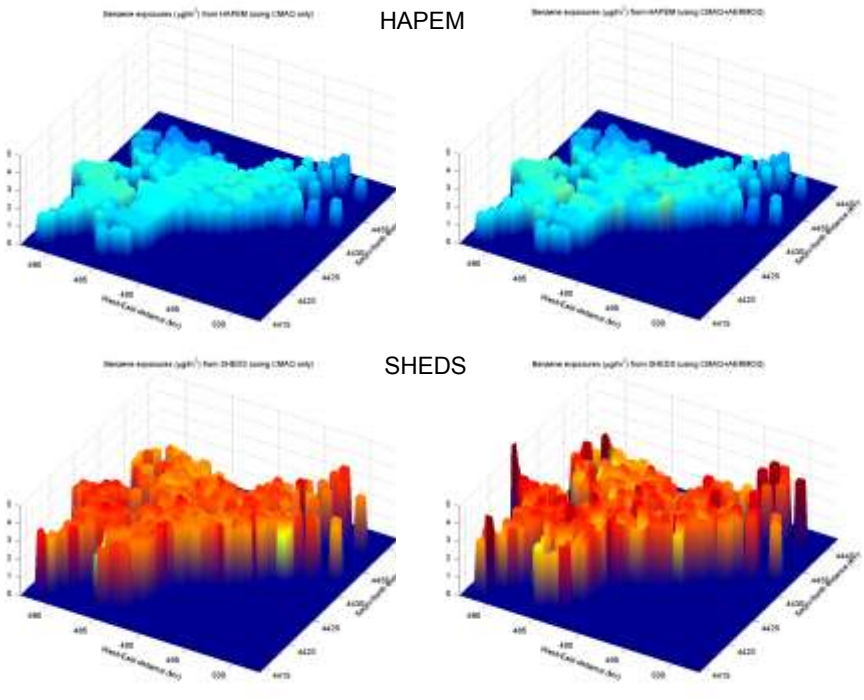
Data Sources Available for Modeling Environmental Exposures in the Older Adult Population

Report for APM 70 (2010): Provide program offices and the exposure science community with human exposure activity pattern and exposure factor data for older adults



Source: Dr. Janet Burke. The figures display exposure estimates for different scenarios using the HAPEM (Hazardous Air Pollution Exposure Model) and SHEDS (Stochastic Human Exposure and Dose Simulation) model.

Thomas McCurdy
Exposure Modeling Research Branch
National Exposure Research Laboratory
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Executive Summary

This report, "Data sources available for modeling environmental exposures in the older adult population," focuses on information sources and data available for modeling environmental exposures in the U.S. elderly, defined here to be people 60 years and older, with an emphasis on those aged greater than 65. The information was gathered as part of the U.S. Environmental Protection Agency's (EPA's) Aging Initiative project.

This report is intended to address EPA Human Health Research Program Annual Performance Measures (APM) requirements #70 (2010). In general, this report contains the same type of information found in EPA's *Exposure Factors Handbook* (e.g., NCEA, 1997), but with older adults as the sole population subgroup of interest. We envision that this report will be used to inform exposure assessors about the data available for modeling exposures to the elderly. In addition, the data allow scientists to check or evaluate results obtained from the modeling assessments for older adults, such as determining if the distribution of ventilation (breathing) rates seen in a particulate matter (PM) intake dose rate assessment, for example, are realistic or not. The same is true for the elderly's time spent in motor vehicles, outdoors, or indoors. Intra-individual and inter-individual variability measures are discussed for all of these parameters, where available. In the situation where a time-averaged exposure model is used, the data in this report can provide aggregate information on many of the inputs needed for that type of model. This report can be a useful "source book" on elderly exposure modeling, in other words, similar to the *Exposure Factors Handbook*. The report is centered on the inputs needed for two of EPA's inhalation exposure models, the Air Pollution Exposure (APEX) model and the Stochastic Human Exposure and Dose Simulation (SHEDS) model.

The report also includes a review of physical activity data available for evaluating model outputs. In addition, the report includes discussion of how general health status of older adults might affect exposure to environmental contaminants and an assessment of the interactions between exposure and possible impacts of the elderly on environmental loadings. The latter category largely focuses on pharmaceutical discharges into bodies of water. The final Appendix provides information on developing conditional probabilities for that portion of the elderly population that has both arthritis and one or more co-morbidities often associated with it.

Data shortcomings and research needs are described for each topic covered.

Finally, this report presents detailed information on changes in time use, activity, and physiology as people age. It is important to understand these changes because the elderly are becoming a larger proportion of the total U.S. population, and more and more societal resources will be directed toward their maintenance.

Table of Contents

List of Figures

List of Tables

Acknowledgements

Most of the research reviewed here involves studies and literature reviews conducted for or directed by the author. Some of this effort was done in coordination or cooperation with colleagues in other groups in NERL or in EPA's National Health and Environmental Effects Research Laboratory (NHEERL), and has been so recognized and cited in this report. Melissa Smarr, student contractor to the Exposure Modeling Research Branch (EMRB), a part of NERL, developed some of the figures used in this report; she also obtained a lot of the "raw data" on the elderly that appear in the many tables provided. Jennifer Hutchinson and A'ja Moore, student contractors, also reviewed papers and abstracted relevant information for the tables.

I owe a lot of gratitude to the staff of EPA's Research Triangle Park NC library, both contract employees and student interns from the University of North Carolina's School of Library Science. Susan Forbes, Assistant Director of the Library, and Michael Cummings were particularly helpful in obtaining articles and overseeing literature searches. This report would be a lot less synoptic without their help. Almost all of the references cited, even if not used directly, are available locally.

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Abbreviations, Symbols, and Acronyms Used

♀:	Female(s)
♂:	Male(s)
±	Use to depict the standard deviation of the mean.
μE:	Microenvironment--a location having a constant C_T for a time period
ADL:	Activities of Daily Living
APEX:	Air Pollution Exposure Model (an OAQPS model)
AT:	Anaerobic threshold (L/min)
ATUS:	American Time Use Survey (a yearly BLS survey)
BLS:	Bureau of Labor Statistics; U.S. Department of Labor
BM:	Body Mass ["weight"] (kg)
BMI:	Body Mass Index (BM/HT^2 in kg/m^2)
BMR:	Basal Metabolic Rate (kilocalories/day)
BSA:	Body Surface Area (m^2)
C:	Concentration (various units; e.g., $\mu g/m^3$, ppm)
CO:	Carbon monoxide
C_{OUT}:	Concentration outdoors (various units)
$C_{OUT.h}$:	Hourly-specific outdoor concentration (various units)
C_T:	Concentration for a specified time period, T (various units)
CHAD:	Consolidated Human Activity Database (www.epa.gov/chadnet1/)
D:	Dose (various units; moles per minute is the most general)
D_{IN}:	Intake dose rate (moles/min)
D_T:	Dose for a particular time period (moles per specified T: minute, hour, etc.)
D_T/dt:	The time rate of dose rate received (moles/min over some specified T)
DHHS:	Department of Health and Human Services
EE:	Energy expenditure (various units)
EE_a:	Activity-specific energy expenditure (kilocalories/minute)
EE_{ai}:	EE_a for a particular modeled individual
EFH:	EPA's *Exposure Factor's Handbook*
EMRB:	Exposure Modeling Research Branch
EPA:	The U.S. Environmental Protection Agency
EVR:	Equivalent Ventilation Rate (L/BSA; liters/m^2 for a specified time period)
FFM:	Fat-free mass (kg); equal to LBM
h	Hour
HEASD:	Human Exposure and Atmospheric Sciences Division
HR:	Heart rate (beats/minute)
HR_{MAX}:	Maximal heart rate (beats/minute)

HR_R:	Resting heart rate (beats/minute)
HR_{RES}:	Heart rate reserve [$HR_{MAX} - HR_R$] (beats per minute)
HT:	Height (in centimeters or meters)
IADL:	Independent Activities of Daily Living [minimal ADL for independent living]
kcal:	Kilocalories, a measure of energy used [1 kcal≈4.185 kJ]
L:	Liters
LBM:	Lean body mass (kg); equivalent to FFM
METS:	Metabolic equivalents of work (unitless)
$METS_A$:	Activity-specific METS (unitless)
min	Minute
MMSE:	Mini-Mental State Exam [an often-used measure of cognitive impairment]
NCEA:	National Center for Environmental Assessment
NCHS:	National Center for Health Statistics
NERL:	National Exposure Research Laboratory
NHEERL:	National Health and Environmental Effects Laboratory
NHIS:	National Health Interview Survey
NO_2:	Nitrogen dioxide
O_3:	Ozone
OAQPS:	Office of Air Quality Planning and Standards
OAR:	Office of Air and Radiation
ORD:	Office of Research and Development
PA:	Physical activity
PAI:	Physical Activity Index (many alternative units; generally TDEE/BMR)
PAL:	Physical Activity Level
PM:	Particulate
$PM_{2.5}$:	PM >2.5 microns in average effective diameter
RMR:	Resting Metabolic Rate [approximately equivalent to BMR]
RQ:	Respiratory Quotient [VCO/VO_2, both as volumes] (unitless)
SHEDS:	Stochastic Human Exposure and Dose Simulation model
TDEE:	Total Daily Energy Expenditure (generally kcal/day)
U:	A conversion factor used to relate EE to VO_2 (kcal-to-L/min)
V_A:	Alveolar ventilation rate (L/min or BM-adjusted mL/min-kg)
V_D:	Dead-space volume (L)
V_E:	Ventilation [breathing] rate (L/min or mL/min-kg)

$V_{E.Max}$:	Maximal V_E, defined by an exercise protocol (L/min or mL/min-kg)
$V_{E.R}$	Ventilation rate measured at rest [basal conditions] (L/min or mL/min-kg)
$V_{E.Reserve:}$	Ventilatory reserve [$V_{E.Max}$-$V_{E.R}$] (L/min or mL/min-kg)
VO_2:	Oxygen consumption rate (L/min or mL/min-kg)
$VO_{2.Max}$:	Maximal VO_2, defined by an exercise protocol (L/min or mL/min-kg)
$VO_{R:}$	VO_2 measured at rest [basal conditions] (L/min or mL/min-kg)
$VO_{2.Reserve:}$	Oxygen consumption reserve [$VO_{2.Max}$-$VO_{2.R}$] (L/min or mL/min-kg)
VQ:	Ventilatory equivalent [V_E/VO_2] (unitless)
V_T:	Tidal volume (L)
VT:	Ventilatory threshold (L/min)
y	Year

1. Introduction and Overview

This report focuses on information sources and data available for modeling environmental exposures in the US older adults, defined here to be people 60 years and older, with an emphasis on those aged 65+. This sub-population is increasing rapidly, both in relative and absolute terms (Administration on Aging, 2009), which makes them an ever-increasing group of concern (or cohort) from an exposure and risk assessment perspective. The information was gathered as part of EPA's **Aging Initiative** project (Geller & Zenick, 2005), supplemented by work directed toward improving risk estimates for the elderly. This is a review of the main topics needed to undertake and evaluate exposure and *intake dose rate* modeling in the elderly, in particular, the time use, physical activity, exercise, and physiology inputs needed for the Air Pollution Exposure model (APEX; Palma et al., 1999) and the Stochastic Human Exposure and Dose Simulation model (SHEDS; Burke et al., 2001). These inputs are delineated in detail below. Related, but less important, physiological considerations are more briefly addressed.

This review reflects the current "state of the science" regarding exposure modeling in the independent-living elderly as of the end of 2009. Thus, the elderly who are confined to a nursing home or other institution are only briefly mentioned in this report.[1] This also is true for the elderly suffering from dementia or other health circumstances that preclude them from functioning without help, even if they are still living at home.

Most of the data and citations to the literature come from U.S. studies, although significant information on physiology in the elderly comes from non-U.S. data. In general, people of a specified age and gender are physiologically similar regardless of ethnic background or where they live. There are some physiological parameters where ethnicity seemingly makes a difference, but these associations are confounded by genetics and lifestyle aspects of a society's culture that affect selected physiological systems. Basal metabolic rate and fitness levels are two examples. Others will be discussed in context. Since there is a substantial "cultural" component associated with many of the non-physiological topics covered, particularly time use and physical activity participation, focusing on U.S. data is a practical necessity.

It should be noted that the tabular data for the most part only include subjects whose **mean** age is ≥60 y. More information is available for subjects whose mean age is >55 y and having a large enough standard deviation so that a considerable portion of the sample would be 60+ y of age. In most cases these data are not presented. Most readers will feel that there is a large enough sample of data provided here for 60+ y aged individuals; including slightly younger people does not alter the trends or findings of this report but would increase its length substantially.

[1] For elderly residential types not discussed here, see, for example, Eckert & Murrey (1984), Marans et al. (1984), Moos & Lemke (1984), and Pruchno & Rose, 2002). The approximate proportion of the elderly not living in their home or other residence for two age groups is: 65-74 y= 2.2-2.4% ♀, 2.1-3.6% ♂; and 75+ = 8.9-11.7% ♀, and 6.3-7.1% ♂ (Czaja, 1990). See the discussion of Impairment, Functional Limitations, and Disability for additional information.

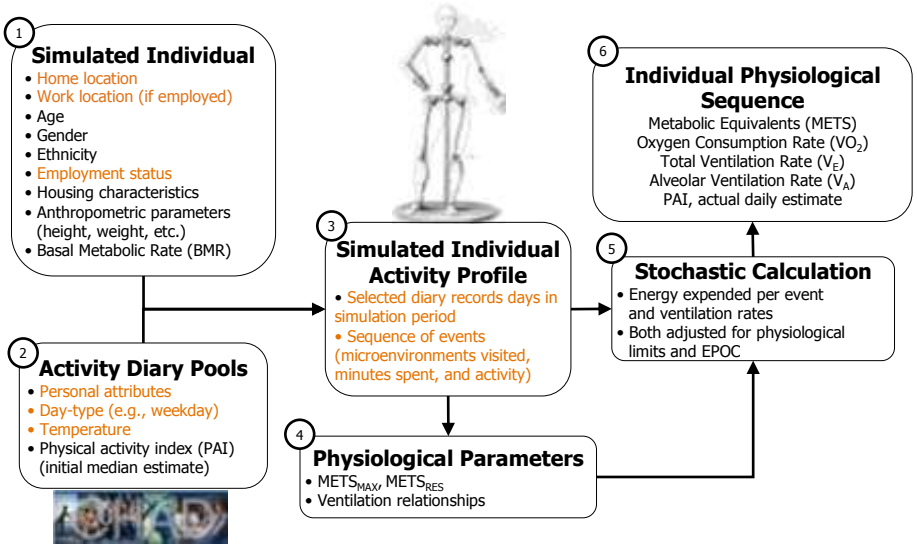
1.A Exposure modeling overview and principles

This report is focused on time use, physical activity, and physiological inputs needed for modeling inhalation exposures and intake dose rates, such as the APEX and SHEDS models. This subsection describes, in general terms, the approach, algorithms, and important variables used in both models. APEX is the primary air exposure model used by EPA's Office of Air Quality and Standards (OAQPS) to evaluate existing and proposed alternative National Ambient Air Quality Standards (NAAQS). APEX is also part of OAQPS's TRIM (Total Risk Integrated Methodology) program (U.S. EPA, 2008a, 2008b), along with the EPA's Hazardous Air Pollutant Exposure Model (HAPEM). HAPEM is a longer-term exposure model that uses many of the same activity and physiological inputs as does APEX and SHEDS (Palma et al., 1999), but functions primarily to evaluate exposures to hazardous air pollutants from mobile and stationary sources of air toxics. The SHEDS model is an "umbrella" term for NERL's Stochastic Human Exposure and Dose Simulation model, of which there are a series of route-specific versions (dietary/non-dietary, pesticides, etc.). It was developed by staff of the Human Exposure and Modeling Branch (EMRB) in NERL's Atmospheric Research Division (HEASD) and staff of Alion Science and Technology, Inc. The SHEDS model discussed here is oriented toward modeling exposures and intake dose rates for airborne pollutants (SHEDS-Air), but since the activity/time use and physiological concepts are similar in all of the SHEDS models, the findings reported here are more widely applicable to the modeling of all routes of exposure.

