Appendix K

Comparison of Breathing Rates Distribution to Energy Expenditure Information

Comparison of Breathing Rate Distributions with Energy Expenditure Literature

This appendix summarizes information generated in response to comments regarding the inapplicability of short-term activity patterns and breathing rate measurements to development of a breathing rate distribution for use in a chronic exposure scenario. Use of short-term data to extrapolate to chronic exposure scenarios has inherent limitations. However, in this case, it appears from comparison to the literature on human energy expenditure that the error introduced by using short-term activity patterns studies as a basis for the breathing rate distribution is not large. The following paragraphs present available information that supports continued use of the CARB activity patterns surveys and Adams (1993) breathing rate data for estimating a distribution of long-term breathing rates.

Given the lack of longitudinal studies on activity patterns in a given population, we are limited in the amount of information we can use to develop the distribution. We therefore chose to use surveys of activity patterns of California residents that recorded activities over a 24 hour period as a basis for a daily breathing rate distribution. Standard statistical methods were used in both of the surveys. Survey participants were interviewed over four seasons to help account for seasonal influence on activity pattern. The large random sample included 1200 people 12 years and younger for children, and 1762 people older than 12 years for adults. The activity patterns of people in varying age groups including working and retired individuals are included in the survey, and therefore in our distributional analysis. We have also used standard statistical methods in characterizing the distributional aspects of daily breathing rates.

I. *Narrow Distribution*

The breathing rate distributions for adults and children are narrow (coefficient of variation = 28% for adults, 15% for children) and not particularly skewed (coefficient of skewness = 2.07 for adults, 0.957 for children). There is about a 2-fold difference between the 5th and 95th percentiles (171 vs.367 L/kg-day) for adults, and less than 2-fold for children (365 vs. 581 L/kg-day). Part of the reason the distribution is narrow is that the activities were binned into five categories, resting, light, moderate, moderately heavy, or heavy for the adult activity patterns survey. Each activity was assigned a mean breathing rate from one of the protocols in the Adams study that was chosen to represent breathing rate at that activity level. Similarly, children's activities were lumped into one of four categories, resting, light, moderate, and heavy. The majority of activities fell into light. About one-third of the day is at resting (i.e., when you are asleep). A small number of occupational categories and other activities fell into moderately heavy or heavy. Consequently, the light activities dominate the breathing rate distribution. This procedure of binning the activities into categories tends to limit the variance (e.g., all office workers breathe at the same rate during their time at work, and so forth) in the final distribution of breathing rates. Binning the data into categories with assigned breathing rates that represent a mean for that type of activity also decreases the range of the distribution, in comparison to using a distribution of breathing rates for each activity category. In addition, differences between males and females or between young and older adults performing the same specific tasks in the Adams breathing rate study disappeared once the breathing rates were normalized to body weight for most of the protocols. If interindividual variability were large, one would expect to see a highly skewed distribution or platykurtic distribution. That doesn't appear to be the case. The question arises if it were possible to take into account the intraindividual variability how much of an effect would it have on OEHHA's breathing rate distribution given the methodology we used to develop that distribution?

II. *Longitudinal Studies Unavailable*

OEHHA is unaware of a single human exposure variate for which longitudinal data are available for an appreciable fraction of a human lifetime. Longitudinal studies on a variety of human exposure variables would be highly desirable and no doubt improve the accuracy of human exposure assessment. Such studies, however, are necessarily limited to small fractions of a human lifetime. If the criteria of having longitudinal data to build distributions for chronic exposure scenarios were applied strictly, there would be no data-derived distributions for use in chronic human health risk assessment. It should be pointed out that the use of short-term or cross-sectional data for exposure variates is standard practice in both point estimate and stochastic risk assessments. For example, almost all if not all of the distributions for use in risk assessment in the published literature are based on short-term or cross-sectional data. In a paper written by Donald Murray and David Burmaster (DM Murray and DE Burmaster, *Estimated distributions for average daily consumption of total and self-caught fish for adults in Michigan angler households*. Risk Analysis 14:513-519, 1994), the authors points out that the use of a 7-day fish consumption survey should be extrapolated to substantially longer periods of time with caution, but notes that the analyst may have no alternative. That is where the risk analyst frequently finds him or herself - using point estimates or distributions that are limited by data availability.

III. *Intraindividual Variability*

The argument that a given individual won't be breathing at the 95th percentile, as defined in the distribution using the one-day activity patterns survey, his or her entire lifetime is the most difficult issue to address. While it is true that people may change jobs, retire or pass through other life transitions that impact activity, it is also true that we are creatures of habit. There are active people and inactive people and those groups of people will have different average lifetime breathing rates. There are people who retire from sedentary jobs and become more active just as there are people who retire and become less active. A factor limiting intraindividual variability may be the large fraction of the day spent on two activities, namely sleeping and work with little intraindividual variability in breathing rates for those activities.

