58	0.251	0.189	0.198	0.220	0.245	0.279	0.312	0.340	0.471
16 to <21 years	1182	13.59	9.86	10.61	11.78	13.20	15.02	17.12	18.29	30.11	0.214	0.158	0.169	0.190	0.208	0.235	0.268	0.284	0.357

Individual daily averages are weighted by their 4-year sampling weights as assigned within NHANES 1999-2002 when calculating the statistics in this table. Ventilation rate was estimated using a multiple linear regression model.

Source: Lordo et al., 2006

Table 7-19. Descriptive Statistics for Duration of Time (hr/day) Spent Performing Activities Within the Specified Activity Category, by Age and Gender Categories

Age Category	Duration (hr/day) Spent at Activity – Males										Duration (hr/day) Spent at Activity – Females									
	N	Mean	Percentiles							Maxi-mum	N	Mean	Percentiles							Maxi-mum
			5th	10th	25th	50th	75th	90th	95th				5th	10th	25th	50th	75th	90th	95th	
Sleep or nap (Activity ID = 14500)																				
Birth to <1 year	419	13.51	12.63	12.78	13.19	13.53	13.88	14.24	14.46	15.03	415	12.99	12.00	12.16	12.53	12.96	13.44	13.82	14.07	14.82
1 year	308	12.61	11.89	12.15	12.34	12.61	12.89	13.13	13.29	13.79	245	12.58	11.59	11.88	12.29	12.63	12.96	13.16	13.31	14.55
2 years	261	12.06	11.19	11.45	11.80	12.07	12.39	12.65	12.75	13.40	255	12.09	11.45	11.68	11.86	12.08	12.34	12.57	12.66	13.48
3 to <6 years	540	11.18	10.57	10.70	10.94	11.18	11.45	11.63	11.82	12.39	543	11.13	10.45	10.70	10.92	11.12	11.38	11.58	11.75	12.23
6 to <11 years	940	10.18	9.65	9.75	9.93	10.19	10.39	10.59	10.72	11.24	894	10.26	9.55	9.73	10.01	10.27	10.54	10.74	10.91	11.43
11 to <16 years	1337	9.38	8.84	8.94	9.15	9.38	9.61	9.83	9.95	10.33	1451	9.57	8.82	8.97	9.27	9.55	9.87	10.17	10.31	11.52
16 to <21 years	1241	8.69	7.91	8.08	8.36	8.67	9.03	9.34	9.50	10.44	1182	9.08	8.26	8.44	8.74	9.08	9.39	9.79	10.02	11.11
Sedentary & Passive Activities (METS # 1.5 -- Includes Sleep or Nap)																				
Birth to <1 year	419	14.95	13.82	14.03	14.49	14.88	15.44	15.90	16.12	17.48	415	14.07	12.86	13.05	13.53	14.08	14.54	15.08	15.49	16.14
1 year	308	14.27	13.22	13.33	13.76	14.25	14.74	15.08	15.38	16.45	245	14.32	13.02	13.25	13.73	14.31	14.88	15.36	15.80	16.40
2 years	261	14.62	13.52	13.67	14.11	14.54	15.11	15.60	15.77	17.28	255	14.86	13.81	13.95	14.44	14.81	15.32	15.78	16.03	16.91
3 to <6 years	540	14.12	13.01	13.18	13.54	14.03	14.53	15.26	15.62	17.29	543	14.27	12.88	13.15	13.56	14.23	14.82	15.43	15.85	17.96
6 to <11 years	940	13.51	12.19	12.45	12.86	13.30	13.85	14.82	15.94	19.21	894	13.97	12.49	12.74	13.22	13.82	14.50	15.34	16.36	18.68
11 to <16 years	1337	13.85	12.39	12.65	13.06	13.61	14.30	15.41	16.76	18.79	1451	14.19	12.38	12.76	13.34	14.05	14.82	15.87	16.81	19.27
16 to <21 years	1241	13.21	11.39	11.72	12.32	13.08	13.97	14.83	15.44	18.70	1182	13.58	11.80	12.17	12.79	13.52	14.29	15.08	15.67	16.96
Light Intensity Activities (1.5 < METS # 3.0)																				
Birth to <1 year	419	5.30	2.97	3.25	3.71	4.52	7.29	8.08	8.50	9.91	415	6.00	3.49	3.70	4.26	5.01	8.43	9.31	9.77	10.53
1 year	308	5.52	2.68	2.89	3.37	4.31	8.23	9.04	9.73	10.90	245	5.61	2.83	2.94	3.46	4.39	8.28	9.03	9.39	10.57
2 years	261	5.48	3.06	3.26	3.85	4.58	7.58	8.83	9.04	9.92	255	5.78	3.20	3.54	4.29	5.33	7.48	8.46	8.74	9.93
3 to <6 years	540	6.60	3.86	4.25	5.16	6.20	8.26	9.31	9.70	10.74	543	6.25	3.78	4.10	4.79	5.84	7.86	8.84	9.38	10.32
6 to <11 years	940	7.62	5.07	5.57	6.63	7.63	8.72	9.78	10.12	11.59	894	7.27	4.63	5.46	6.33	7.17	8.34	9.42	9.79	11.06
11 to <16 years	1337	7.50	4.48	5.59	6.75	7.67	8.51	9.19	9.63	10.91	1451	7.55	4.89	5.62	6.75	7.67	8.55	9.27	9.57	10.85
16 to <21 years	1241	7.13	4.37	4.97	6.00	7.02	8.29	9.43	10.03	11.50	1182	6.98	4.60	5.08	5.91	6.85	7.96	9.16	9.57	12.29