APEX and SHEDS now have similar features and input needs. Both use NERL's CHAD for their time use input data (McCurdy et al., 2000). CHAD, therefore, is discussed in some detail in this report.

There are a number of important principles that have guided exposure and intake dose modeling since 1980 (Johnson, 1995; McCurdy, 1995, 1997). In general, these principles apply to all groups and not just to the elderly. They follow:

1. **An individual is the unit of analysis (Figure 1-1)**. Each individual has a unique dose-response (D/R) relationship (National Research Council, 2009), which often is called a dose-effect curve (D/E) to distinguish it from the population-level D/R association. D/E uniqueness is due to genetic factors, pre-existing disease considerations, age/gender differences in biology, physiology, time use patterns [location and activities], and lifestage and lifestyle differences among people (Dörre, 1997; McCurdy, 2000). EPA's exposure models are designed to reproduce such uniqueness. Being elderly can greatly influence D/E relationships in individuals both directly and indirectly due to physiological changes, immune system challenges, neurological impairment (cognitive decline), and other physical alterations (Hertzog et al., 2009; Jette, 2006; Kiely et al., 2009).



Source: Dr. Stephen Graham, OAQPS

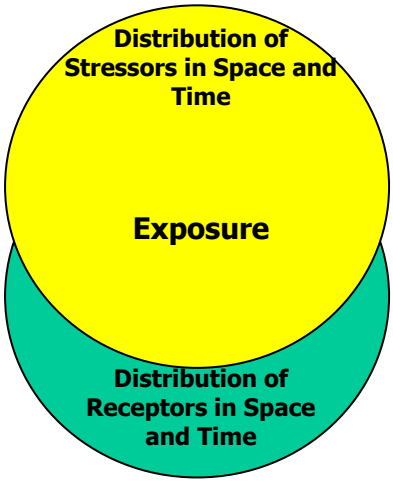
Figure 1-1. The individual is the unit of analysis. APEX and SHEDS constructs simulated populations based upon the above characteristics.

2. **Location** is critical to evaluating an exposure to an environmental pollutant (often termed a "stressor") since, by definition, exposure is the "contact between an agent [substance, pollutant] and a receptor [a person in our case]" (Figure 1-2). Contact takes place at an exposure surface over an "exposure period" (Zartarian et al., 2005),[2] directly implying a specific location. It should be noted that there is a correlation structure to location patterns in an individual, both within and among days; locations that a person inhabits cannot be modeled using a "random-walk" process. On the other hand, there is day-to-day variability in locations that any individual frequents (unless confined to bed or an institution), so using "averaged" data does not capture daily variability in this important exposure variable either (Glen et al., 2008). This point is elaborated upon under principles #12-13 below.

3. An individual is not averaged over time or space; a person can be in only one location at any particular time.

4. A location having a constant concentration (C_T) for a specified period of time is called a "**microenvironment**" (μE). Microenvironmental data are crucial inputs to an exposure model (locations and concentrations), and time spent in the various μE's vary greatly with age, gender, and lifestyle. In the APEX and SHEDS models, locational data come from CHAD, while μE concentration data are derived from ambient measurement data or route/pathway-specific model algorithms.

[2] From the "Official Glossary" of the International Society of Exposure Science.



Source: Adapted from NERL Framework for Exposure Science

Figure 1-2. A "Venn diagram" of exposure.

5. An **exposure event** is the smallest unit of time used in the two models and is characterized by a person being in a unique μE; undertaking a single type of activity, and therefore, experiencing a specific "activity-level." (See below.) By definition, an event does not cross a clock hour; longer activities are subdivided into two or more exposure events in that case (McCurdy et al., 2000). If any of these factors change, a new event occurs.

6. The event-based time pattern of concentrations experienced by an individual is called the **exposure profile**, or the exposure time-series. An example of an exposure profile is depicted in Figure 1-3. A number of alternative exposure metrics may be derived from this profile, such as the number of peak exposures over a specified concentration level, the mean exposure level, and the time-integral of exposures over some important value.

7. **Activity-level** is the amount of energy expended (EE) by an individual to complete the activity undertaken (in kcal or kJ/minute per kg). Other metrics performing the same function were used in the past by both OAQPS and NERL.[3] Activity level affects how much dose is received given an exposure. Activity-levels are correlated over time in an individual, since prior physiological circumstances affect subsequent ones when EE reaches individually-specific limits (Isaacs et al., 2008). These limits are determined, in

[3] Activity level generally was defined to be the breathing rate (L/min) associated with the activity. The EE metric is a more generalized approach to modeling activity level and accommodates non-air exposure modeling (McCurdy, 2000).

part, by an individual's age, gender, fitness level, and functional (health) limitations that may exist (Figure 1-4).

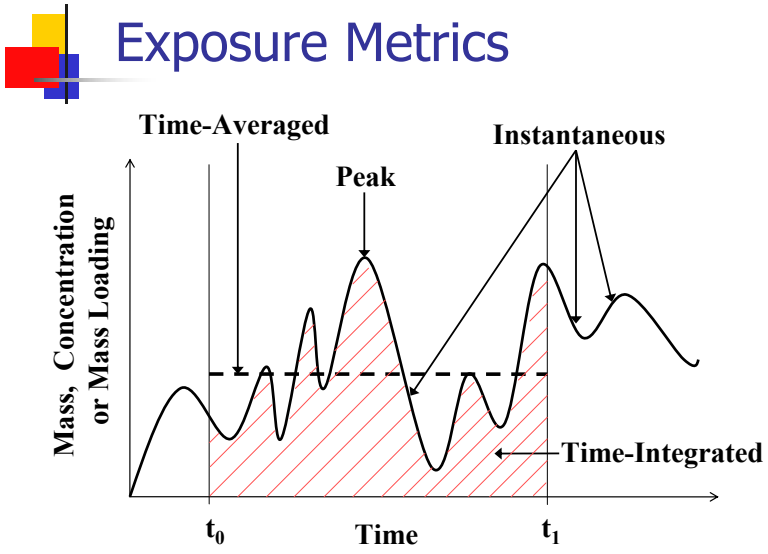
8. Work is defined to be **activity-specific energy expenditure**. In the APEX and SHEDS models, activity-level specific energy expenditure (EE_a) by an individual *i* (EE_{ai}) is estimated by multiplying an activity-specific relative energy value in "metabolic equivalents of work" ($METS_a$) sampled from a literature-derived distribution by the modeled person's basal metabolic rate (BMR_i).

   $EE_{ai} = BMR_i * METS_a$

   See Ainsworth et al. (1993) and McArdle et al. (2001) for a discussion of the METS concept. A person's BMR is dependent upon age, gender, health conditions, and lifestyle factors. Numerous equations exist in the nutrition literature for estimating BMR_i using a multitude of independent variables (Froehle, 2008; Müller et al., 2004; Schofield, 1985; Speakman, 2005). It is important to note that BMR in the elderly is quite different than for younger adults; see Section 2.B.

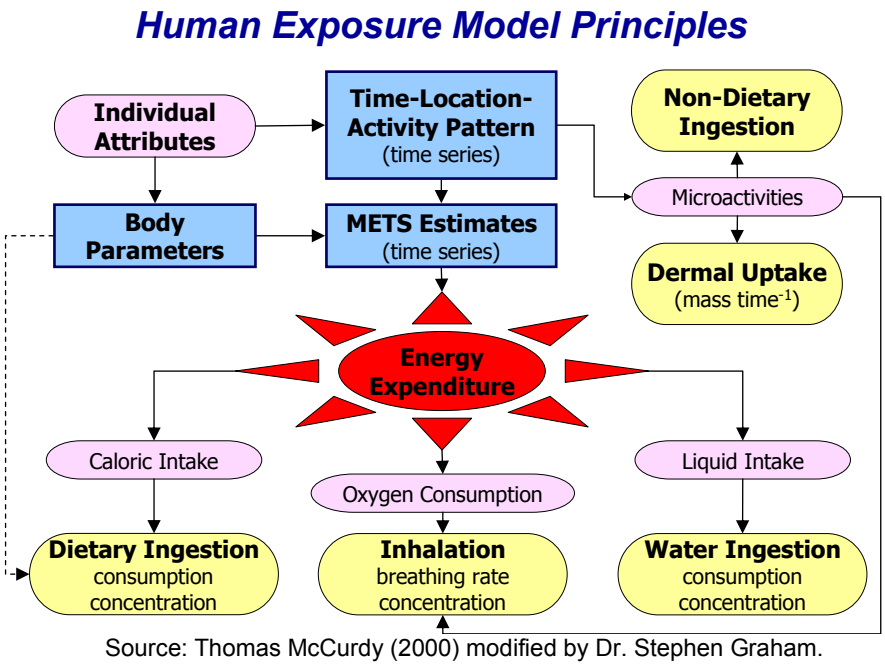
9. Given a μE exposure concentration, activity-level ultimately determines a person's **intake dose rate**, the amount of material inhaled, ingested, or absorbed into an individual (Figure 1-4). For inhalation exposures, intake dose rate is a function of the amount of air breathed per unit time multiplied by the μE concentration; its units ideally are in moles/min, but alternative metrics are sometimes used. The magnitude of intake dose rate is greatly affected by the amount of work being undertaken by an exposed person at the time of exposure. The pattern of intake dose rate experienced over time is often called the **intake dose profile**, and is similar in appearance to the exposure profile depicted in Figure 1-3.

10. A relevant **dose-metric** must be utilized to properly address individual dose-effect (D/E) or population dose-response (D/R) relationships (Lorenzana et al., 2005; National Research Council, 2009). However, in general, health effects are associated with the *time pattern of dose rate received* (Lippmann, 1989; McCurdy, 1997). Knowing this specific pattern (abbreviated as D_T / dt) allows any longer-term dose metric to be calculated, including dose levels exceeding selected levels one or more times in a year, the mean dose rate, and other metrics of interest. For example, an exposure assessment conducted for the most recent ozone (O3) NAAQS review U.S. EPA, 2007a) focused on 8-h peak exposures coincident with moderate or greater exercise levels occurring within a year. Multiple, short-term peak dose metrics like these cannot be uniquely determined from an aggregated, time-averaged dose metric. They can only be modeled using an intake dose rate simulation approach that calculates the time series of exposures such as that produced by the APEX and SHEDS models.



Source: Duan et al., 1990 as modified by Thomas McCurdy (1996)

Figure 1-3. Exposure metrics available from an exposure time-series.



Source: Thomas McCurdy (2000) modified by Dr. Stephen Graham.

Figure 1-4. Human exposure model principles. This schematic diagram illustrates the relationship between activity level, energy expenditure, and the intakes needed to maintain that activity level.

11. Multiple-route intake/uptake dose rates are correlated in an individual due to the **bioenergetics** of human metabolism. Basically this principle derives from conservation of mass and energy (McArdle et al., 2001). In contrast, "micro-activity" dose rate uptakes, such as non-dietary ingestion associated with hand-to-mouth or hand-to-surfaces activity--of concern with respect to environmental exposures of children--are **not** directly associated with bioenergetics, but are related to age/gender differences in behavioral characteristics of children inhabiting a particular location. Thus, there is a correlation among pathways, and it is maintained in SHEDS-Multimedia by basing dietary and water consumption, as well as ventilation rate, on activity-level considerations. Micro-activity intake dose rate modeling will not be considered further in this paper. See Tulve et al. (2002) or Xue et al. (2007) for a discussion of micro-activity exposure modeling. For modeling air route exposures to the elderly, we assume that there is no non-dietary (or dietary for that matter) ingestion due to hand-to-mouth activity in that population. This assumption can be evaluated if data on non-dietary mouthing behavior become available for older people.

12. There are seasonal, day-of-week (or workday/non-workday), and meteorological (temperature and precipitation) **differences** in time use within and among individuals (Fisher et al., 2005; Hill, 1985). EPA exposure models maintain the time-use patterns via targeted selection of appropriate CHAD diaries for each day of the simulated year for each individual. This is another reason why average time use data are deficient in capturing and interpreting what people do in time and space.

13. There are day-to-day **similarities and differences in locations inhabited and activities undertaken** by an individual, and among individuals within a larger population cohort (Xue et al., 2004; Glen et al., 2008). These similarities and differences are affected by the contextual culture of a society, habits, and technology. Viewed over time, there is a structure to these effects, resulting in longitudinal patterns of locations visited and activities performed in a population (Echols et al., 1999, 2001; Frazier et al., 2009; Glen et al., 2008). Ramifications of this observation are that both intra- and inter-individual variability have to be addressed in an exposure modeling effort, as well as day-to-day correlations within an individual.

14. There are **long-term patterns to a person's use of time**—called "tracking'—that can be addressed analytically to some extent in multi-year exposure modeling (Elgethun et al., 2005, 2007). Tracking is greatly affected by changing physiological, functional limitations, and housing pattern changes in the elderly. It is difficult to obtain information on this subject, except in the physical activity literature; see Section 5.

15. Because of the inherent nature of the risk assessment process where judgments have to be made regarding uncertain future events, including intake dose rates associated with inhaling a pollutant by population subgroups undertaking multiple activities in many locations, said assessments often use a stochastic simulation modeling approach (Jordan et al., 1983; Ott et al., 1988). A simulation model facilitates evaluation of variability and uncertainty in parameters of the model, often ignored in many exposure modeling efforts.

Uncertainty in the model structure itself, however, can only be addressed by using a different model and comparing output estimates to measured data. This rarely is done due to resource limitations.