IV. *Mean Estimate Inadequate*

The population mean is inadequate to characterize the exposure of individuals who are active or very active relative to their sedentary counterparts. Use of the distribution is necessitated by the need to estimate risks not just to the average person but to those who have relatively higher exposures (active to very active people). Whether these individuals are as active at 59 or 69 as they are at 29 is open to debate. By using our distribution for a chronic lifetime exposure scenario, we are making the assumption that the distribution applies equally to young and elderly adults. From activity and energy expenditure studies in the literature (see below) it is clear that energy expenditure declines with age primarily due to a decrease in basal metabolic rate (BMR) and physical activity level. It is also clear that there are people who remain physically active and have energy and oxygen requirements well above the mean for their entire lifetime. In addition, there is a decline in lung efficiency over a lifetime (McClaran et al, 1995). This means an individual must breathe more air to sustain the same energy expenditure. This may offset somewhat the decline in BMR and activity with aging. The error introduced by assuming a 59 or 69 year old has the same breathing rate as a 29 or 39 year old is minimal in comparison to overall uncertainty in a risk assessment.

V. *Analysis of Breathing Rate vs. Age*

As a first step in addressing the issue of changes in breathing rate over a lifetime, staff examined the adult (over 12 years of age) distribution of daily breathing rates to see if we can make any inferences about the relationship between breathing rate and age. We regressed age against breathing rate to look at trends in the one-day survey. For adults 18 to 94 there was no correlation between age and calculated daily breathing rate ($r^2 = 0.06$). This indicates that at least in the methodology OEHHA used, age is not a determinant of breathing rate. This could be due to the methodology used in which we normalized breathing rate to body weight, and binned all recorded activities into one of five possible breathing rates thereby minimizing the variability possible in breathing rate for a given activity. Categorizing the myriad activities into one of five breathing rates would decrease variability and possibly mask any age differences. In addition, the heterogeneity in activity levels at all ages might obscure any relationship between age and breathing rate. In the absence of a strong correlation between age and breathing rate, it would not be productive to develop separate breathing rate distributions by age grouping (e.g., 20-29, 30-39, and so forth). Such an approach raises other statistical problems when combining the distributions. For example, what correlation does one choose between distributions when they are combined. In addition, it is not a complete fix to the issues associated with the lack of longitudinal data.

VI. Data Supporting Utility of Breathing Rate Distribution for Chronic Exposure Scenarios

The following information describes data in the literature which support our breathing rate distribution in terms of applicability across a lifetime and across a population, and indicate that the range of breathing rates in our distribution is consistent with measured energy expenditures in a variety of studies.

1. *Energy Intake*

One way to validate the breathing rate distribution is to ascertain whether the calculated caloric intake that would equate to the mean or median and upper percentiles of the distribution are reasonable values. If one is neither gaining nor losing weight, the amount of air breathed in a day is proportional to the amount of oxygen required to burn the calories consumed. Even if weight is changing slowly over time, there is little impact on the daily oxygen requirement. Energy expenditure at our 50th percentile was calculated using the equation in Layton (1993):

$$V = E \times H \times VQ$$

where V = ventilation in L/day
E = energy expenditure in kcal/day
H = O_2 uptake factor, L O_2/kcal; it is the reciprocal of the energy yield from oxidation of fats, carbohydrates, and protein in a typical diet
VQ = ventilatory quotient = ratio of minute ventilation to O_2 uptake = 27 (Layton, 1993)

Thus, for a 70 kg individual breathing 209 L/day,

$$\begin{aligned} E &= V / H \times VQ \\ &= 14{,}630 \text{ L/d} / (0.21 \text{ L } O_2/\text{kcal})\ (27) \\ &= 2567 \text{ kcal/day} \end{aligned}$$

For a 60 kg person, the median breathing rate would equate to a caloric equivalent of 2211 kcal/day. Estimates of caloric equivalents representing energy expenditure at the mean, 90th percentile and 95th percentile of the OEHHA breathing rate distribution are shown in Table 1 below.

Table 1. ***Caloric Equivalents Estimated To Correspond To Oxygen Consumption AtVarious Breathing Rates Taken From OEHHA Breathing Rate Distribution And Estimated For A 60 Kg And A 70 Kg Individual.***

Point On The Distribution	60 Kg Individual	70 Kg Individual
Mean	2455	2864
Median	2211	2567
90th percentile	3249	3790
95th percentile	4031	4703

Basiotis et al (1989) measured the energy intake of a small sample of men and women over a year. The 13 male (age 22 to 49 years) and 16 female (age 21 to 53 years) subjects kept a daily diary of foods eaten. In addition, over one week in each season of the year, the subjects collected duplicate samples of all foods and beverages consumed for nutrient analysis. The average caloric intake of the group of females was 1848.3 ± 622.5 kcal per day. The average of the males was 2756.3 ± 867.7 kcal/day. As noted in Layton's study and elsewhere (Schoeller, 1988), dietary diaries are known to underestimate food consumption. Thus, these caloric intakes may be underestimates. Indeed, compared to measures of total energy expenditure (TEE) by the doubly labeled water technique reported by Poehlman (1993), these estimates are encompassed by the measured TEE but lower than the upper portion of the measured range of daily energy expenditure. The average energy intake estimated in Basiotis et al (1989) of the men and women is 2300 kcal per day. This falls close to the caloric equivalent of the median of the OEHHA breathing rate distribution (2200 kcal for a 60 kg person). It is also consistent with the caloric equivalent of the mean OEHHA breathing rate (2600 kcal for a 60 kg person). Assuming the data in Basiotis et al (1989) are normally distributed, the mean plus 1.635 standard deviations (about the 95th percentile) of caloric intake of the men is 4175 kcal per day. If the data are lognormally distributed, the 95th percentile would be larger. This estimate of the 95th percentile compares favorably with the calories that could be burned by breathing at the 95th percentile of the OEHHA breathing rate distribution by a 70 kg person (4700 calories). The women's mean plus 1.635 standard deviations is 2866 kcal/day which can be compared with a 95th percentile of 4031 kcal/day for a 60 kg person. It is probable that the women's caloric intake was more of an underestimate than the men's (see Layton, 1993). It is also probable that the caloric intake is lognormally distributed and we have underestimated the 95th percentile of the Basiotis data. In summary, while one cannot generalize the results from the small sample size studied to the general population, the measured caloric intakes reported in Basiotis et al (1989) are consistent with the caloric equivalents of our breathing rate distribution, especially in view of the underreporting of caloric intake observed by many investigators.