Age Category	Duration (hr/day) Spent at Activity – Males										Duration (hr/day) Spent at Activity – Females									
	N	Mean	Percentiles							Maxi-mum	N	Mean	Percentiles							Maxi-mum
			5th	10th	25th	50th	75th	90th	95th				5th	10th	25th	50th	75th	90th	95th	
Moderate Intensity Activities (3.0 < METS # 6.0)																				
Birth to <1 year	419	3.67	0.63	0.97	1.74	4.20	5.20	5.80	6.21	7.52	415	3.91	0.53	0.74	1.10	4.87	5.77	6.27	6.54	7.68
1 year	308	4.04	0.45	0.59	1.14	5.29	6.06	6.61	6.94	7.68	245	4.02	0.52	0.73	1.08	5.14	6.10	7.00	7.37	8.07
2 years	261	3.83	0.59	0.76	1.23	4.74	5.37	5.82	6.15	7.40	255	3.27	0.50	0.78	1.22	4.01	4.88	5.35	5.57	6.93
3 to <6 years	540	3.15	0.55	0.75	1.30	3.80	4.52	5.11	5.32	6.30	543	3.35	0.70	0.89	1.61	3.88	4.71	5.29	5.65	7.58
6 to <11 years	940	2.66	0.65	0.92	1.65	2.68	3.57	4.36	4.79	5.95	894	2.57	0.65	0.95	1.82	2.66	3.41	3.95	4.32	6.10
11 to <16 years	1337	2.35	0.88	1.09	1.66	2.30	3.02	3.62	3.89	5.90	1451	2.01	0.89	1.08	1.45	1.96	2.51	3.03	3.28	4.96
16 to <21 years	1241	3.35	1.13	1.42	2.19	3.45	4.37	5.24	5.59	6.83	1182	3.26	1.27	1.48	2.21	3.39	4.24	4.74	5.07	6.68
High Intensity (METS > 6.0)																				
Birth to <1 year	183	0.20	0.00	0.00	0.01	0.14	0.28	0.50	0.59	0.96	79	0.17	0.03	0.05	0.09	0.14	0.21	0.33	0.40	0.58
1 year	164	0.31	0.01	0.01	0.03	0.22	0.56	0.78	0.93	1.52	55	0.22	0.03	0.05	0.09	0.18	0.35	0.40	0.43	0.48
2 years	162	0.10	0.00	0.01	0.03	0.05	0.14	0.25	0.33	0.48	130	0.15	0.00	0.01	0.03	0.08	0.16	0.48	0.65	1.01
3 to <6 years	263	0.27	0.02	0.03	0.04	0.13	0.33	0.75	1.16	1.48	347	0.19	0.01	0.02	0.05	0.10	0.22	0.46	0.73	1.43
6 to <11 years	637	0.32	0.01	0.01	0.03	0.13	0.38	1.10	1.50	3.20	707	0.24	0.02	0.03	0.06	0.12	0.26	0.67	0.98	1.71
11 to <16 years	1111	0.38	0.03	0.04	0.10	0.21	0.47	1.03	1.34	2.35	1170	0.30	0.03	0.04	0.08	0.19	0.40	0.66	0.96	3.16
16 to <21 years	968	0.40	0.03	0.04	0.14	0.27	0.53	0.99	1.29	2.59	887	0.24	0.01	0.03	0.08	0.18	0.34	0.51	0.60	1.61