1.B Functional structure of the APEX model

How these principles are implemented in the APEX and SHEDS-Air models appears as Figure 1-5. Those symbols and abbreviations not already described above are defined in the list of Abbreviations, Symbols, and Acronyms used (p. 7). The Figure depicts the event-based exposure and intake dose rate simulation logic frequently used in the two models. Specific applications of them may differ in the details depicted. Major model inputs are shown outside of the dashed-line portion of the Figure; they are (1) environmental concentration data, (2) U.S. Census population data, (3) CHAD time use data, and (4) daily meteorological data for the geographical area being modeled. This review focuses on the model processes inside the dashed line portion. Because some of the inputs differ between the APEX and SHEDS models--and among different applications of either one of the models--it would be tediousfor the reader to continually distinguish among the versions. The following discussion is oriented toward a generalized ideal APEX model.

Area of analysis and population groups of concern. APEX usually is applied at the community or urban scale level for three specified air quality conditions, generally described by a period of time: (1) some past time period having a measured (or modeled) ambient concentration field data, and (2) current (or *as is*) air quality conditions also using either measured or modeled concentrations, and (3) some indefinite future time when environmental concentrations just meet one or more alternative standards being evaluated. Comparing outputs for these three scenarios provides a quantitative estimate of the "effectiveness" of each scenario modeled. An example is New York City for *as is* conditions in 2007 versus just attaining a specified standard level occurring at some future time. (This approach is called a "***standards objective***" analysis. If a *specific control scenario* is evaluated, usually compared to an alternative control approach, it is called a "***standards impact***" assessment. (See Feagans, 1986.) The population groups of concern may be the entire population or a specific portion of it: exercising children (a small subset of U.S. children) was the focus of EPA's recent O3 NAAQS exposure analyses (U.S. 2007a, b). Older adults with compromised cardiovascular systems (COPD, angina, etc.) will likely be an important subpopulation to consider for modeling exposures in the next particulate matter (PM) NAAQS review.

Environmental concentration field. An environmental concentration field, or profile, is estimated for all outdoor locations in the selected geographic area, often referred to as the modeling domain. This concentration field may be measured (monitored) and/or modeled ambient data, the latter data are usually used for future-time air quality scenarios. The output of this step typically is a time series of hourly concentrations for every hour of the day during the modeling period: usually over an entire year. See **Sequence of Hourly Environmental Concentrations** depicted inside of the dashed lines in Figure 1-5.

Microenvironmental-specific concentration estimates are developed from these hourly concentration profiles. If a person is outdoors, the hourly environmental concentration ($C_{OUT.h}$) value itself often—but not always--is equivalent to the ambient concentration and used for this μE for the duration of the exposure event. In other words, every C_t is the same as the hourly $C_{OUT.h}$ value. Note that if there is within-hour variability in C_{OUT}, then $C_{OUT.t}$ would be based on the sub-hourly time period of concern, such as 5-minutes used in the SO_2 NAAQS review.

If a person is indoors or inside a motor vehicle, the concentration within that μE depends upon a variety of chemical/physical factors, such as the chemical deposition and removal rates, air exchange rate, and indoor source strengths. There have been a number of approaches used to model these factors over the years, but three are most commonly used:

1. solving a mass-balance equation for the specific location.

2. sampling from literature-derived "indoor/outdoor" ratios specific to the μE being modeled (McCurdy, 1995).

3. using a linear regression-based algorithm that relates outdoor-to-indoor concentrations (the regression slope), with an additive term (the regression intercept) for indoor sources.

The number of indoor locations used in EPA's exposure models range varies with the pollutant being analyzed, but is generally between 7 and 27 specific locations. Usually <10 locations are used. Some examples are (1) home, (2) work, (3) school, (4) retail establishments, (5) motorways, (5) retail stores, and (6) a "residual" location: "other indoors." Outdoor locations are also subdivided, but the concentration assigned to them may be the ambient concentration estimate noted above. The output of these steps is a time-series of μE concentration estimates $\{C_1, C_2, C_3 \ldots C_T\}$ for all outdoor and indoor locations that the simulated population may inhabit. See Figure 1-5.

It is possible to model more μE's than the 7-27 locations noted above, but input data to calculate the μE concentration are limited for many locations. Most time use studies use a hierarchical locational coding scheme, some down to individual rooms in a home, but rarely do subjects provide data on time spent in them, even for contemporaneous diary studies. (Where subjects are supposed to record in some manner where they were at the time, with a new entry for every location inhabited.) Remembering specific locations in the commonly-used *ex post* time use recall surveys done over the phone ("What did you do yesterday ?") is almost impossible. Misleading modeling results would occur for specific locations using most recall survey data for exposures in detailed μE's, as there would be a lot of false negatives ("0 time") spent in isolated locations of interest. Thus, only a handful of general microenvironments are considered in most exposure modeling efforts.

There is a lively literature on the diary versus recall protocols used to gather time use data; see Ås, 1978; Collopy, 1996; Fenstermaker, 1996; Geurts & De Ree, 1993; Harvey, 1993; Nickols & Ayieko, 1996; Niemi, 1993; and Stinson, 1999, among others. CHAD contains both recall and

contemporaneous diary time use information. See Section 4 for a more detailed discussion of time use data.

Census data. U.S. Census data is a major input to EPA's exposure models. The data are used to define how many people are within the modeling domain and their age, gender, employment, housing, and commuting characteristics. The proportion of people in each one-year age category by gender for the population groups of interest is derived from the Census data and governs the number of simulations undertaken. The Census also provides frequency distributions of work commuting trips among every census tract in the U.S. (centroid to centroid distances). These data provide an estimate of commuting trips between any pair of census tracts in the area being modeled (e.g., U.S. EPA, 2007).

After characterizing the simulated population, development of an actual "pool" of simulated persons begins. Suppose that we are interested in modeling the exposures to 45-65 y old workers of both genders. A single person within that age range is randomly selected; say it is a 65 y old female. That person has some probability (using the Census data) of living in a single family residence having gas heating and cooking. A random draw from this probability distribution will "assign" the person to a single housing type based on the Census probability. Work (paid)/or non-work status is determined from Census probabilities for the subject's age/gender combination. If a worker, the subject will be assigned to a work "district" (census tract) location based on Census commuting probabilities. Thus, the simulated example person is characterized by a specific age, gender, housing type, and home and work location. Additional characteristics are sometimes used if warranted. This could include variables such as health status, body mass index, etc., all "defined" by population probabilities that exist in additionally provided external data—but not in the Census. For example, additional information is needed to determine, the proportion of asthmatics aged 65-69 y relative to the total population residing within the modeling domain. Activity patterns explicit for people having specific health conditions are uncommon, thus judgments are used to determine the appropriateness of available diary data for use in the assessment (typically not available for the health compromised). If the existing activity data do not reflect what people having a health condition do in time and space, then selected attributes of the diary information have to be adjusted to better represent time use patterns of the modeled group. Sensitivity analyses can then be implemented to evaluate the implications of making these modifications.

This process is repeated until the simulated population has proportionally the same characteristics of the Census-derived population data.

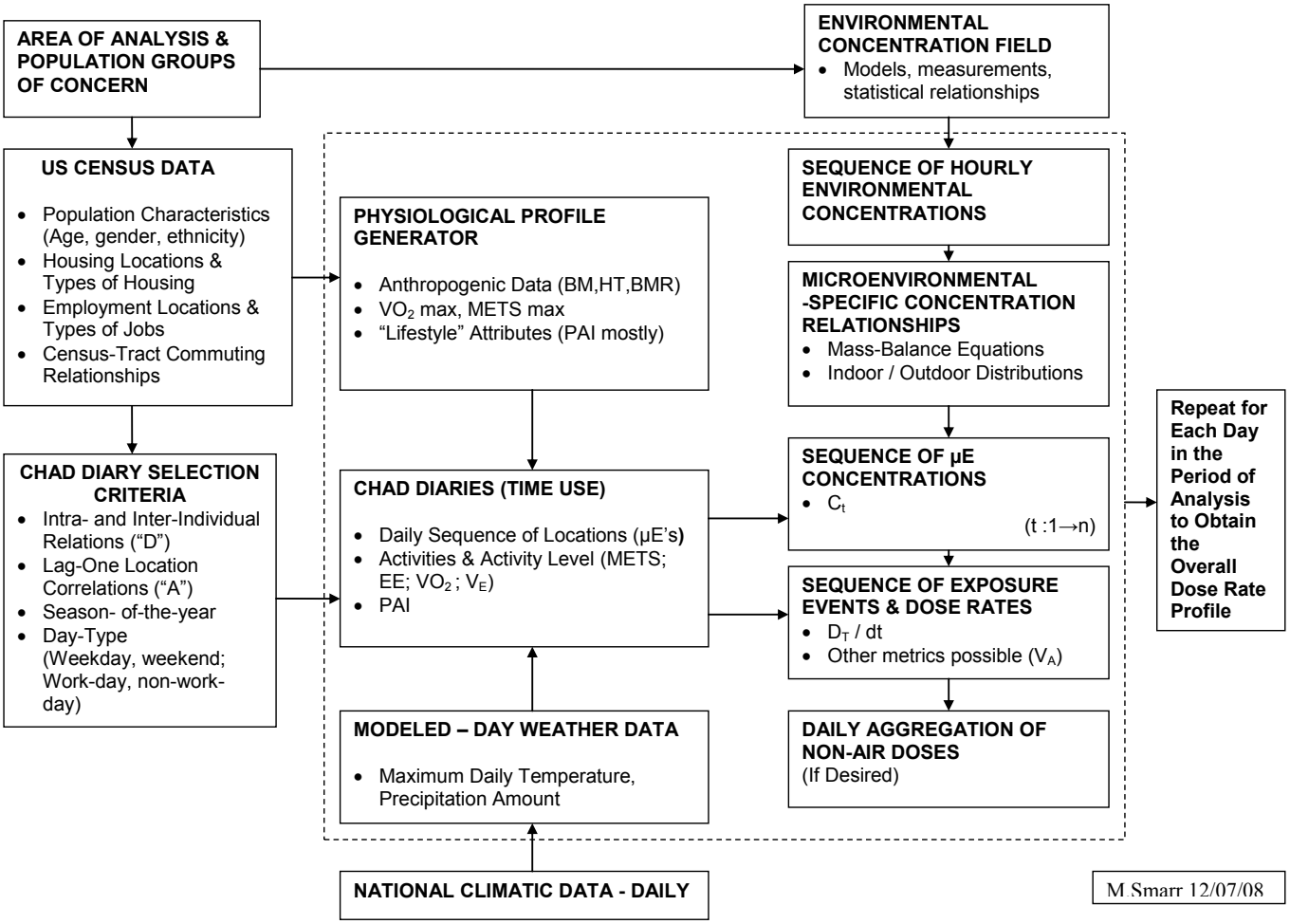


Figure 1-5. APEX/SHEDS exposure simulation process.

Physiological Profile Generator. Physiological characteristics are needed for every simulated person in the population pool. The main inputs required to do so are derived from the person's anthropogenic data, such as age, gender, weight (body mass: BM), height (HT), Body Mass Index (BMI), and health status variables that might affect a person's physiology (e.g., asthma, cardiovascular problems, poor fitness, etc.). Basal metabolic rate (BMR) is a very important bioenergetic parameter, as we shall see, and it is derived from the age, gender, BM, and HT data for each person. While a number of equations are available for estimating BMR, and the APEX and SHEDS models currently use the Schofield (1985) set of equations that account for variability in age, gender, and body mass. Due to criticisms that the Schofield (1985) derived equations may not reflect current population characteristics, such as the higher BM and larger BMI[1] seen in the current population (Frankenfield et al., 2005; Livingston & Kohlstadt, 2005), the BMR equations used in APEX and SHEDS will change in the near future.

The variables mentioned above also affect a person's maximal oxygen consumption rate ($VO_{2.Max[i]}$), which in turn places an "upper limit" on the amount of air that a person can breathe at maximal exercise ($V_{E.Max[i]}$); see Blomstrand et al. (1997). Using commonly-available physiological relationships (McArdle et al., 2001), $VO_{2.Max[i]}$ can be directly related to a person's $METS_{Max[i]}$. As noted above, METS are activity-specific "metabolic equivalents of work" based on the ratio of energy expenditure (EE) needed to undertake an activity (EE_A) to a person's BMR_i (Ainsworth et al., 1993, 2000). Activity-specific VO_2 is a function of a person's $VO_{2.Max[i]}$ and prior event work rates (EE) undertaken (Isaacs et al., 2008).

Activity-specific METS, EE, VO_2, and breathing rate (V_E) are all related to each other via well-accepted physiological principles (Isaacs et al., 2008). However, there is still a lot of uncertainty regarding applications of the known principles to actual cases, with limited knowledge concerning the relationship among fitness level, lifestyle, and the physiological parameters mentioned. Many of these uncertainties are amenable to sensitivity analyses, so that implications of the assumptions and relationships used can be quantitatively addressed. If needed for a particular standard assessment, alveolar ventilation (V_A) can be derived from the V_E estimates; OAQPS staff currently is working on defining new $V_E \rightarrow V_A$ functional relationships for use in the APEX model, assisted by EMRB staff.

CHAD diary selection criteria. CHAD has 34,773 person-days of diary data available for use in the APEX and SHEDS models. About 41% of them (14,249) are single-day (cross-sectional) diaries. The remainder has between 2-369 days of data per person. See Table 1-1. To simulate year-long activity patterns requires that single-day diaries be sampled multiple times—a problem that exists with every exposure model because of the dearth of longitudinal time use data. We have developed a method (called the "D&A" approach) of simulating longitudinal activity patterns based upon (1) maintaining the intra- and inter-individual variability in time use seen in the few repeated-measures analyses of variance that have been undertaken on multi-day surveys, and (2) replicating the day-to-day correlations within individuals in the time spent in selected, important

[1] BMI = BM (kg) / HT^2 (m); a widely-used index of relative fatness.

locations. The method is quite complex but is logically straight-forward and runs fast in the simulations; see Glen et al. (2008). In essence, the method "imposes" only as much habitual behavior on individuals and the population (as a whole) that is described in the literature. See Section 4.E for additional discussion of the method and metrics used to implement it.

Conflating CHAD diaries / time use data with the physiological profiles. The crux of APEX and SHEDS is combining simulated individually-specific time use data (activity/location) and concentration patterns with simulated activity-specific breathing rates ($V_{E.A}$) to obtain intake dose rates. The first step in doing so is to match simulated people with their appropriate diary pool, including seasonal and daily meteorological constraints on human activities. Day-specific National Climatic Center (NCC) data are used to classify every day into one of 8 **seasonal and meteorological categories** (4 temperature classes and 2 precipitation categories: "none/trace" and >0.5" per day). These become "diary day bins" for the model simulations. Bin definitions are not fixed but are defined according to the simulation objectives.