2. *Energy Expenditure*

Another way to validate the breathing rate distribution is to look at measures of energy expenditure in humans and compare that to the equivalent calories burned by breathing oxygen at the mean and upper percentiles of the OEHHA daily breathing rate distribution. Total energy expenditure consists of that energy expended for basal metabolism, that expended to digest food (measured as diet-induced thermogenesis), and that expended for physical activity. Basal metabolic rate does not vary greatly between individuals (about two-fold) and represents a large fraction (30-80%) of the energy expended.

Haggarty and colleagues (1994) looked at energy expenditure in 10 healthy men from the UK using the doubly-labeled water method and activity diaries. The doubly-labeled water technique for energy expenditure measures CO_2 production for up to 2 weeks following administration of $^{2}H_2{}^{18}O$ water. This provides a more longitudinal basis for extrapolating energy expenditure (and breathing rates) to chronic scenarios. The oxygen of expired CO_2 is in isotopic equilibrium with the oxygen of body water. When a subject is loaded with $^{2}H_2{}^{18}O$, the decrease in ^{18}O in the body water is a measure for H_2O plus CO_2 outputs and the decrease in ^{2}H is a measure for H_2O output alone. Hence the CO_2 output can be calculated by the difference (Westerterp and Saris, 1991). The isotopes are measured in urine at varied intervals using Isotope Ratio Mass Spectrometry. The method is considered to be accurate to within 8% (Schoeller, 1988; Schoeller and Hnilicka, 1996). The 10 subjects in the Haggarty study ranged in age from 25 to 54 years and all had sedentary occupations. However, their leisure time activity ranged from nonactive to very active. Their measurements of sedentary to very active men indicated total energy expenditures on the order of 1.6 to 2.4 times the basal metabolic rate. These authors noted that only two of their subjects fell within the range of BMR X 1.4-1.6, the estimate of the UK Department of Health for individuals with light occupations; the authors expressed the opinion that 1.6 X BMR is a bare minimum to subsist. The latter value is higher than the value of 1.2 x BMR reported by Black et al (1996) (described below) as a bare minimum to exist. The group mean of measured total energy expenditures for the summer season was 14.49 $\pm$ 2.69 MJ/day, while that in the winter was 13.51 $\pm$ 3.01 MJ/day. Using the relationships kcal = kJ/4.184 and 1000 kJ = 1 MJ (*Principles of Biochemistry*, White, Handler, Smith, Hill, and Lehman, eds. McGraw-Hill, 1978), from these measurements one derives caloric needs of 3229 kcal/day in winter and 3463 kcal/day in the summer for the men in this study. This estimate of caloric needs also seems to indicate that our breathing rate distribution is reasonable. The mean body weight of the 10 men was 66.6 kg; caloric equivalents for a 66.6 kg person breathing at the mean of our distribution would be 2725 kcal/day. This is lower than but comparable to mean energy expenditure measured in Haggarty et al (1994). Assuming a normal distribution of energy expenditure, the approximate 95th percentile of total energy expenditure was 4405 kcal/day in the winter and 4514 kcal/day in the summer (Table 2). The caloric equivalent for a 66.6 kg person breathing at the 95th percentile of our breathing rate distribution is 4475. This estimate is in good agreement with the approximate normal 95th percentile of the Haggarty et al (1994) energy expenditure measurements. The data from the Haggarty study tends to support the use of our breathing rate distribution.

Table 2. ***Caloric equivalents [a] of total energy expenditure (TEE) measured in Haggarty et al (1994) and of a 66.6 kg person breathing at the mean and 95th percentile of the OEHHA breathing rate distribution.***

	Total Energy Expenditure	**Total Energy Expenditure**	
	Summer	**Winter**	**BR distribution [b,c]**
mean	3463	3229	2725
approximate 95th percentile	4514	4405	4475

a. Caloric equivalents were estimated using the relationship kcal = MJ x 1000/4.184.
b. Calculated using Layton’s equation (see previous section on energy intake)
c. We took the mean (232 L/kg-day) or the 95th percentile (381 L/kg-day) of the OEHHA breathing rate distribution and multiplied that by the mean body weight in Haggarty et al. of 66.6 kg to get total L per day. This was then used in the equation $E = V_E / (H)(VQ)$ where V_E = L/day, H = 0.21 L O_2/kcal, and VQ = ventilatory quotient = 27 (Layton, 1993).