Individual measures are weighted by their 4-year sampling weights as assigned within NHANES 1999-2002 when calculating the statistics in this table. Ventilation rate was estimated using a multiple linear regression model.

Source: Lordo et al., 2006.

Table 7-20. Confidence in Inhalation Rate Recommendations

Considerations	Rationale	Rating
Study Elements Peer Review	The key study used in the recommendations has undergone internal peer review, but not external review yet. The primary data used in the study have been peer reviewed.	Medium
Accessibility	The Lordo et al. 2006 is not yet available in the peer review literature, however the primary data sets used in the study are publicly available.	Medium
Reproducibility	Results can be reproduced using the primary data publicly available.	Medium
Focus on factor of interest	Study focused on ventilation rates and factors influencing them.	High
Data pertinent to U.S.	Studies conducted in the U.S.	High
Primary data	Lordo et al. 2006 is an analysis of existing primary data.	Medium
Currency	Recent studies were evaluated.	High
Adequacy of data collection period	Effort was made to collect data over time.	High
Validity of approach	Measurements were made by indirect methods.	Medium
Representativeness of the population	The key study sampled a large and representative of the U.S. general population.	High
Characterization of variability	Variability was presented in a cursory manner through calculation of summary statistics.	High
Lack of bias in study design	Subjects were selected randomly from the U.S. population.	High
Measurement error	Inhalation rates were not measured directly. Rather, they were estimated using other measurements (i.e., activity patterns, metabolic equivalents and body weight). Measurement error is well documented by statistics, but procedures measure factor indirectly.	Medium
Other Elements Number of studies	One key study contributed the recommended values; five additional relevant studies were evaluated.	Low
Agreement between researchers	There is general agreement among researchers using different experimental methods.	High
Overall Rating	Recommendations are based on one study not yet published, but it is the most recent data and scientific methodology available.	**Medium**