The simulations are undertaken on an event-by-event basis, starting at midnight on the first day of the analysis period. For each person, a diary is selected from the appropriate bin and a breathing rate is modeled for each event undertaken. This is repeated for the daily sequence of activities, and the output is a string of hourly-averaged V_E estimates developed from event-specific EE estimates. A daily Physical Activity Index (PAI) is calculated from the time-weighted average of the sum of all the event-specific EE estimates for the day. PAI can be used to provide a check on the physiological modeling procedure used in APEX and SHEDS (McCurdy and Xue, 2004) and as a *surrogate* for a person's lifestyle and fitness level. In fact, each person's median PAI can be calculated directly from the CHAD data, and could be one of the physiological metrics used to develop the diary pools in the first place (see above).

Table 1-1. Summary of the CHAD database.

Study Name	Year*	No. of Diaries	Number of Days Of Data per Person: Range	Median	Sponsor
Denver MSA	1983	805	1	1	EPA
Washington DC MSA	1983	699	1	1	EPA
Cincinnati MSA	1986	2,614	1 - 3	3	EPRI
California - adolescents	1988	183	1	1	CARB
California - adults	1988	1,579	1	1	CARB
Los Angeles - elementary	1989	51	3	3	API
Los Angeles - high school	1990	43	2 - 3	3	API
California - children	1990	1,200	1	1	CARB
Valdez AK	1991	397	1	1	Oil Companies
NHAPS - A	1994	4,723	1	1	EPA
NHAPS - B	1994	4,663	1	1	EPA
PSID (CDS) I	1997	5,616	1 - 2	2	NICHHD
Baltimore Elderly	1998	391	1 - 24	14	EPA
EPA #1	2000	367	367	367	EPA
RTP Unhealthy	2001	1,000	8 - 33	32	EPA
Seattle MSA	2002	1,693	5 - 10	10	EPA
EPA #2	2002	197	197	197	EPA
PSID (CDS) II	2003	4,782	1 - 2	2	NICHHD
RTI Averting Behavior	2003	2,907	1 - 6	4	EPA
Internal EPA	2007	432	35 - 69	54	EPA
EPA #1	2007	369	369	369	EPA
Mother & Child	2008	62	31	31	EPA
Totals		34,773			

Notes & Abbreviations

* The last year of a multi-year study is used.

Number (of days)

API = American Petroleum Institute

CARB = California Air Resources Board

CDS = Child Development Supplement

EPA = Environmental Protection Agency

MSA = Metropolitan Statistical Area

NHAPS = National Human Activity Pattern Survey (A=air version; B=water version)

NICHHHD = National Institute of Child Health and Human Development

PSID = Population Study of Income Dynamics

RTI = Research Triangle Institute

RTP = Research Triangle Park

All of these steps use stochastic processes. The C_i estimates are partly the result of sampling from known or approximated distributions of mass-balance equation parameters (or from indoor/outdoor μE relationship data). Monte Carlo techniques are used for this sampling. The same is true for most of the physiological parameters needed to estimate energy expenditure, oxygen consumption, ventilation (breathing) rate, and alveolar ventilation rate, if needed. This stochastic approach is used to ensure that population variability is addressed regarding the parameters of interest.

Modeling Intake or Uptake Dose. The second major step in estimating exposure and dose patterns is to combine the μE-specific concentration field with the physiological profiles described above. The simulated person goes through her or his day, comes in contact with a concentration (or not) on an event-by-event basis, and receives a dose based upon the estimated activity level. When the day is completed, the next day is modeled for the person, continuing for every day in the simulation period, usually a year. The entire process is repeated for every individual in the simulated population.

Intermediate model outputs (for inhalation exposure analyses) are **strings** of 1 h averaged exposure estimates, 1 h averaged V_E estimates, and 1 h dose estimates (e.g., E * V_E) for each person, plus any aggregation of them for whatever time period is of interest.[2] This is the dose profile mentioned earlier. For O3, for example, the main APEX output of interest is the number of 8 h daily maximum (the highest 8 h in each day) incidences of exposures when people, especially children, were exercising at $\geq$27 L min^{-1} m^{-2} (this is a body surface area normalized ventilation metric). An illustration of this type of model output appears as Figure 1-6. It depicts the 8 h daily maximum exposure estimates for 3 population groups in 12 Metropolitan Statistical Areas for one air quality scenario: 2002 air quality just meeting the current O_3 8 h daily maximum standard. Five other scenarios were evaluated (not shown). Separate sensitivity analyses of many of the model parameters were simulated in this assessment, giving an estimate of confidence intervals about the percentage values depicted in Figure 1-6, (though not shown in the Figure).[3] A more thorough discussion of this sensitivity analysis is presented in U.S. EPA (2007b).

Modeling Response to a Dose

The next step after modeling the dose profile is estimating a response—adverse or not—from the time pattern of dose rate received. The loci of the response eventually will be at the cellular level, but currently is at the organ level or at a "whole-body" systems level, using some type of toxicokinetic modeling approach. EPA has funded a number of reports describing how this approach can be used to model adverse health effects to the

[2] The same metrics could be saved on an event-time basis, the smallest time interval used in the models, but usually the data are summed to an hour, and saved on that basis.

[3] The SHEDS model directly includes uncertainty analyses in its simulations, and provides the same type of output in cumulative distribution format. It thus combines in one output estimates of population variability and uncertainty in that variability. OAQPS has found that approach to be difficult to explain to decision-makers, and so uses the two-step approach to addressing variability and uncertainty.

elderly associated with exposures to xenobiotic substances. See Hattis & Russ (2003), Ginsberg et al. (2005), and Krishnan & Hattis (2005) for *example* risk assessment documents focused on the elderly. While dose-response and toxicokinetic modeling are needed to explicitly define health effects associated with intake dose rates, the topics are discussed extensively in the scientific literature and are really one step removed from the exposure/intake dose modeling focus of this report.

1.C Exposure model evaluation

The APEX and SHEDS models have received only a limited amount of evaluation against measured personal monitoring data over the years. In general, OAQPS compares some of their exposure estimates against personal monitoring data but usually the latter are for longer averaging times than those of interest in the exposure assessment. For instance, OAQPS compared O_3 exposure estimates for children against weekly average personal monitoring data obtained for a few weeks in 1995-6 in two separate areas of San Bernardino County: urban Upland, CA and two small mountain towns (Langstaff, 2007; U.S. EPA, 2007a). That was the only data set available to the Agency for such a comparison, even though it was relatively old and based on a longer averaging time (6-7 days) than of interest in the assessment (1h or 8 h daily exposures). The APEX model performed reasonably well in the mid-range of the cumulative distribution of weekly exposure estimates (20-70 percentiles), but systematically overestimated the low end of the exposure distribution and systematically underestimated the high end (U.S. EPA, 2007a). This phenomenon has been found in all synoptic short-to mid-term model evaluation efforts that the author is aware of: Burke et al. (2001), Law et al. (1997), Ott et al. (1988), and Zartarian et al. (2000, 2006). The over-estimate of low-end exposures is not of much interest, since health risks associated with low-end exposures generally are not of regulatory concern (McCurdy, 1995). The probable cause of systematically underestimating high-end exposures is due to the models' inability to "mimic" **repeated** daily activity patterns that lead to high exposures seen in the measured data (Law et al., 1997). Thus, the main reason for model underestimation is basically a longitudinal time use issue, although the current D&A procedure may reduce activity variability over time and improve model performance. The impact of using the D&A approach has not been thoroughly evaluated with respect to exposure model output distributions. In practice, EPA decision-makers must qualitatively factor in underestimated high-end exposure/dose risk estimates when deciding upon how much protection exists in each of the alternative environmental standards being reviewed.

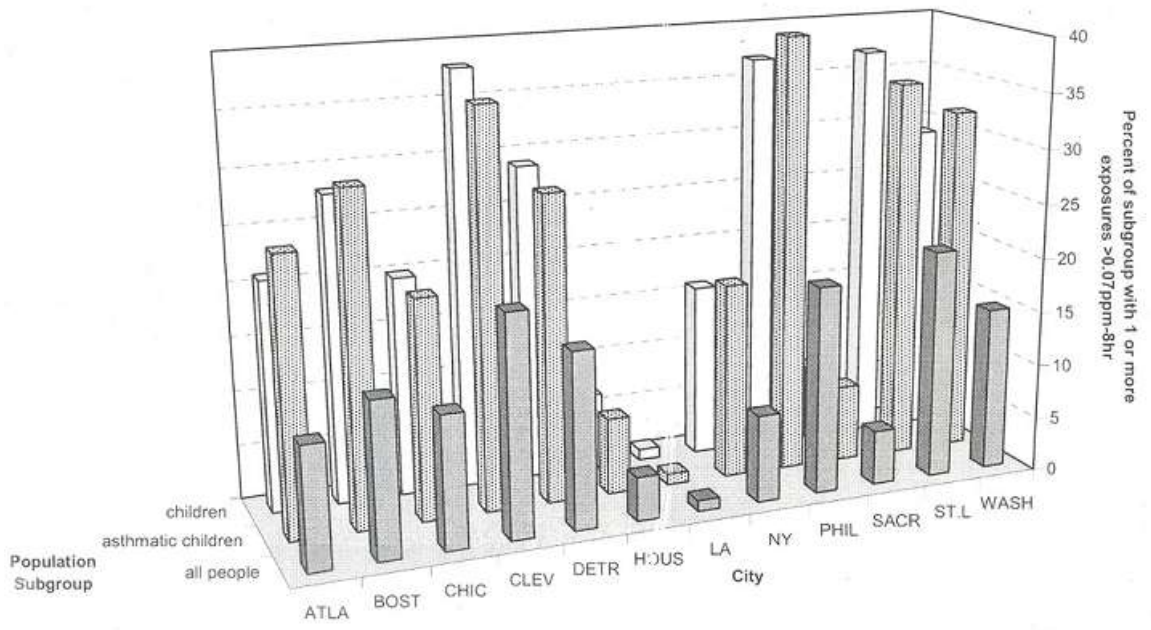


Figure 1-6. Percent of people in 3 groups—all children, asthmatic children, and all persons—estimated to experience 1+ days with an 8 h daily maximum O_3 exposure >0.07 ppm while at moderate exercise when the current 8 h daily maximum NAAQS of 0.08 ppm is just met.

The impact that time use data *per se* has on APEX exposure modeling results has received a limited amount of "uncertainty" (actually, sensitivity) analyses (Nysewander et al., 2009). These analyses consisted of 5,000 simulations of seven time use variables in two urban areas, Atlanta and Boston, using the APEX model. The locational codes used in CHAD were collapsed to twelve aggregated locations that accounted for all places visited by every individual in the simulations. (All 24 h were accounted for, in other words.) A number of "impact" indices were used to describe sensitivity: time spent in each microenvironment, daily average and one-hour maximum O_3 exposure estimates, and distributional tests. The seven variables included:

a) Selection of the appropriate intra- and inter-individual statistics to combine diary days into longitudinal patterns.
b) Choice of the "key location" used to sort the above statistics (e.g., in-vehicles versus outdoor time).
c) Differences in start and stop times for the diary day: all events were shifted forward and backward one hour.
d) Using diaries from different years to test changes in time spent outdoors by children (there was a 5.2 min decrease per year in this time for CHAD diaries from the 1980's to the 2007's).
e) Alternative assignments of "ambiguous location codes" to either indoors or outdoors (e.g., travel by boat—indoors or outdoors?).
f) Modifying the diary "weights" used in the NHAPS survey.

g) Level of detail in the diaries: short events were collapsed into longer durations of 2, 5, 10, and 15 min durations.

Using the exposure impact indices, differences between the various simulations were greater than simply selecting diaries at random, but the differences were small: ~1-2% versus ~0.2-0.5%. The one exception was **age** of the diary data itself: the year the data were obtained. Using the older diaries *increased* exposure estimates by ~1.5-21.8% (Nysewander et al., 2009), mostly because high-end O_3 exposures are associated with time spent outdoors, which has decreased over the years. However, this finding may be a result of how the diaries themselves were coded for the different μE's, and not a function of age of the diary. More work on understanding the impacts of age of diary data is needed before a definitive conclusion can be made about the topic.

It should be noted that obtaining longitudinal personal exposure data is extremely expensive, especially when using "active" short-term monitors (as opposed to passive long-term "diffusion tubes" that are based upon Brownian movement). Active personal monitoring involves attaching a monitor having a small pump to each individual on a daily basis, usually at the subject's home at a preselected time. Active monitoring requires a field staff, multiple (expensive) monitors, and detailed logistics. These types of studies also involve collecting time use data. Needless to say, these are invasive protocols, and it is difficult to retain subjects for periods of time longer than a week at a time. A monitoring study—passive or active--reflects "the state of nature" at the time of the study, including the unique societal and environmental conditions present at that time. Since these conditions generally will not be present at some future time when environmental control scenarios being modeled are implemented, there is uncertainty concerning applicability of exposure/dose relations found in the past in one area being applicable in another area at a different time. From the modeling perspective, the best use of monitoring data is to "ground-truth" performance of the model itself.

We recommend that the Agency undertake a concerted sensitivity/uncertainty evaluation of the APEX and SHEDS models following the principles advocated in Saltelli et al. (2000). The work can be done in-house and would provide insights into those variables and parameters in the two models that significantly affect their output distributions.

1.D Section 1 concluding comments

As we shall see in subsequent Sections of this report, there are quite large differences between the general adult population and the elderly in how and where the elderly as a group spends time, travels, undertakes physical activity, and how much of their physical work capacity is spent on the normal activities of life. There also are large differences among elders themselves regarding these attributes. We explore these issues further from an environmental exposure modeling perspective. These within-group differences result in large inter-individual variability in exposure and dose profiles in the elderly, not often addressed in exposure modeling applications for this population subgroup. There also is

a surprising amount of intra-individual variability in elderly time use and physiological inputs, and this rarely is addressed in current modeling efforts. (APEX addresses intra-individual variability to some extent, as noted above; SHEDS has not utilized the approach to date but will do so in the future.) Intra-individual (within-person) data are provided wherever possible in the following Sections, but such information is difficult to obtain.

Besides the citations provided above, there is a wealth of general information available on the elderly, including trends over time in their health and well-being, quality of life, lifestyle, and living accommodations (Birren et al., 1991; Crimmins, 2004; Federal Interagency Forum, 2006; Lawton, 1991; Simon et al., 2001). Basically, people are living longer and are healthier than they have been in the past but just recently have gotten more overweight/obese (Zamboni et al., 2005). U.S. Census and other projections of the *numbers* of elderly people that are expected in the future indicate that they will be an ever-increasing percentage of the total US population. The projections only affect our estimates of the numbers of people that belong to a particular subgroup of concern, but will not affect our modeling procedures.[4]

Some caveats to this report. We do not discuss certain "extra-biological" considerations that may affect how the elderly responds to exposure to xenobiotic substances. Some of these considerations might moderate disease progression given an exposure. They include religious views and practices of the elderly and their psychological makeup (Olman & Reed, 1998; Sloan & Wang, 2005). While important considerations in the etiology of disease once exposed, we have no *a priori* data on these factors to use in our exposure models. Similarly, possible differential cognitive affects on exposure are also slighted given the lack of information on the topic. If better data become available on these issues, we could simulate their impact on health end points via our stochastic approach. This is not a theoretical or even a methodological problem from the modeling perspective, in other words; it is a data input problem. The transparency of a model, albeit complex, allows outside interested observers to interject their own parameters to see what happens under alternative assumptions.