2.a. *Range of Sustainable Physical Activity Levels.*

In their review and analysis of 1614 published and unpublished measurements in 1156 subjects, Black et al (1996) examined human energy expenditure in affluent societies. Energy expenditure in all cases was measured by the doubly labeled water technique that essentially measures CO_2 production over a period of 1 to 3 weeks. The aims of the Black et al (1996) analysis were to establish limits of sustainable human energy expenditure, to establish the range and average of habitual energy expenditures by age and sex, and to describe lifestyles and activity patterns associated with measures of physical activity level. Looking at data from non-ambulatory patients and elite endurance athletes, they estimate the limits of human daily energy expenditure to be between 1.2 x BMR and 4.5 x BMR. The authors state that physical activity levels (PALs), expressed as the ratio of total energy expenditure to BMR, of 2.8 and 3.1 were found during periods of rigorous training for athletes. PAL of 2.0 to 2.3 were found in periods of routine training and are likely sustainable for extended periods of time. The authors state that data from all the studies together indicate a PAL range of 1.2 - 2.5 for sustainable lifestyles, with 2.5 representing a very physically active lifestyle. This is consistent with the daily breathing rate distribution we estimated in which the range is slightly over 2 fold between the 5th and 95th percentile.

2.a.1. *Measurements in Relatively Sedentary Population*

Black et al (1996) analyze average energy expenditures by sex and age grouping for a subset of 574 free-living subjects (255 males and 319 females). The studies cited by Black typically recruited from among colleagues, employees in research centers, universities, or hospitals, or were volunteers from local advertising. Thus women and men 20-30 who are readily recruited around academic institutions are well represented. There were fewest in the age range 40-60. Only three individuals were specifically identified as manual laborers; the rest were classified as relatively sedentary occupations (student, housewife, white collar, unemployed, or retired). Subjects excluded from the analysis included those recruited for cited studies because of a special circumstance, occupation or activity. Athletes and other high-energy expenders were excluded from the group of 574 subjects. The population is not a random sample designed to represent the general population and Black et al (1996) note that the population appears to be predominantly sedentary. The OEHHA breathing rate distribution was meant to encompass active individuals as well as sedentary individuals.

The energy expenditures for the subset of 574 free-living adults from age 18 to 74 as analyzed by Black et al (1996) are shown in Table 3 along with the equivalent caloric requirements. Note that the mean of our breathing rate distribution is equivalent to a caloric requirement of 2,778 kcal/ day for a 70 kg person, and 2381 kcal/day for a 60 kg person. The equivalent caloric intake for each group in the Black et al paper was calculated using the reported mean body weights for the group. These caloric equivalents are presented in the 5th column of Table 3 below.

The caloric equivalents of the mean total energy expenditure (TEE) from each group correspond well with that calculated for the mean body weights of the groups utilizing the OEHHA breathing rate mean (L/kg-day). The caloric equivalents representing the 95th percentile of the OEHHA breathing rate distribution for body weight means from Black et al are in relatively good agreement with the estimated 95th percentile caloric equivalents of the TEE cited in Black et al for younger men (18-39) (last two columns of Table 3). The caloric equivalents of the 95th percentile breathing rates for body weight means cited in Black et al are 33 to 50% higher than the estimated 95th percentile TEE cited in Black et al (1996) for all female subjects and older men (40-74 yrs). This is not surprising given that the population of

574 individuals is described in Black et al (1996) as relatively sedentary. Black et al (1996) specifically excluded high energy expenders such as athletes and soldiers in training from their analysis although there were some individuals in the 18 to 40 year range that indicated 30 minutes of strenuous activity on average each day. Thus, the population analyzed in Black et al (1996) more likely represents the more sedentary members of the population rather than a random sample inclusive of very active individuals such as that drawn for the activity patterns studies used to develop the OEHHA breathing rate distribution. While the studies cited in Black et al (1996) do not represent a random sample of the California population, the comparison is still useful and the data indicate that our distribution of adult breathing rates is reasonable.

Table 3. Total Energy Expenditure (TEE) And Caloric Equivalents Of Subjects Between 18 And 74 Summarized From BlackEt Al (1996) And Caloric Equivalents Of Mean And 95th Percentile Of The OEHHA Breathing Rate Distribution.

	Body Weight [a] ± s.d. (kg)	**Total Energy Expenditure [b], mean ± s.d.**	**Caloric Equivalents[c] for Mean TEE**	**Caloric Equivalents of mean of OEHHA BR distribution using mean BW from Black et al [d]**	**Caloric Equivalents of 95th percentile assuming LogN distribution of TEE means [e]**	**Caloric Equivalents of 95th percentile on BR distribution using BW from Black et al [f]**
Females						
18-29	69.3 ± 22.3	10.4 ± 2.2	2476	2867	3444	4650
30-39	67.9 ± 13.9	10.0 ± 1.7	2381	2813	3119	4562
40-64	70.0 ± 13.3	9.8 ± 1.7	2333	2900	3082	4700
65-74	60.2 ± 9.6	8.6 ± 1.6	2048	2495	2744	4044
Males						
18-29	75.6 ± 18.4	13.8 ± 3.0	3286	3132	4628	5079
30-39	86.1 ± 31.4	14.3 ± 3.1	3405	3567	4764	5785
40-64	77.0 ± 10.0	11.5 ± 1.7	2738	3191	3474	5173
65-74	76.4 ± 11.2	11.0 ± 1.6	2619	3166	3300	5133

a. BW = mean body weight in kg reported in Black et al (1996) for each age grouping and sex.

b. Mean total energy expenditure reported in Black et al (1996) for subjects in age grouping indicated.

c. Caloric equivalents were estimated using the relationship kcal = MJ x 1000/4.184.