Table 7-21. Summary of Recommended Values For Inhalation

Activity Level	Age Range (years)	Males		Females	
		Mean m^3/day	N	Mean m^3/day	N
Long-term Exposures					
(All)	birth to <1 year	8.76	419	8.53	415
	1 to <2 years	13.49	308	13.31	245
(Percentiles see Tables 7-13 and 7-14)	2 to <3 years	13.23	261	12.74	255
	3 to <6 years	12.65	540	12.16	543
	6 to <11 years	13.42	940	12.41	894
	11 to <16 years	15.32	1337	13.44	1451
	16 to <21 years	17.22	1241	13.59	1182
Short-term Exposures					
Sleep or Nap	birth to <1 year	4.44	419	4.20	415
	1 to <2 years	6.48	308	6.61	245
(Percentiles see Tables 7-15 and 7-16)	2 to <3 years	6.64	261	6.57	255
	3 to <6 years	6.28	540	6.02	543
	6 to <11 years	6.64	940	6.28	894
	11 to <16 years	7.57	1337	6.93	1451
	16 to <21 years	7.65	1241	6.34	1182
Sedentary/Passive	birth to <1 year	4.58	419	4.32	415
	1 to <2 years	6.65	308	6.78	245
(Percentiles see Tables 7-15 and 7-16)	2 to <3 years	6.90	261	6.81	255
	3 to <6 years	6.60	540	6.34	543
	6 to <11 years	7.01	940	6.68	894
	11 to <16 years	8.12	1337	7.50	1451
	16 to <21 years	8.29	1241	6.85	1182
Light Intensity	birth to <1 year	11.43	419	10.54	415
	1 to <2 years	16.65	308	16.73	245
(Percentiles see Tables 7-15 and 7-16)	2 to <3 years	16.80	261	17.27	255
	3 to <6 years	16.36	540	15.72	543
	6 to <11 years	16.76	940	15.94	894
	11 to <16 years	19.04	1337	17.31	1451
	16 to <21 years	19.31	1241	15.96	1182
Moderate Intensity	birth to <1 year	20.87	419	20.13	415
	1 to <2 years	30.74	308	30.21	245
(Percentiles see Tables 7-15 and 7-16)	2 to <3 years	31.02	261	30.73	255
	3 to <6 years	30.28	540	28.81	543
	6 to <11 years	32.08	940	30.24	894
	11 to <16 years	38.02	1337	33.91	1451
	16 to <21 years	41.79	1241	33.44	1182
High Intensity	birth to <1 year	39.56	183	34.83	79
	1 to <2 years	57.96	164	52.53	55
(Percentiles see Tables 7-15 and 7-16)	2 to <3 years	58.25	162	54.12	130
	3 to <6 years	56.22	263	49.72	347
	6 to <11 years	62.81	637	56.72	707
	11 to <16 years	73.18	1111	67.05	1170
	16 to <21 years	76.56	968	63.49	887

APPENDIX 7A

VENTILATION DATA

Table 7A-1. Mean Minute Ventilation (V_e, L/min) by Group and Activity for Laboratory Protocols

Activity		Young Children[a]	Children[a]
Lying		6.19	7.51
Sitting		6.48	7.28
Standing		6.76	8.49
Walking	1.5 mph	10.25	DNP
	1.875 mph	10.53	DNP
	2.0 mph	DNP	14.13
	2.25 mph	11.68	DNP
	2.5 mph	DNP	15.58
	3.0 mph	DNP	17.79
	3.3 mph	DNP	DNP
	4.0 mph	DNP	DNP
Running	3.5 mph	DNP	26.77
	4.0 mph	DNP	31.35
	4.5 mph	DNP	37.22
	5.0 mph	DNP	DNP
	6.0 mph	DNP	DNP

[a]Young Children, male and female 3-5.9 years old; Children, male and female 6-12.9 years old;

DNP: group did not perform this protocol or N was too small for appropriate mean comparisons.

Source: Adams , 1993

Table 7A-2. Mean Minute Ventilation (V_e, L/min) by Group and Activity for Field Protocols

Activity[a]	Young Children[b]	Children[b]
Play	11.31	17.89

[a]Activities for which groups did not perform the protocol or N was too small for appropriate mean comparisons were car driving, car riding, yardwork, housework, car maintenance, mowing, and woodworking.

[b]Young Children, male and female 3-5.9 years old; Children, males and females 6-12.9 years old.

Source: Adams, 1993

Table 7A-3. Statistics of the Age/gender Cohorts Used to Develop Regression Equations for Predicting Basal Metabolic Rates (BMR)

Gender, Age (years)	BMR		CV	Body Weight (kg)	N	BMR Equation[a]	r
	MJ d^{-1}	SD					
Males							
Under 3	1.51	0.918	0.61	6.6	162	0.249 bw - 0.127	0.95
3 to < 10	4.14	0.498	0.12	21	338	0.095 bw + 2.110	0.83
10 to < 18	5.86	1.171	0.20	42	734	0.074 bw + 2.754	0.93
Females							
Under 3	1.54	0.915	0.59	6.9	137	0.244 bw - 0.130	0.96
3 to < 10	3.85	0.493	0.13	21	413	0.085 bw + 2.033	0.81
10 to < 18	5.04	0.780	0.15	38	575	0.056 bw + 2.898	0.8

[a]Body weight (bw) in kg
SD: Standard deviation.
CV: Coefficient of variation (SD/mean)
r: coefficient of correlation

Source: Layton, 1993