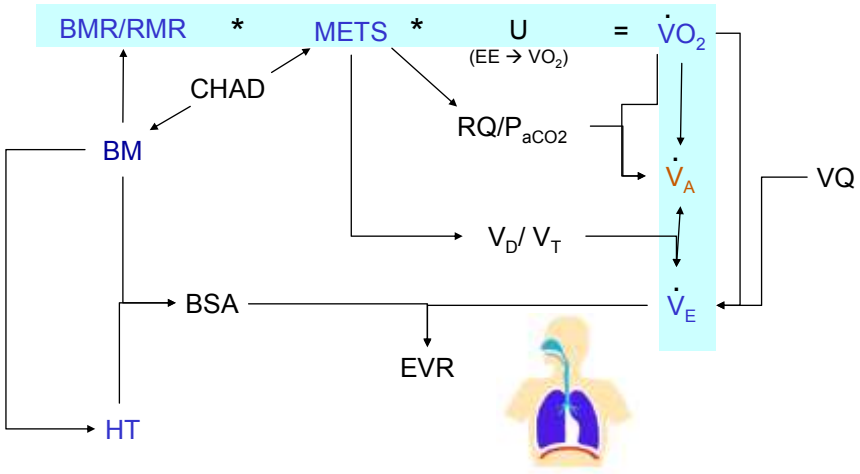
In sum, the elderly population is increasing rapidly, both in the U.S. and worldwide (Goulding et al., 2003). They will become an important population subgroup from an exposure modeling perspective, and not just for particulate matter. For a discussion of the detailed type of information that we need as inputs to our exposure models, or to evaluate their performance, we turn to the broader literature regarding anthropogenic and physiologic studies of the elderly.

[4] However, appropriate physiological parameters relevant to changing elderly body composition—such as increasing body mass--would be needed to reflect the current situation.

2. Adjustments to Anthropogenic and Physiological Inputs to the APEX and SHEDS Models when Modeling Elderly Populations

Topic: This chapter covers the the physiological input data required by EPA's human exposure models and identifies the data sources available to parameterize these variables for aging or elderly persons.
Issue /Problem Statement: In most cases, the population distributions of these physiological characteristics differ between the general population and the elderly, and thus may directly impact exposure estimates for older persons. Unique, age-specific distributions for the elderly should be developed.
Data Available: In general, due to the extensive general physiology literature (even in the elderly), this topic is quite data-rich.
Research Needs: The identification or collection of additional data on maximum oxygen consumption and maximal METS in the elderly are needed, although these data are difficult to come by due to limitations on maximal exercise testing for this age group. The development of better age-dependent estimates of basal metabolic rate should also be a priority.

A more detailed look at some of the anthropogenic and physiological variables in the APEX and SHEDS inhalation exposure models appears as Figure 2-1. Variables depicted in this Figure are listed in Table 2-1. The structure of the modeling logic applies to all population subgroups, but we will emphasize those variables needed to model the elderly as a unique population. Note that most of the respiratory variables are rates (*per* unit time, such as L / min) and as such are normally depicted with a "dot" over the V symbol. However, because Microsoft Word does not allow overstrikes, except in "equation writer", the dots are not depicted in our discussion. This may cause some confusion, since V is also used in the physiological literature to represent "volume," such as "dead space volume" (V_D) and "tidal volume" (V_T). Those metrics are often normalized by body mass, and have units of L / min-kg (or L / kg-min or L min^{-1} kg^{-1}). The negative exponential format is the one used most often in the physiological literature.



Source: Dr. Stephen Graham.

Figure 2-1. Activity-specific metabolic and ventilation metrics used in EPA exposure models.

Anthropogenic and physiological variables used in our models follow; not all of them are depicted in Figure 2-1, but are mentioned due to their widespread use in the physiological literature. Our units are all in the SI convention except EE, where kcal is used (1 kcal=1,000 calories). The SI unit is the Joule (J); 1 kcal ≈ 4.184 kJ or 1 KJ ≈ 0.239 kcal. Kuczmarski et al. (2000) provides descriptive statistics from the 1988-1994 National Health and Nutrition Examination Survey (NHANES) for a number of important anthropogenic parameters used in our models.

Table 2-1. Variables used for activity-specific metabolic and ventilation metrics used in APEX and SHEDS exposure models

Variable	Definition and Source of Data
A:	Age: [years]. Obtained from U.S. Census data.
G:	Gender. U.S. Census [female (♀), male (♂)]. Obtained from U.S. Census data and generally treated as a nominal variable.
BM:	Body mass [kg]. Random-sample BM from age/gender-specific NHANES distributions and assign the "realization" to a simulated person [kg].
BMI:	Body mass index [kg m^{-2}]. Calculated from BM / HT^2.
BMR:	Basal metabolic rate [kcal/time period]. Calculated from age/height data using (currently) the Schofield (1985) equations [in kcal min^{-1}, or kcal min^{-1} Kg^{-1}, kcal day^{-1}, kcal $24h^{-1}$, etc., as appropriate].
BSA:	Body surface area [m^2]. In APEX, BSA is estimated from body mass using an exponential relationship reported in Burmaster (1998): $BSA=e^a * BM^b$..
EE_A:	Activity-specific energy expenditure estimates (EE_A = BMR * $METS_A$) [kcal min^{-1} for the activity duration]; CHAD contains activity-specific distributions of METS; see below.
EI:	Energy intake [kcal per some defined time period]. We do not currently use EI in our exposure models.
EVR:	Equivalent ventilation rate [L min^{-1} m^{-2}]. A BSA-normalized total ventilation rate (V_E). This parameter has been used in the APEX exposure assessments for ozone and SO_2.
FFM:	Fat-free mass [kg]; also called lean-body mass (see LBM).
HR:	Heart rate [beats/min]. This variable is not used in our exposure models to date.
HT:	Height [m]. Derived distributions from NHANES age/gender-specific measurements in the overall population.
LBM:	Lean body mass [kg]. The amount of bone and muscle mass in the body; muscle is the primary component of LBM by weight. It does not include non-subcutaneous fat. Generally it is quantified by subtracting an *estimate* of fat mass (measured indirectly by a variety of methods) from total BM. Most physiological parameters have improved relationships with one another when normalized to LBM rather than BM alone.
$METS_A$:	Metabolic equivalents of work [unitless]. They are sampled from activity-specific distributions in CHAD (McCurdy, 2000).

$METS_{Max}$: Maximum measured METS estimates [unitless]. CHAD-specified and age/gender-specific.

$PaCO_2$: The arterial partial pressure of carbon dioxide [torr]. Not currently used in our exposure models (except APEX-CO, the carbon monoxide version of APEX).

PAI: Physical Activity Index [unitless]: the daily time-averaged METS estimates for an individual ((Σ $METS_A$*$time_A$ [min])/1440 min) Also known as the Physical Activity Level (PAL).

PEFR: Peak expiratory flow rate [L min^{-1}]. The maximum rate of expelled airflow during a forced expiration. It is used as an indicator of asthma or other lung diseases. While it is believed to be a measure of large airways function, it is an insensitive measure because it is heavily reliant on each subject's effort, which is highly variable (Cook et al., 1989).

RQ: Respiratory quotient [unitless]. The ratio of volume of carbon dioxide produced (VCO_2) to oxygen consumed (VO_2). Not used in our exposure models currently.

TDEE: Total Daily Energy Expenditure [kcal day^{-1}].

U: A conversion factor to convert energy expenditure [kcal] into oxygen consumption [L/kcal]; L O_2 ≈ 4.85 kcal, values between 4.69-5.01 are seen in the literature, depending upon the foodstuffs being metabolized. Using the 4.85 conversion, 1 kcal = 206 ml O_2. APEX randomly samples from uniform distributions of 200-210 mL ♀ and 210-220 mL ♀.

V_A: Alveolar ventilation rate [L min^{-1}] The effective ventilation rate of the alveoli in which gas exchange with blood occurs in the pulmonary capillaries. A "dot" should be over the V.

V_D: Dead-space volume in the respiratory system [L]. The combined volume of all air passages in the respiratory system in which no gas exchange occurs. Values of V_D come from the literature.

V_E: Breathing rate or "minute ventilation rate" [L min^{-1}] calculated from regression equations relating age/gender-specific BM to V_E. A "dot" should be over the V.

$V_{E.Max}$: Maximum V_E rate for an individual; a nonlinear relation of VO_{2Max} [L min^{-1}]. A "dot" should be over the V.

VQ: Ventilatory equivalent [unitless]; the ratio of VE -to-VO_2 at any specified energy expenditure rate. It varies from about 20-32 in healthy individuals, with the lower ratio being at rest. It no longer is used in our exposure models.

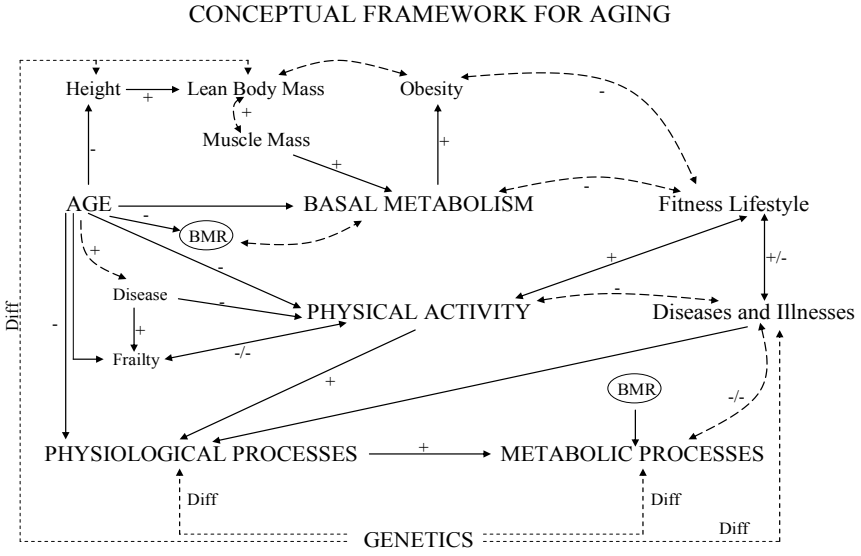
V_T: Tidal volume [L] in the respiratory system: the volume of air that is inhaled or exhaled. V_T increases greatly from rest to maximal EE.

VO_2: Activity-specific oxygen consumption rate [mL O2 min^{-1}]. Estimated using a gender-specific U (EE-to-VO_2). A "dot" should be over the V since it is a rate.

VO_{2Max}: Age/gender-specific maximal oxygen consumption rate [mL min^{-1} kg^{-1}]. Also known as VO_{2Peak}; it is considered to be "aerobic capacity." A "dot" should be over the V.

2.A Conceptual framework of physiological changes due to aging

To account for factors that affect intake dose rate for older adults, we developed a conceptual framework of important anthropogenic and physiological attributes that might affect metabolic parameters used in our exposure models. This is depicted as Figure 2-2. The Figure basically is a *qualitative* "path analytical" framework of physiological relationships in people, with a focus on elderly attributes. Not all of the attributes are included in APEX or SHEDS, but all can influence how a person metabolizes xenobiotic substances following an exposure. Direct, causal relationships are depicted with a solid line; indirect, correlated relationships are depicted by curved dashed lines. Important genetic factors that directly affect an attribute are depicted by straight, lightly-dashed lines.



Source: Thomas McCurdy.

Figure 2-2. Conceptual framework of important relationships that affect physiological processes in the body.

A plus sign on a relational line, either direct or correlated, indicates a positive impact, while the opposite is true for a negative sign. Looking at the diagram, and starting with age, as age increases in the elderly, the person's height usually decreases (-); morbidity (disease) increases (+) but possibly not as a function of age *per se*; frailty increases (+); BMR decreases (-) both on an absolute and relative-to-BM basis; physical activity usually decreases (-); and, "physiological processes" of many types decrease. These might include maximal oxygen consumption, maximal breathing rate, maximal heart rate, and body strength. The "Diff" note indicates a complex relationship between the two linked variables that probably is non-linear and one that varies with gender; we make no *a priori* hypothesized direction of change between the two variables.

Those variables in Figure 2-2 that are an explicit part of our exposure models include the anthropogenic variables: age, height [HT], body mass [BM]—but not lean body mass [LBM] or BMI. Other explicit variables in the models are: basal metabolism [BMR], fitness--as estimated by maximal oxygen consumption [VO_{2Max}], and a surrogate for "fitness"—the Physical Activity Index [PAI]. Frailty and disease states could be handled in our exposure modeling procedures by sampling from data from people having those types of issues, where available. Model simulations would then provide information about the impact that the altered states have on model results.

It should be noted that many of the factors depicted in Figure 2-2 have been studied and shown to be important in morbidity and mortality in the elderly (Skinner, 1970). Often these factors are known by more precise nomenclature than listed. One of the most important considerations is sarcopenia, age-associated loss of muscle (Rogers & Evans, 1993; Starling et al., 1999a). Another is the "metabolic syndrome" (a complex of symptoms focused on abdominal adiposity, hypertension, high cholesterol, elevated triglycerides, and high glucose), and hormonal changes (Maggio et al., 2006; Metter et al., 1997; Rodriguez et al., 2007; Schranger et al., 2007; and Skinner, 1970). "Aging of the respiratory system" is a major issue in limiting human activities and performance (Zeleznik, 2003). Figure 2-2 is a broad and general depiction of important physiological and metabolic changes in people as they age. These changes undoubtedly affect what people can do, the activities that can be undertaken, and where they occur. These factors, in turn, affect exposures experienced and dose/effect relationships in aging individuals.

What follows is a discussion of variables identified as having (1) significant influence on exposure modeling outcomes, and (2) adequate data available for use in EPA models. They include basal metabolic rate, maximal oxygen consumption, METS, maximal ventilation rate, the ventilatory equivalent, and maximal heart rate.