d. We took the mean breathing rate of 232 L/kg-day from the OEHHA breathing rate distribution and multiplied that by the mean body weights in column one to get total L per day. This was then used in the equation $E = V_E / (H)(VQ)$ where V_E = L/day, H = 0.21 L O_2/kcal, and VQ = ventilatory quotient = 27 (Layton, 1993).

e. We estimated the 95th percentile of the means of TEE as reported by Black et al for each age and sex grouping using the computer program MathCad and assuming a lognormal distribution. Caloric equivalents were then calculated as indicated in footnote c.

f. We took the 95th percentile of our breathing rate distribution of 381 L/kg-day and multiplied that number by the mean body weights in column one to get L/day. This was then used in the equation described in footnote d to estimate the caloric equivalents of the oxygen inhaled at the 95th percentile breathing rate for the body weights in the Black et al study.

2.a.2. Measurements in very active individuals

Studies cited in Black et al (1996) measured TEE in athletic individuals including male Nordic skiers and Tour de France cyclists. These latter categories of athletes had measured TEE between 30.3 and 33.7 MJ/d while engaged in their athletic endeavor. That is equivalent to a required caloric intake of 7200 to 8000 calories per day. These activities are not performed on a daily basis but these individuals maintain athletic performance over years and would breathe much more than the average person over their lifetime. They are absent from the subset of TEE data on 574 individuals in Black's main analysis and are therefore not represented in the mean from that dataset. Information on TEE of athletes reported in various papers cited by Black et al (1996) and the caloric equivalents are presented in Table 4. In this table, we present the caloric equivalents of the average total energy expenditure reported for the group of athletes in Black et al (1996). We also present the expected caloric expenditure if a person with the group's mean body weight were breathing at the mean of the OEHHA breathing rate distribution. In addition, we report the mean of the corresponding age group in Black's main analysis wherein he purposely excluded high energy expenders. As anticipated, for the most part, the studies of TEE in athletic individuals reported in Black et al (1996) indicate higher than average energy expenditures. The energy expenditures are above the mean of the age group in Black's analysis of 574 individuals and above the mean of our breathing rate distribution. Most of them are closer to and some considerably higher than the 95th percentile of the Black et al main analysis of a relatively sedentary population that we estimated using the program MathCad.

Table 4. Total energy expenditure of athletic individuals and soldiers from studies cited by Black et al (1996), and caloric equivalents of mean of age grouping from analysis of relatively sedentary population by Black et al.and of OEHHA mean breathing rate.

Category [a]	**n** [b]	**Body Weight (kg)** [c]	**Total Energy Expenditure (MJ/day)** [d]	**Caloric Equivalents** [e] **of Total Energy Expenditure**	**Caloric Equivalents of mean Breathing Rate** [f]	**Mean Caloric Equivalent for age group in Black analysis** [g] **(95th percentile)**
Female athletes	4	50.6+ 3.2	14.61 + 1.26	3492	2070	2476 (3444)
Female athletes	9	51.6 +3.5	11.82 + 1.31	2825	2111	2476 (3444)
Female runners	9	55.3 + 6.2	12.29 + 1.76	2937	2263	na
Female nordic skiers	4	54.4 + 5.1	18.33 + 2.55	4381	2226	2476 (3444)
Male nordic skiers	4	75.1 + 4.9	30.28 + 4.15	7237	3073	3286 (4628)
Male cyclists	4	68.4 + 5.6	33.7	8000	2799	3286 (4628)
Soldiers, training	4	73.8+ 8.9	19.88 + 2.22	4751	3020	3286 (4628)
Soldiers, field	14	75.2 + 5.7	14.43 + 1.08	3499	3078	3286 (4628)
Marines, winter training	23	79.8 + 6.3	20.58 + 3.9	4919	3263	3286 (4628)
Soldiers, active service	15	70.7 + 5.3	17.8 + 2.82	4254	2893	3286 (4628)
Soldiers, training	10	77 + 7.5	17.82 +4.08	4254	3151	3286 (4628)

a. Category of athletic individual as in Black et al (1996)
b. n = number of people in whom Total Energy Expenditure was measured
c. mean body weight of group studied
d. total energy expenditure measured by the doubly labeled water technique, mean ± standard deviation
e. caloric equivalents of the total energy expenditure is estimated using the relationship 1MJ = 1000kJ and kJ/4,184 = kcal.
f. We took the mean breathing rate of 232 L/kg-day from the OEHHA breathing rate distribution and multiplied that by the mean body weights in column three to get total L per day. This was then used in the equation $E = V_E / (H) (VQ)$ where V_E = L/day, H = 0.21 L O_2/kcal, and VQ = ventilatory quotient = 27 (Layton, 1993).
g. This is the mean caloric equivalent of the TEE for the 574 individuals analyzed in Black et al (1996)'s main analysis; the 95th percentile assuming a lognormal distribution in the main analysis and using MathCad is in parentheses.
h. Nonathletic volunteers after 40 weeks of training.