2.B Basal metabolic rate (BMR)

Basal metabolic rate is also known as resting metabolic rate (RMR) or resting energy expenditure (REE). It approximates the unavoidable loss of heat due to cell metabolism and energy expended in maintaining minimal bodily functions: circulation, respiration, digestion, and involuntary muscle tone (McCurdy, 2000). Most basal energy is expended to keep the brain, liver, and skeletal muscles functioning properly. It has various units, depending upon the application, but all involve energy expenditure in kcal or kJ for some time period. The most commonly used units are kcal day^{-1} or kcal min^{-1}, but body mass (BM)-normalized units are often used (kcal kg^{-1} min^{-1} or kcal kg^{-1} day^{-1}). Alternative BMR units are also used: sometimes BMR is expressed as oxygen consumption in L min^{-1} or mL min^{-1}, and the "U" conversion factor depicted in Table 2-1 is used to convert them into EE units. Also, by definition, BMR=1 MET (unitless). Dividing BMR by BM (BMR/BM in units of Kcal min^{-1} kg^{-1}, or one of the alternative measures) reduces the population variability of the BMR among age and gender groups. Dividing BMR by LBM reduces population variability BMR further especially in the elderly (McArdle et

al., 2001). These transformations are called body mass- or lean body mass-normalized BMR.

There is a strong association between body surface area (BSA) and LBM (McArdle et al., 2001). LBM decreases significantly in the elderly after 60 y or so in both genders and for different ethnic groups, but the rate of change is not the same for all age/ethnic group combinations (Obisesan et al., 2005).

Most studies show a significant decrease in BMR over time both for individuals (longitudinally) and among the elderly (cross-sectionally). See Figure 2-3. This is true for both U.S. (Hunter et al., 2001; Obisesan et al., 2005) and non-US studies (Goldberg et al., 1988; Haveman-Nies et al., 1996; Kwan et al., 2004). This decrease is seen for all the usual BMR metrics: absolute, BM- and LBM-adjusted, and BSA- and BMI-adjusted variations (Dupont et al., 1996). The rate of decline is about 1-2% per decade (Keys et al, 1973). Reduction in BM in the elderly by itself "explains" about 55% of the relative decrease in BMR (Obisesan et al., 1997). BMR is positively correlated with both activity level (fitness) and lean body mass (Anderson et al., 2001). However, other studies indicate that BMR is only slightly lower in the elderly than in young adults (Das et al., 2001). These authors state that weight gain in the elderly—a relatively recent trend—is "compensating" for the differences in body composition of the elderly, and that the net effect is causing BMR to be "similar to, or even higher in older subjects compared to young ones (Das et al., 2001; p. 1837, citations removed). This trend of weight gain in the elderly may affect future BMR predicting equations, as the lean body mass-to-total body mass ratio changes with body composition in overweight and obese people.

Estimates of the daily intra-individual variability range in BMR in people >65 y are about 6-8% (Visser et al., 1995). The cross-sectional population coefficient of variation (COV; mean / standard deviation) for people >70 is somewhat lower, but sample sizes for repeated measures studies of BMR in the elderly are small. For instance, the COV's for females >70 y was between 2.5-3.0% on average, with some individuals showing over a 12% difference over relatively short time intervals (Gibbons et al., 2004). The COV's for males >70 years was 3.6-4.0%, with the highest individual having a 10% COV (Gibbons et al., 2004).

A table of elderly BMR values seen in the literature is not presented here because NERL and OAQPS staff (Graham & McCurdy, in preparation) has compiled extensive U.S. data on BMR measurements. The information will be used to develop *de novo* BMR regression equations to replace the "Schofield equations" (Schofield, 1985) currently used in APEX and SHEDS. In order to provide some basic information in this Report on BMR, the following prediction equations (in kcal day^{-1}) are taken from Nieman (1990), who in turned reproduced them from the sources noted. The equations are for adults >18 unless otherwise noted. BM has units of kg, HT is in cm, age (A) is in Years (y). Gender-specific equations are usually presented for BMR.

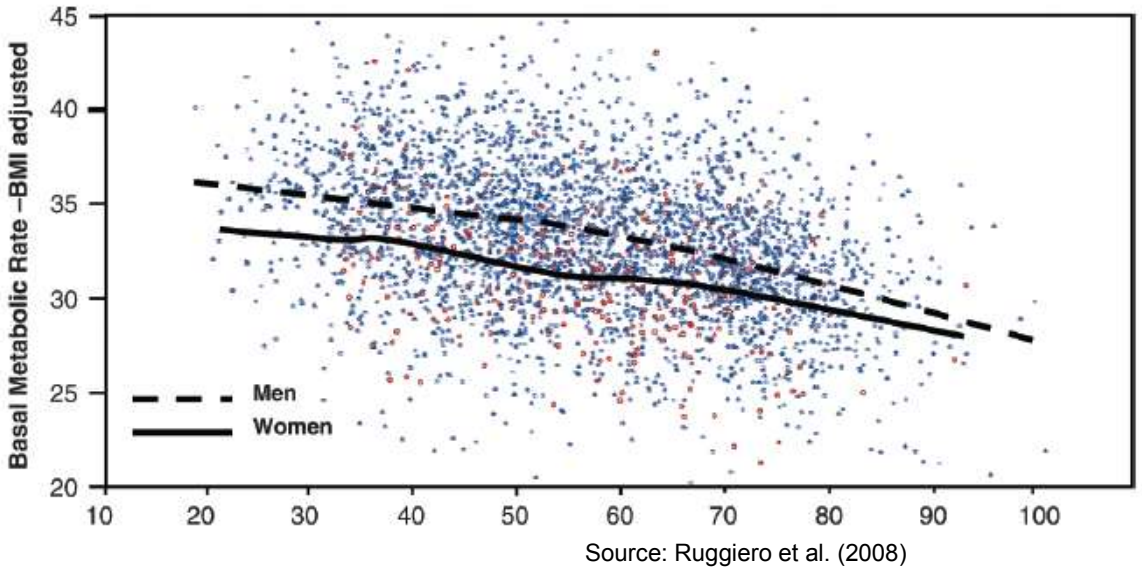


Figure 2-3. Decrease of BMR with age.

From the Owens equations reproduced in Nieman (1990]):

BMR ♂ = 879 + (10.2 * BM)

BMR ♀ = 795 + (7.2 * BM)

From the revised Harris-Benedict equations reproduced in Nieman (1990)

BMR ♂ = 88.4 + (4.8 * HT) + (13.4 * BM) – (5.7 * Age)

BMR ♀ = 447.6 + (3.1 * HT) + (9.2 * BM) – (4.3 * Age)

From the WHO equations depicted in Nieman (1990) for people ≥ 60 y

BMR ♂ = 487 + (13.5 * BM)

BMR ♀ = 596 + (10.5 * BM)

As mentioned, in the exercise physiology literature, BMR is defined to be 1 MET (see the following section). It also is often "fixed" at 3.5 ml kg^{-1} min^{-1} oxygen consumption (Kwan et al., 2004; McArdle et al., 2001), but that equivalency has been shown to be incorrect—even as a mean population value—for the elderly and children (Kwan et al., 2004; McCurdy & Graham, 2004a). Age, gender, fitness level, and health status all affect BMR on an absolute and relative basis. A fixed BMR value is inconsistent with that observation, and will not be further used in this report.

The relationship between BMR and mortality in the elderly is complex and non-linear. Relatively low- and high-BMR groups (compared to the mean group) have increased mortality independent of age, BM, BMI, total physical activity, muscle mass, strength, diabetes status, and a number of other physiological considerations (Ruggiero et al., 2008). These findings come from the Baltimore Longitudinal Study of Aging (BLSA), a comprehensive NIA-funded that started in 1958. The sample used in the Ruggiero et al. (2008) analysis consisted of 1,227 participants enrolled in the 1958-1982 time period that were evaluated in 2000. BMR was measured every 2 years in a clinical setting, along with other physiological and cognitive parameters. Their data are reproduced as Figure 2-3 above.

2.C Metabolic equivalents of work (METS)

METS are "metabolic equivalents of work," the unitless ratio of activity-specific energy expenditure to basal metabolism. Thus, if an activity incurs a 20 mL kg^{-1} min^{-1} oxygen consumption (EE_A in O_2 units), and BMR is 6 mL kg^{-1} min^{-1}, the activity-specific METS ($METS_A$) is 3.3. Maximum METS ($METS_{MAX}$) increases in childhood, gradually declines in adults, and decreases rapidly in the elderly (Lai et al., 2009). The $METS_{MAX}$ values for people ≥ 65 y old are about 67% of those <50 y, and even lower in those people who subsequently died of cardiovascular problems (Lai et al., 2009). McArdle et al. (2001) states that $METS_{MAX}$ drops from about 10.0 in middle age to 7.0 in the elderly, and drops again to 4.0 in the very old. While the precise age descriptors are not defined in McArdle, et al. (2001), they can be estimated from VO_{2Max} data. To facilitate that work, we are developing databases of physiological information for all ages and both genders, and will undertake meta-analyses of that data in the future.

Data are sparse concerning $METS_{MAX}$ values for the elderly. Papers that do discuss them are reviewed below. It should be recognized that due to the general low fitness levels of the elderly, most of the estimates are derived from "symptom-limited" exercise protocols that *estimate* $METS_{MAX}$ from submaximal tests. This is done to avoid severe morbidity and mortality incidents associated with a maximal exercise test. However, maximal exercise protocols are used in the healthy elderly; see Section 2.D below.

The estimates from Amundsen et al. (1989) are quite low relative to younger individuals. $METS_{MAX}$ for sedentary females divided into two groups was 4.5 ± 1.7 for 75.7 y olds (n=14) and was 3.7 ± 0.8 for 71.8 y olds (n=5). The authors do not speculate why the expected pattern of higher $METS_{MAX}$ for younger people did not hold in this case or why the $METS_{MAX}$ values were so low. Yamazaki et al. (2004) provide $METS_{MAX}$ estimates for male patients (no heart-related issues) tested at two Veterans Administration (VA) hospitals. They indicated that $METS_{MAX}$ was 7.0 ± 3.0 METS for males aged 65-75 y, declining down to 6.5 ± 2.8 for 70-74 y olds and to 5.6 ± 2.5 for ≥75 y olds. Sergi et al. (2009) estimated that $METS_{MAX}$ for 81 females aged 70.4 ± 3.9 y was 6.1± 1.2, and Sagiv et al. (1989) stated that $METS_{MAX}$ for 40 males aged 67± 4 y was 9.1± 1.2. These

scant data seem to indicate that there are relatively large age and gender differences in the $METS_{MAX}$ parameter.

CHAD—a direct input to the APEX and SHEDS models—contains distributions of activity-specific METS that were derived from an statistical analysis of METS values contained in Ainsworth et al. (1993; updated by Ainsworth et al., 2000) and other sources of information. McCurdy et al. (2000) describes how the METS distributions in CHAD were developed. Activity-specific METS are discussed in Section 3.

2.D Maximum oxygen consumption (VO_{2Max})

VO_{2Max} is maximal oxygen consumption and is also known as maximal aerobic power (Jones & Lindstedt, 1993). It is highly related to the genetic makeup of an individual. McArdle et al. (2001) state that between 40-90% of variability in VO_{2Max} can be attributed to heredity alone. VO_{2Max} values are generally obtained from empirical testing of the amount of oxygen consumed by subjects undertaking a strenuous exercise test. The estimates usually come from cycle ergometer or treadmill tests of whole-body exercise, but also are derived from specific tasks that mimic the "real world." There are many articles presenting VO_{2Max} information for children and adults, but many fewer for the elderly (Conley et al., 2000; Goodman & Thomas, 2002). An early summary of cross-sectional VO_{2Max} data on the elderly is presented in Smith & Gilligan (1989). VO_{2Max} estimates for the elderly seen in the literature are summarized in Tables 2-2a & 2-2b.

In our exposure models, VO_{2Max} is estimated from age/gender-specific equations using a range of "U" coefficients (see above). EPA staff currently is developing a data base of age/gender VO_{2Max} observations from the exercise physiology literature to check on the performance of these equations.

In general, there is a decline in VO_{2Max} with age in both genders on a BM-adjusted basis regardless of the test protocol used (Aminoff et al., 1996; Fleg, 1994; Fleg et al., 2005; Peiffer et al., 2008; Proctor et al., 1998; Smith & Gilligan, 1989). The reduction probably is non-linear with age (Wiswell et al., 2001), but often is depicted as a linear trend. The reduction is thought to be associated with a decrease in large muscle mass but not in muscle metabolic capacity or morphology (Aminoff et al., 1996; Fleg & Lakatta, 1988; Kent-Braun & Ng, 2000; Kirkendall & Garrett Jr., 1998). Thus, physical work capacity seemingly is not reduced in old people—at least into their 60's—when *small muscles* control. However, there also is disagreement on this point; see Conley et al. (2000). Females have a lower VO_{2Max} than males, even on a per-BM basis. Total body fat does not seem to affect $VO_{2.Max}$ after adjusting for LBM (Goran et al., 2000).

Other published information indicates that aging *per se* results in a decline in VO_{2Max} in older people (Goodman & Thomas, 2002). Reduced physical activity, physiological aging (biological functioning), and increased prevalence of pathological conditions

contribute to this decline. They estimate that VO_{2Max} declines 5-15% per decade from early adulthood (Goodman & Thomas, 2002).

McArdle et al. (2001) states that VO_{2Max} decreases about 0.4-0.5 mL kg^{-1} min^{-1} per year in adults after age 20 (p. 882). However, this estimate mixes active and sedentary individuals; VO_{2Max} decreases less in active people than sedentary ones, especially inactive individuals who are overweight or obese. McArdle et al. (2001) provides equations for VO_{2Max} as follows::

$$VO_{2Max}\ ♂\ [mL\ min^{-1}\ kg^{-1}\ ] = 59.48 - (0.46*Age\ [y]) \qquad SE_E=7.12$$

$$VO_{2Max}\ ♀\ [mL\ min^{-1}\ kg^{-1}\ ] = 57.73 - (0.54*Age\ [y]) \qquad SE_E=6.44$$

Other $VO_{2.Max}$ prediction equations for the elderly exist (Blackie et al.,1989). The SE_E's of the McArdle et al. (2001) equations are about 30% of the elderly means, so they are quite large, indicating a lot of variability in that population subgroup, as seen in Tables 2-2a & b for the various fitness categories. In fact, McArdle et al (2001) explicitly state that *sedentary living* produces losses in functional capacity at least as great as the effects of aging itself (p. 883).

Surveying other articles regarding the decline of $VO_{2.Max}$ with age, Bonnefoy et al. (1998) estimate that it decreases about 8.3% per decade in males after their 20's on a BM basis. That estimate is roughly consistent with the prediction equations presented above and to the values given in Fleg (1994). Bruce (1984) states that the decline is about 0.4 mL min^{-1} kg^{-1} y^{-1}, which is somewhat lower than that indicated by the above equations. In males, Jackson et al. (1995) states that the decline is 0.46 mL min^{-1} kg^{-1} y^{-1}. In females, the decline in $VO_{2.Max}$ has been estimated as 0.54 mL kg^{-1} min^{-1} y^{-1} (Jackson et al., 1996). Larson & Bruce (1987) state that the decline is 0.4 mL kg^{-1} min^{-1} y^{-1} in the healthy elderly (both genders) when measured cross-sectionally, but 0.9 mL kg^{-1} min^{-1} y^{-1} in the same people when analyzed longitudinally. Thus, using cross-sectional data to describe $VO_{2.Max}$ change in individuals over time will systematically underestimate the longitudinal impacts of aging (Wiswell et al., 2001). The probable cause of the underestimate is that fitness levels of individuals decrease differentially over time and that is not explicitly accounted for in a cross-sectional analysis.