2.a.3. Measurements in children

Black et al (1996) also examine data available on energy expenditure in children ages 2 to 6. They note that measured energy expenditures for children over age 6 is higher than reported energy intakes, and that this might be due to underreporting of food intake. We compare estimated caloric equivalents for the mean breathing rate from the OEHHA distribution of children's daily breathing rates to the measurements of energy expenditure summarized in Black et al for 2 to 6 year olds. The studies cited provide samples of 9 to 30 children per age grouping. The comparison is made in Table 5 using the equation in Layton (1993) and multiplying the mean breathing rate of 452 L/kg-day by the mean body weights from each age group cited in Black et al (1996). The information in Table 2 indicates that the mean of the children's daily breathing rate distribution is reasonable. The estimated caloric equivalents of oxygen consumed at the mean compares well with the mean total energy expenditures summarized in Black et al (1996) for these age groups (Table 5).

Table 5. Total Energy Expenditure (TEE) and caloric equivalent of data on children cited in Black et al (1996); comparison to caloric equivalent of mean of children's breathing rate distribution.

	BW [a] (kg)	**TEE from Black et al, MJ/day**	**caloric equivalent of TEE [b]**	**caloric equivalent of mean BR [c]**
Females, age (yr)				
2-3	13.0	4.45	1059	1036
3-4	14.9	4.73	1126	1188
4-5	16.8	4.87	1160	1339
5-6	18.8	5.71	1360	1498
6-7	21.5	6.46	1538	1713
Males, age (yr)				
2-3	12.7	4.5	1071	1012
3-4	15.2	5.22	1243	1212
4-5	17.5	5.50	1310	1395
5-6	19.7	6.18	1471	1570
6-7	22.9	6.74	1605	1825

a. BW = mean body weight for age grouping as reported in Black et al (1996)

b. Calculated using the relationship MJ = 1000kJ and kJ/4.184 = kcal.

c. We took the mean (452 L/kg-day) of the children's breathing rate distribution and multiplied by BW in column 1 to get L/day. This was then used in the equation $E = V_E / (H) (VQ)$ where V_E = L/day, H = 0.21 L O_2/kcal, and VQ = ventilatory quotient = 27 (Layton, 1993).

2.b. Effects of Age

There are a number of studies in the literature reporting a decrease in basal or resting metabolic rate (RMR) and overall energy expenditure with age. The curvilinear decrease in RMR with age shows up in women after 50 years of age. In a large cohort of healthy women, there was no significant decrease in RMR in women from 18 to 51 years of age (Poehlman, 1993). Thereafter, there is about a 4% decline per decade from 51 to 81 years. Similarly in men, the decrease begins to appear after age 40 years and the decline is larger than that in women. Reduction in fat-free mass accounts for about 75% of the decline in RMR with age. Poehlman (1993) notes another major contributor is the reduction in cellular Na+ - K+ ATPase activity in elderly people accounting for another 1/4 of the decline in RMR with age in measured in his laboratory. The activity level of an individual has a large influence on caloric needs. Poehlman and colleagues measured caloric needs of between 1.25 and 2.11 times the RMR in elderly men and women. In one study (as reviewed in Poehlman, 1993), a high degree of interindividual variation in daily energy expenditure was noted in 13 elderly subjects. This was due in part to the range in RMR measured in these people (1856 to 3200 kcal/day) and in part to the range of variation in energy expenditure for physical activity (187 to 1235 kcal/day). There was a high degree of variability in physical activity energy expenditure in this small group of subjects. This group also studied the relationship between total energy expenditure, body composition, RMR, leisure time physical activity, VO_{2max} and reported energy intake. Total energy expenditure is most significantly related to VO_{2max} which accounted for 79% of the variability in TEE in the healthy adult volunteers. VO_{2max} is most likely a proxy measure for the level of physical activity in these individuals.

Roberts and colleagues (1995) noted that elderly men (age 68 $\pm$ 1.5 yrs) have a significantly lower total energy expenditure than young men (age 22 $\pm$ 0.6 yrs). This appears to be due to both a lower resting energy expenditure and lower amounts of physical activity in general. Using the doubly-labeled water technique, this study measured mean total energy expenditures of 14.48 MJ/day and 11.26 MJ/day in 17 young and 18 elderly men, respectively, over a 10 day period. These mean energy expenditures are roughly equivalent to 3460 kcal/day in the young men and 2690 kcal/day for the elderly men (Table 6). The authors note that compared to their measurements of energy expenditure, dietary surveys underestimate total caloric requirements and current recommended dietary allowances for energy are underestimates. The measured caloric requirement in the older adults is close to the equivalent caloric requirement for the mean of our breathing rate distribution, while that measured in younger adults (3460 kcal/day) is above the equivalent of the mean of OEHHA's breathing rate distribution as estimated for the mean body weight of 71.6 kg in the Roberts study (2930 kcal/day). The mean energy expenditure measured for the young men in the Roberts study would be associated with about the 80th percentile in our breathing rate distribution. Although not a long-term study, the 10 day energy expenditure average is more longitudinal than the one-day activity patterns survey upon which our breathing rate distribution is based. The data from Roberts et al (1995) indicate that our breathing rate distribution underestimates breathing rate for young men but overestimates for elderly men; the breathing rate distribution may be more reflective of a lifetime average.

Table 6. Caloric Equivalents of Mean Total Energy Expenditure (TEE) Measured In Young And Elderly Males In Roberts et al (1995), and of the Mean Breathing Rate from OEHHA Distribution Using Body Weights Reported for Subjects in Roberts et al.