Probably the most comprehensive review of reduced maximal oxygen consumption in aging individuals is Hawkins & Wiswell (2003). They indicate that the decline in $VO_{2.Max}$ is due to both central and peripheral physiological adaptations, especially reductions in maximal heart rate and lean body mass (muscle). They distinguish between the decline rate in inactive people (10-15% per decade) and athletic people (5-7% per decade). The decline is non-linear with age, declining faster after 70 y (Hawkins & Wiswell, 2003). They also state that results from cross-sectional studies of $VO_{2.Max}$ in the elderly give quite different results longitudinal studies of that cohort, especially for formally-active individuals. The reader is advised to review Hawkins & Wiswell (2003) for an excellent and succinct discussion of the topic. Kenney (1997) and Stamford (1988) support the same findings. See also the Pollock et al. series of articles

(1974,1987,1997) measuring $VO_{2.Max}$ (and V_E) in current and former athletes over extended periods of time: 10 and 20 years.

Evidence exists indicating that prolonged dynamic exercise at the same percentage of $VO_{2.Max}$ (~65%) under controlled conditions represents no more of a physiological strain in **healthy** older adults than in young people (Davy et al., 1995). This finding could have been affected by the protocol: to get the ~65% of $VO_{2.Max}$ exercise level in young adults, they had to run, while older adults (65 ± 2 y) only had to walk (Davy et al., 1995). There were other testing differences that might affect their findings. This was the only paper with this type of finding, so its results need to be considered carefully.

$VO_{2.Max}$ has been used as an indicator of cardiorespiratory fitness and is a strong predictor of successful cognitive functioning in the elderly (Shephard, 2009), explaining more variance in cognitive measures than "higher order" measures of cognition (memory, speed of processing information, "executive functioning," etc.); see: Newson & Kemps (2006). In addition, a $VO_{2.Max}$ <30-35 mL kg^{-1} min^{-1} in the elderly is thought to be the "threshold level" for increased mortality risk (Leaf & Reuben, 1996).

The first part of Table 2-2a consists of $VO_{2.Max}$ estimates (in units of mL / kg-min) from text books presenting highly aggregated data for both genders. Standard deviations, for instance, are not available for these estimates. The following groupings contain data from more narrowly-focused papers that provide mean and standard deviation parameters for the samples monitored.

Table 2-2a. Literature reported estimates of VO_{2Max} for older adults.

Age Range (Mean & SD)	Ethnic Group	Health Status	VO_{2Max} Estimate (mL / kg-min)	Citation	Comment
60 – 69	NS	NS	≤ 15.9	McArdle et al. 2001	Poor cardio. fitness
	NS	NS	16.0 - 22.9	McArdle et al. 2001	Fair cardio. fitness
	NS	NS	23.0 - 35.9	McArdle et al. 2001	Average cardio. fitness
	NS	NS	36.0 - 40.9	McArdle et al. 2001	Good cardio. fitness
	NS	NS	≥ 41.0	McArdle et al. 2001	Excellent cardio. fitness
60 – 69	NS	N	25.1	Shephard 1966	Untrained: Canada
	NS	N	32.1	Shephard 1966	Untrained: US
	NS	N	33.2	Shephard 1966	Untrained: Scandinavia
	NS	N	24.6	Shephard 1966	Untrained: General
	NS	Ath	25	Shephard 1966	Active/Ath.: General
70 - 79	NS	N	25.5	Shephard 1966	Untrained: US
	NS	N	20.3	Shephard 1966	Untrained: General
	NS	N	24.7	Shephard 1966	Active/Ath.: General
80 – 89	NS	Ath	21.9	Shephard 1966	Active/Ath.: General

Age Range (Mean & SD)	Ethnic Group	Health Status	VO_{2Max} Estimate (mL / kg-min)	Citation	Comment
60 – 69	NS	NS	≤ 12.9	McArdle et al. 2001	Poor cardio-fitness
	NS	NS	13.0 - 20.9	McArdle et al. 2001	Fair cardio-fitness
	NS	NS	21.0 - 32.9	McArdle et al. 2001	Average cardio-fitness
	NS	NS	33.0 - 36.9	McArdle et al. 2001	Good cardio-fitness
	NS	NS	≥ 37.0	McArdle et al. 2001	Excellent cardio -fitness
≥ 60	NS	NS	≤ 27	Baumgartner & Jackson 1999	Poor aerobic fitness
	NS	NS	28 - 30	Baumgartner & Jackson 1999	Fair aerobic fitness
	NS	NS	31 - 37	Baumgartner & Jackson 1999	Average aerobic fitness
	NS	NS	38 - 40	Baumgartner & Jackson 1999	Good aerobic fitness
	NS	NS	≥ 41	Baumgartner & Jackson 1999	Excellent aerobic fitness
≥ 60	NS	NS	≤ 21	Baumgartner & Jackson 1999	Poor aerobic fitness
	NS	NS	22 - 24	Baumgartner & Jackson 1999	Fair aerobic fitness
	NS	NS	25 - 30	Baumgartner & Jackson 1999	Average aerobic fitness
	NS	NS	31 - 33	Baumgartner & Jackson 1999	Good aerobic fitness
	NS	NS	≥ 34	Baumgartner & Jackson 1999	Excellent aerobic fitness
60 – 69	NS	H	25.7 ± 4.4	Fleg et al. JAP 1995	n=12
60 – 77	NS	H	19.4 ± 0.9	Parker et al. 1996	n=14
61 ± 3	NS	N	26 ± 3	Hagberg et al. 2003	n=9
61 ± 4	NS	N	22.2 ± 4.7	Hunt et al. 1997	n=15
62 ± 3	NS	N	33.4 ± 7.6	Hagberg et al. 1998	n=22;ACE=II
62 ± 6	NS	N	23.1 ± 3.3	Sheldahl et al. 1996	n=9
62 ± 7	NS	N	21.7 ± 3.3	Sheldahl et al. 1996	n=11
63 ± 5	NS	N	30.1 ± 8.5	Hagberg et al. 1998	n-57;ACE=ID
63.3 ± 2.9	NS	N	21.8 ± 2.6	Kohrt et al. 1991	n=16
64 ± 4	NS	N	24.3 ± 4.3	Proctor et al. 2003	n=13
64 ± 6	NS	N	29.1 ± 4.8	Farquhar & Kenney 1999	n=8
64.0 ± 3.1	NS	N	21.6 ± 2.9	Kohrt et al. 1991	n=57
65 ± 5	NS	N	27.1 ± 5.8	Hagberg et al. 1998	n=DD; ACE=DD
65.5 ± 7.8	NS	N	17.0 ± 5.6	Carter et al. 1994	n=16
66 ± 4	M	N	32.5± 4.7	Clausey et al. 2001	n=27
66.8 ± 15.9	NS	N	29.4 ± 14.5	Wilund et al. 2008	n=6
67 ± 4	NS	N	19.3 ± 3.9	Treuth et al.1995	n=15
67 ± NS	NS	N	21.2 ± 4.6	Hollenberg & Tager 2000	n=579
68.0 ± 7.0	NS	N	23.2 ± 5.3	Pescatello et al. 1994	n=11
68.7 ± 5.7	NS	N	21.9 ± 4.2	Panton et al. 1996	n=36
70.0 ± 6.1	NS	N	21.5 ± 4.3	Parise et al. 2004	n=117

Age Range (Mean & SD)	Ethnic Group	Health Status	VO_{2Max} Estimate (mL / kg-min)	Citation	Comment
70.4 ± 3.9	NS	N	17.5 ± 2.8	Sergi et al. 2009	n=81
70.4 ± 6.1	NS	N	17.6 ± 5.0	Ainsworth et al. 1997	n=18
70.9 ± 8.1	NS	N	20.3 ± 4.1	Simonsick et al. 2006	n=46
71 ± 6	NS	N	24.8 ± 3.6	Stachenfeld et al. 1998	n=9
71.2 ± 3.5	NS	N	22.6 ± 3.2	Fehling et al. 1999	n=42
72.3 ± 2.1	NS	H	19.5 ± 4.1	Melanson et al. 1997	n=8
73 ± 9	NS	N	25.2 ± 6.2	Stachenfeld et al. 1998	n=8
73.3 ± 2.7	NS	N	31.8 ± 8.5	Perini et al. 2000	n=11;Indiv. 70-79
80 – 89	NS	H	21.2 ± 1.3	Fleg et al. JAP 1995	n=2
60 ± 5	NS	Sed	22.9 ± 4.1	Jones et al. 1997	n=12
60.0 ± 7.0	NS	O	15.0 ± 2.8	Jordan et al. 2005	n=24
60 ± 8	NS	O	21.1 ± 1.6	Tanaka et al. 1998	n=9; Sed
62.0 ± 8.10	W	Sed	22.6 ± 4.0	Seals et al. 1999	n=20
62 ± 2	NS	Sed	22.8 ± 1.4	Tanaka et al. 1998	n=9
62 ± 6	W	Sed	23 ± 3	Hagberg et al. 2003	n=9; HRT
64 ± 4	NS	Sed	22.4 ± 4.8	Tanaka et al. 1997	n=16
64 ± 4	NS	Sed	22.2 ± 3.1	Ogawa et al. 1992	n=14
64 ± 4	W	Sed	21.5 ± 4.7	Schiller et al. 2001	n=18
64 ± 5	NS	O,OW	36.3 ± 8.2	Nicklas et al. 2003	n=29
64.4 ± 3.2	M	Sed	22.0 ± 2.2	Turner et al. 1999	n=10
65 ± 4	His	Sed	20.7 ± 2.9	Schiller et al. 2001	n=5
65 ± 5	NS	OW	20.2 ± 3.6	Thompson et al. 1997	n=40
65.7 ± 6.3	NS	Sed	19.9 ± 3.1	Kohrt et al. 1998	n=112
65.7 ± 6.3	NS	Sed	19.9 ± 3.1	Kohrt et al. 1998	n=112
66 ± 6	W	Sed	23 ± 3	Hagberg et al. 2003	n=10; no HRT
67.0 ± 4.9	NS	Sed	16.2 ± 3.5	White et al. 1998	n=60
68.0 ± 5.6	NS	O,OW	12.0 ± 2.3	Kara et al. 2005	n=45
69.2 ± 11.0	NS	Sed	20.3 ± 7.6	Wilund et al. 2008	n=6
71.1 ± 5.1	NS	Sed	17.3 ± 4.0	Pererson et al. 2003	n=114
71.3 ± 4.4	NS	Sed	23.7 ± 4.7	Audette et al. 2006	n=8
71.5 ± 4.6	NS	Sed	21.5 ± 5.2	Audette et al. 2006	n=11
71.5 ± 4.8	NS	Sed	16.4 ± 2.7	Ades et al. 2005	n=21
72 ± 8	NS	Sed	19.1 ± 3.6	Weiss et al. 2006	n=83
73.5 ± 5.7	NS	Sed	26.8 ± 8.3	Audette et al. 2006	n=8
75.3 ± 4.6	NS	Sed	25.0 ± 4.2	Kent-Braun & Ng 2000	n=9
60 ± 3	NS	Fit	30.7 ± 6.6	Hunt et al. 1997	n=10
61 ± 8	NS	Ath	35.1 ± 4.5	Proctor et al. 1998	n=8
63.3 ± 2.0	NS	Ath	46.2 ± 9.0	Hawkins et al. 2001	n=13; visit #1
64 ± 7	W	Act	26 ± 3	Hagberg et al. 2003	n=11; no HRT
64.6 ± 3.8	NS	Ath	39.4 ± 4.8	Hawkins et al. 2001	n=9;visit #1
65 ± 3	W	Ath	39 ± 6	Hagberg et al. 2003	n=9; HRT
65 ± 3	W	Ath	38 ± 7	Hagberg et al. 2003	n=12; no HRT
65 ± 4	NS	Ath	31.5 ± 2.4	Tanaka et al. 1997	n=13
67.0 ± 5.1	NS	Fit	45.3 ± 7.2	McClaran et al. 1995	n=18;visit #1
72.9 ± 5.5	NS	Fit	21.0 ± 4.3	McClaran et al. 1995	n=18;visit #2
73.2 ± 5.7	NS	Ath	31.8 ± 8.4	Hawkins et al. 2001	n=9; visit #2