	Young Men (22.7 + 0.6yrs) TEE = 14.48 + 0.65 MJ/day	**Elderly Men (68 + 1.5 yrs) TEE = 11.26 + 0.54 MJ/day**
Caloric Equiv of Mean TEE [a]	3460	2690
Caloric equiv for BR Mean using BW from Roberts et al (1995) [b]	2930	3220

a. Caloric equivalents were estimated using the relationship kcal = MJ x 1000/4.184.

b. We took the mean breathing rate of 232 L/kg-day from the OEHHA breathing rate distribution and multiplied that by the mean body weights in Roberts et al (1995) to get total L per day. This was then used in the equation $E = V_E / (H)(VQ)$ where V_E = L/day, H = 0.21 L O_2/kcal, and VQ = ventilatory quotient = 27 (Layton, 1993).

Pannemans and Westerterp (1995) examined the energy expenditure, physical activity, and basal metabolic rate of young (nineteen men age 30.4 ± 5.0 years; ten women age 27.2 ± 3.9 years) and elderly (sixteen men age 71.3 ± 4.9 years; ten women age 67.6 ± 4.1 years) adult subjects. The mean of the elderly subjects (both male and female) was 9.6 + 1.56 MJ/day while that for the young subjects was 11.89 + 1.84 MJ/day. Energy expenditure and BMR were significantly lower in elderly subjects. This implies that the need for oxygen and therefore breathing rate for elderly subjects would be less than young adults, all other things being equal (e.g., lung function, oxygen carrying capacity of the blood). The energy expenditure difference between young and elderly adults is explained in this study mostly by a decreased basal metabolic rate and partly by decreased fat-free mass and decreased physical activity. The absolute amount of energy expended on activity was higher for the younger subjects although there was no significant difference in physical activity index (energy expenditure/BMR). Thus when expressed as a multiple of BMR, physical activity was not different between the young adults and elderly adults. However, total energy expenditure was less by about 19% in this study. A comparison of the caloric equivalents of the mean energy expenditure measured in Pannemans and Westerterp (1995) and the caloric equivalents of subjects at the mean of the OEHHA breathing rate distribution is presented in Table 7. Note that the mean caloric expenditure is well estimated by the mean of the OEHHA breathing rate for the younger subjects but is overestimated for the elderly subjects in the Pannemans and Westerterp (1995)study.

Table 7. Caloric Equivalents Of Mean Total Energy Expenditure (TEE) Measured In Young And Elderly Subjects And That Predicted From Our Mean Breathing Rate Using Bodyweight Reported In Pannemans And Westerterp (1995).

	Young Subjects (Average Of Male And Female,)	**Elderly Subjects (Average Of Male And Female)**
Caloric Equivalents of Measured Mean TEE [a]	2842	2294
Caloric Equivalents for BR mean [b] **using BW from Pannemans and Westerterp**	2901	2893

a. Caloric equivalents were estimated using the relationship kcal = MJ x 1000/4.184.

b. We took the mean breathing rate of 232 L/kg-day from the OEHHA breathing rate distribution and multiplied that by the mean body weights of male and female subjects combined in Pannemans and Westerterp (1995) to get total L per day. This was then used in the equation $E = V_E / (H) (VQ)$ where V_E = L/day, H = 0.21 L O_2/kcal, and VQ = ventilatory quotient = 27 (Layton, 1993).

Visser and colleagues (1995) investigated the relationship between age and energy expenditure, resting metabolic rate (RMR) and diet-induced thermogenesis (DIT). They studied 56 young (27 females, 23 ± 2 yr; 29 males, 27 ± 2 yrs) and 103 elderly (71 females, 72 ± 5 yrs; 32 men, 73 ± 6 yrs) subjects, measuring body composition, physical activity level, RMR and DIT. DIT fell in elderly men compared to young men but not in elderly women compared to young women. RMR was significantly lower in the elderly subjects both men and women, than in the young subjects. RMR of 3.87 ± 0.27 kJ/h/kg body weight was measured in the younger women while older women had RMR of 3.01 ± 0.37 kJ/h/kg body weight. After adjustment for differences in body composition and age between sedentary and active elderly women, the RMR and DIT were slightly higher in the active elderly women. Staying physically active appears to result in a smaller decrease in RMR. This was seen for elderly men in the Murray et al (1996) study and for aging women athletes in the Ryan et al study (1996) described below.

Murray et al (1996) conducted a longitudinal study of changes in BMR and body composition in 22 elderly men who were physically active. There was no statistically significant decrease in BMR or fat-free mass over a 6.5 year period in these subjects. In a number of cases the measurements showed an increase rather than a decrease. The authors discuss the results of other studies in their paper and note that longitudinal studies have shown less of an effect of age than cross-sectional studies. They also note that their method for determining body composition (skinfolds) is more precise than those used in previous studies. The active lifestyles may be the reason for the maintenance of BMR and fat-free mass in these subjects.

A cross-sectional study on body composition and energy expenditure in women athletes was conducted by Ryan et al (1996) using measures of RMR, substrate oxidation, and measures of intraabdominal adipose tissue (IAAT) in 43 highly trained athletes (18-69 years) and 14 sedentary adults. The athletes were grouped by age as follows: 18-29, 30-39, 40-49, 50-69 yrs. The controls were grouped into two groups, 18-39 and 40-50 yrs of age. Maximum oxygen consumption declined with age as did RMR. Levels of VO_{2max} remained relatively stable until the 5th decade in the athletes. A possible explanation for the observed decline may be related to menopausal status. Nonetheless, the VO_{2max} was higher in older athletes relative to older sedentary controls. Athletes did not experience the decline in fat-free mass commonly observed in a sedentary population. The IAAT scores were almost double in older control women relative to older athletes. Although rates of carbohydrate metabolism did not differ between athletes and controls, the athletes had higher rates of resting fat oxidation than the controls despite having lower total fat content. Thus, physically active women who remain so into old age have higher energy expenditures than their sedentary counterparts and thus would continue to have a higher demand for oxygen.

Using stepwise linear regression, both Schulz and Schoeller (1994) and Black et al (1996) found that the majority of the variance in energy expenditure could be accounted for by fat-free mass and age. Both analyses indicate that physiological components of energy expenditure are greater than behavioral components (activity level).

In the Black et al (1996) study, the authors state that people over age 65 years have a lower energy expenditure than younger adults. Since activity levels varied widely, Black et al (1996) note that a truly random sample is necessary to characterize the distribution of energy expenditure in adults over age 65. Poehlman (1993) reported a high degree of variability in activity level in elderly subjects with PAL ranging from 1.25 to 2.11 times the BMR. The Black study indicates that 14.6% of PAL measurements fell in the range of 2.0-2.5 representing a high level of physical activity, including six subjects >60 years of age. In the study of aging women athletes (Ryan et al, 1996), women who continued their exercise regimens in later years had reduced decrease in BMR and total energy expenditure, and did not have the characteristic decline in fat-free mass as their sedentary counterparts. These studies and others indicate that there are people who have energy and oxygen requirements at the upper end of the distribution for a substantial portion of their lifetime. This supports the use of our breathing rate distribution for lifetime analyses of exposure in the Air Toxics Hot Spots program. The breathing rate distribution we presented in the document was developed from activity pattern and breathing rate data across all ages (greater than 12 years for adults), occupations, and lifestyles and across both sexes. Those at the upper end of the distribution in early adulthood might also be at the upper end in middle and later adulthood.

The lung and chest wall become less compliant with aging. McClaran et al (1995) studied the longitudinal effects of aging on lung function. The study evaluated 18 healthy, active elderly men and women to examine lung function over a 6 year period. They were initially tested at a mean age of 67 years and retested at a mean age of 73 years. The authors note at any given submaximal work rate, minute ventilation (L air/min) and breathing frequency were higher in the second test than in the first. The work of breathing increased for a given level of output. This means that an older person has to breathe more to do the same work. It appears from other studies noted in the article that this change might occur in the 6th and 7th decades of life and not earlier. The individuals studied were healthy active nonsmokers. At maximum exercise, VO_{2max}

fell 11% between the first and second testing but was still 200% higher on average than that predicted for a sedentary individual of the same age. There was a significant change in resting lung volumes and maximal expiratory flow rates with aging. Habitual exercise training did not seem to stop the age-dependent decreases in resting lung volume and expiratory flow rates. The McClaran et al (1995) study indicates that as lung function decreases in the elderly, the breathing frequency, minute ventilation, end-expiratory and end-inspiratory lung volume increase to compensate. Thus, for a given activity level, individuals in their late sixties and older may be breathing more than when younger. Thus decreased breathing rates in older subjects due to decreased physical activity levels may be offset somewhat by the increased work of breathing.

The decrease in energy expenditure with age should be reflected in the OEHHA breathing rate distribution because the activity patterns study surveyed elderly as well as young subjects in a random sample of the California population. However, there was no obvious relationship between age and an individual's estimated daily breathing rate in our analysis, although using smoothing techniques in the statistical package Splus, a visual slight trend downward was apparent over age 75 years. The lack of correlation between age and breathing rate in the OEHHA breathing rate analysis may be due to binning the large variation in recorded daily activities into a handful of categories with assigned breathing rates.

VII. Summary

Although it is not possible in the absence of longitudinal data to definitively answer the question of intraindividual variability in activity (and therefore energy expenditure and breathing rate), given the overall uncertainty in risk assessment, the error associated with use of a short-term activity patterns survey to infer long term daily breathing rates appears to be small. Given the expense and difficulty of recruiting individuals to participate in studies over a period of years, it is unlikely that many such studies will be forthcoming. Therefore, our approach represents the current state-of-the-art. In summary, data on energy expenditure in humans supports the mean and range of our breathing rate distribution.

- Our breathing rate distribution expressed in L/kg-day is narrow - there is only a slightly larger than 2-fold difference between the 5th and 95th percentile. This range is consistent with the range of physical activity indices measured in a number of studies including nonambulatory and athletic subjects and reported in Black et al (1996).

- Relatively longitudinal measurements of total energy expenditure by the doubly-labeled water method in a number of studies are consistent with caloric equivalents of the OEHHA breathing rate distribution.

- While the OEHHA breathing rate distribution appears to overestimate energy expenditure in the elderly (over 65 years), it also appears to underestimate energy expenditure in active young men. The documented decrease in energy expenditure appears to occur largely in the 6th and 7th decades of life. Therefore, by comparison to measures of total energy expenditure, the OEHHA breathing rate distribution is a good approximation of what occurs over a 70 year lifetime.

- There are studies that show that while in general age results in decreased activity level and BMR and decreased energy expenditure, some active elderly adults do have significantly higher energy expenditures and therefore a need for more oxygen than their more sedentary counterparts. Decreased energy expenditure in the elderly and a presumed decrease in breathing rate may be somewhat offset by the increased work of breathing in the elderly.

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