Age Range (Mean & SD)	Ethnic Group	Health Status	VO_{2Max} Estimate (mL / kg-min)	Citation	Comment
63.7 ± 5.8	NS	COPD	11.3 ± 3.0	Carter et al. 1994	n=58; severe
64.8 ± 6.4	NS	COPD	16.6 ± 4.1	Carter et al. 1994	n=23; mild
65.0 ± 5.2	NS	COPD	13.9 ± 3.5	Carter et al. 1994	n=42;moderate
72.9 ± 6.1	NS	Cardio	14.2 ± 2.9	Ades et al. 2005	n=21
60 -67	NS	Ex-Ath.	37 ± NS	Saltin & Grimby 1968	No training in 10 y
60 – 69	NS	H	30.4 ± 8.2	Fleg et al. JAP 1996	n=26; non-obese
60 – 79	NS	N	24.2 ± NS	Buccola & Stone 1975	n=16
60.0 ± 8.5	NS	N	22.5 ± 5.2	Carter et al. 1994	n=13
61 – 79	NS	N	23.7 ± NS	Buccola & Stone 1975	n=20
62 ± 6	NS	N	34.9 ± 3.3	Sheldahl et al. 1996	n=9
63 ± 3	NS	N	26.5 ± 3.5	Proctor et al. 2005	n=10
63 ± 3	NS	N	35.3 ± 5.4	Hunt et al. 2001	n=12
63 ± 6	NS	N	30.1 ± 8.6	Fleg et al.1995	n=23
63.7 ± 3.1	NS	N	27.5 ± 4.2	Kohrt et al. 1991	n=53
64 ± 5	NS	N	32.9 ± 5.6	Tankersley et al. 1991	n=7
64 ± 5	NS	H	41.8 ± 2.9	Kenney & Ho 1995	n=6
64.2 ± 9.4	NS	Ex-Ath.	45.9 ± 6.7	Pollock et al. 1987	n=13
64.8 ± 3.6	NS	N	28.3 ± 4.3	Kohrt et al. 1991	n=19
65 ± 2	NS	N	31.5 ± 2.3	Davy et al. 1995	n=6 untrained; healthy
66.0 ± 5.2	M	N	30.0 ± 5.9	Clausey et al. 2001	n=35
67 ± 1	NS	N	23.9 ± 1.0	Thomas et al. 1999	n=4
67 ± 2	NS	N	27.4 ± 4.0	Thomas et al. 1999	n=3
68 ± NS	NS	N	26.5 ± 6.1	Hollenberg & Tager 2000	n=419
68 ± 3	NS	N	29.9 ± 7.4	Thomas et al. 1999	n=7
68.0 ± 5.8	NS	N	20.7 ± 6.7	Ainsworth et al. 1997	n=10
68.6 ± 10.5	NS	N	20.7 ± 6.8	Andros & Gerber 1998	n=12
68.6 ± 5.1	NS	N	27.7 ± 3.7	Panton et al. 1996	n=19
68.7 ± 4.8	NS	N	26.3 ± 5.2	Lost reference	n=19
69 ± 2	NS	N	39 ± 7	Sheffield-Moore et al. 2004	n=6
69 ± 3	NS	N	24.8 ±3.4	Thomas et al. 1999	n=7
70.4 ± 3.8	NS	N	28.9 ± 4.9	Fehling et al. 1999	n=44
70.7 ± 7.5	NS	N	31.3 ± 5.6	Pescatello et al. 1994	n=14
71.1 ± 3.8	NS	N	29.5 ± 4.7	Bonnefoy et al. 1998	n=37
71.4 ± 6.3	NS	N	28.2 ± 5.0	Parise et al. 2004	n=95
71.6 ± 2.4	NS	N	16.4 ± 2.8	Sabapathy et al. 2004	n=9
71.7 ± 5.2	NS	N	25.4 ± 3.9	McAuley et al. 2007	n=126;folowup
72.1 ± 7.6	NS	N	23.7 ± 4.0	Simonsick et al. 2006	n=56
73.1 ± 5.9	NS	N	25.8 ± 4.5	Talbot et al. 2002	n=27;Cardio
73.6 ± 5.9	NS	N	27.9 ± 6.2	Talbot et al. 2002	n=140;no Cardio
74 ± 4	NS	N	24.6 ± 5.6	Proctor et al. 2005	n=14

Age Range (Mean & SD)	Ethnic Group	Health Status	VO_{2Max} Estimate (mL / kg-min)	Citation	Comment
74 ± 5	M	N	29 ± 5	Fleq et al. 1993	n=16
74.7 ± 2.8	NS	N	41.5 ± 3.7	Perini et al. 2000	n=12;Indiv. 70-79
80 – 89	NS	H	23.2 ± 5.8	Fleg et al.1995	n=3
60.0 ± 5.1	NS	Sed	32.1 ± 4.4	Schulman et al. 1996	n=6
61.1 ± 6.2	NS	Sed	30.1 ± 5.5	Katzel et al. 2001	n=42
61.4 ± 5.2	NS	Sed	33.9 ± 6.4	Rogers et al. 1990	n=14
62 ± 6	NS	Sed	31.0 ± 6.4	Van Pelt et al. 2001	n=34
63 ± 3	NS	Sed	27.2 ± 5.1	Ogawa et al. 1992	n=13
63 ± 7	NS	Sed	48 ± 4	Goldberg et al. 2000	n=12
63 ± 5	NS	Sed,O	26 ± 5	Goldberg et al. 2000	n=26
64 ± 3	NS	Sed	29.6 ± 4.1	Ehsani et al. 2003	n=10
65 ± 2	NS	Sed	28.0 ± 2.4	Ho et al. 1997	n=6
65 ± 3	NS	Sed	29 ± 3	Monahan et al. 2001	n=8
65 ± 5	NS	Sed	29 ± 5	Tanaka et al. 2002	n=24
65 ± 5	NS	Sed	18.8 ± 5.1	Ari et al. 2004	n=11
66 ± 5	NS	Sed	27.0 ± 2.2	Hagberg et al. 1988	n=10
66.4 ± 5.6	M	Sed	28.0 ± 3.6	Turner et al. 1999	n=11
66.7 ± 5.4	NS	Sed	22.9 ± 5.3	McAuley et al. 2007	n=174
66.7 ± 14.9	NS	Sed	25.4 ± 13.7	Wilund et al. 2008	n=6
67 ± 2	NS	Sed	30 ± 6	Vaitkevicius et al. 1993	n=38
67.9 ± 5.6	NS	Sed	22.2 ± 5.4	White et al. 1998	n=45
72.2 ± 5.7	NS	Sed	26.1 ± 7.9	Takeshima et al. 1996	n=172
72.5 ± 4.9	NS	Sed	21.7 ± 4.8	Pererson et al. 2003	n=59
75.7 ± 4.7	NS	Sed	27.6 ± 0.6	Kent-Braun & Ng 2000	n=9
76 ± 9	NS	Sed	21.4 ± 6.3	Weiss et al. 2006	n=33
59.6 ± 8.5	NS	Ath	49.9 ± 5.4	Schulman et al. 1996	n=8
60 -67	NS	Ath	43 ± NS	Saltin & Grimby 1968	Current athlete
60.2 ± 8.8	NS	Ath	50.1 ± 7.0	Pollock et al. 1987	n=21
60.0 ± 4.7	NS	Ath	53.5 ± 5.4	Pollock et al. 1997	n=11
61.8 ± 8.8	NS	Ath	44.3 ± 9.8	Wiswell et al. 2002	n=54
62.0 ± 8.9	NS	Ath	54.0 ± 6.6	Rogers et al. 1990	n=15
63 ± 4	NS	Ath	47.5 ± 4.3	Ogawa et al. 1992	n=14
63 ± 6	NS	Ath	45 ± 3	Monahan et al. 2001	n=8
63 ± 6	NS	Ath	42.3 ± 7.4	Van Pelt et al. 2001	n=32
63.4 ± 6.5	NS	Ath	49.6 ± 5.8	Katzel et al. 2001	n=42
64 ± 5	NS	Fit	36.3 ± 8.2	Jones et al. 2004	n=21
64 ± 6	NS	Ath	39.9 ± 4.0	Proctor et al. 1998	n=8
65.0 ± 6.0	NS	Fit	43.3 ± 6.3	Lost reference.	n=9
65 ± 3	NS	Ath	50.0 ± 4.9	Hagberg et al. 1988	n=10
65 ± 4	NS	Ath	45.9 ± 4.6	Peiffer et al. 2008	n=8
65 ± 8	NS	Ath	45.9 ± 4.7	Fleg et al. 1995	n=16

Age Range (Mean & SD)	Ethnic Group	Health Status	VO_{2Max} Estimate (mL / kg-min)	Citation	Comment
66 ± 3	NS	Fit	46.4 ± 5.1	Tankersley et al. 1991	n=6
66 ± 8	NS	Ath	48 ± 4	Goldberg et al. 2000	n=18
66.3 ± 11.6	NS	Ath	36.5 ± 17.2	Wilund et al. 2008	n=7
67 ± 1	NS	Ath	38 ± 2	Tanaka et al. 2002	n=17
68 ± 6	NS	Ath	31.2 ± 6.2	Ari et al. 2004	n=10
68.4 ± 9.8	NS	Fit	40.7 ± 7.3	Trappe et al. 1996	n=10
69 ± 8	NS	Ath	45.0 ± 4.1	Vaitkevicius et al. 1993	n=14
70.4 ± 8.8	NS	Ath	40.5 ± 8.9	Pollock et al. 1997	n=21:followup
71.1 ± 3.2	NS	Ath	36.4 ± 9.4	Hawkins et al. 2001	n-=13: visit #2
71.3 ± 5.8	NS	Ath	36.4 ± 9.5	Takeshima et al. 1996	n=72
76.0 ± 4.8	NS	Ath	41.5 ± 3.8	Hawkins et al. 2001	n=8; visit #1
82.8 ± 4.0	NS	Ath	28.4 ± 7.6	Hawkins et al. 2001	n=8; visit #2
64 ± 3	NS	Heart	27.6 ± 5.7	Sheldahl et al. 1996	n=9
65.3 ± 6.5	NS	COPD	47.2 ± 5.9	Carter et al. 1994	n=32; mild
65.9 ± 6.0	NS	COPD	9.9 ± 2.7	Montes de Oca et al. 1996	n=25; severe
66.3 ± 6.2	NS	COPD	16.2 ± 4.0	Carter et al. 1994	n=57; moderate
66.6 ± 6.7	NS	COPD	13.5 ± 3.8	Carter et al. 1994	n=176; severe
68 ± 6	NS	Heart	25.3 ± 2.8	Sheldahl et al. 1996	n=8
69 ± 3	NS	Heart	26.0 ± 5.3	Sheldahl et al. 1996	n=11
76 ± 8	M	IS	24 ± 4	Fleq et al. 1993	n=8
	Both Genders				
60 – 69	NS	N	30.3 ± 8.2	Heil et al. 1995	n=66
60 – 69	NS	N	34.5 ± 6.1	Heil et al. 1995	n=8
60 – 83	NS	Sed	24.0 ± 4.1	Sidney & Shephard 1978	n=12
60 – 83	NS	Sed	30.9 ± 7.1	Sidney & Shephard 1978	n=8
60 – 83	NS	Sed	30.4 ± 4.9	Sidney & Shephard 1978	n=14
60 – 83	NS	Sed	29.8 ± 1.4	Sidney & Shephard 1978	n=8
61 ± 4	NS	Sed	24 ± 7	Meijer et al. 2001	n=28
62.5 ± 3.1	NS	Ath	24.4 ± 4.8	Marker et al. 1998	n=23
63 ± 3	NS	N	25.4 ± 4.6	Seals et al. 1984	n=24
63.5 ± 3.1	NS	N	30.4 ± 6.2	Marker et al. 1998	n=21
63.5 ± 3.0	NS	Fit	41.5 ± 7.7	Hillman et al. 2002	n=12
63.5 ± 3.0	NS	N	30.2 ± 5.0	DeVito et al. 1997	n=11
63.6 ± 2.7	NS	N	27.9 ± 7.0	Kline et al. 1987	n=34
64 ± 7	NS	COPD	14.2 ± 4.1	Singh et al. 1994	n=10
64.2 ± 4.0	NS	N	23.4 ± 2.5	DeVito et al. 1997	n=5;control
64.4 ± 2.5	NS	N	29.2 ± 6.5	Kline et al. 1987	n=36
64.8 ± 6.6	NS	N	18.5 ± 4.3	Hays et al. 2006	n=11
65.0 ± 2.8	NS	Sed	23.3 ± 3.9	Hillman et al. 2002	n=12
65 ± 2	NS	H	27.3 ± 2.3	Scheuermann et al.	n=8

Age Range (Mean & SD)	Ethnic Group	Health Status	VO_{2Max} Estimate (mL / kg-min)	Citation	Comment
				2002	
65 ± 6	NS	N	27.3 ± 6.5	Scheuermann et al. 2002	n=8
65.1 ± 2.9	NS	N	26.6 ± 4.4	Meredith et al. 1989	n=10
65.3 ± 4.7	NS	Sed	25.8 ± 5.6	Woods et al. 1998	n=33
66 ± 3	NS	N	36.0 ± 7.0	Bell et al. 2004	n=10; 60-73
66 ± 5	NS	M	32 ± 10	Bell et al. 2001	n=26
66.0 ± 5.1	NS	N	32.0 ± 11.0	Bell et al. 2001	n=26; non-obese
66.2 ± 4.2	NS	Sed	23.6 ± 3.8	Stein et al. 1999	n=16
66.2 ± 8.8	NS	N	28.0 ± 6.0	Correia et al. 2002	n=20
66.3 ± 6.3	NS	N	20.9 ± 6.1	Vincent et al. 2002	n=22;ACE=II
67.3 ± 5.6	NS	N	17.8 ± 4.5	Simmons et al. 2000	n=125
67.5 ± 3.0	NS	N	27.4 ± 5.7	Hays et al. 2006	n=11
67.6 ± 6.3	NS	N	22.2 ± 4.3	Vincent et al. 2002	n=24
67.8 ± 3.0	NS	Ath	38.6 ± 6.1	Arbab-Zadeh EA 2004	n=12
67.8 ± 7.5	NS	N	29.0 ± 8.2	Chick et al. 1991	n=8
68.1 ± 9.8	NS	N	32.6 ± 10.1	Hernandez & Franke 2005	n=10
68.8 ± 6.1	NS	Heart	13.4 ± 2.6	Maldonado-M. et al. 2006	n=47
69 ± 5	NS	N	26.6 ± 5.3	Tonino & Driscoll 1988	n=11
69 ± 9	NS	N	21.0 ± 6.3	Bell et al. 2004	n=7
69.1 ± 2.2	NS	Sed	20.9 ± 3.5	Moul et al. 1995	n=10
69.2 ± 5.8	NS	OW	18.4 ± 3.3	Vieira et al. 2007	n=44
69.4 ± 3.4	NS	Fit	34.3 ± 4.1	Smith et al. 2004	n=10
69.4 ± 5.2	NS	Heart	13.7 ± 3.3	Maldonado-M. et al. 2006	n=50
69.6 ± 6.0	NS	Cardio	19 ± 5	Ades et al. 1993	n=43
69.7 ± 2.5	NS	Sed	22.4 ± 3.5	Moul et al. 1995	n=10
69.8 ± 3.0	NS	Sed	21.6 ± 2.8	Arbab-Zadeh EA 2004	n=12
69.9 ± 2.2	NS	Sed	21.4 ± 2.5	Moul et al. 1995	n=10
70 ± 4	NS	Fit	43.7 ± 9.2	Johnson et al. 1991	n=29
70 – 79	NS	N	26.0 ± 5.8	Heil et al. 1995	n=40
70 – 79	NS	N	17.8 ± 3.2	Heil et al. 1995	n=7
70 – 79	NS	H	18.0 ± 2.4	Fleg et al. 1995	n=7
70 – 79	NS	H	30.2 ± 5.6	Fleg et al. 1995	n=14
70 – 79	NS	N	22.5 ± 4.6	Hagberg et al. 1989	n=16
70 – 79	NS	N	22.2 ± 5.1	Hagberg et al. 1989	n=19
70 – 79	NS	N	30.2 ± 5.9	Hagberg et al. 1989	n=12
70.1 ± 5.0	NS	OW	19.7 ± 3.9	Vieira et al. 2007	n=44
70.8 ± 5.4	NS	OW	21.0 ± 5.3	Vieira et al. 2007	n=44
70.9 ± 3.2	NS	Sed	27.1 ± 6.3	Hernandez & Franke 2004	n=10
71.0 ± 4.6	M	NLF	21.3 ± 4.3	Morey et al. 1998	n=53
71.0 ± 4.7	NS	N	22.6 ± 3.4	Vincent et al. 2002	n=16
71.8 ± 5.4	M	LF	17.2 ± 4.3	Morey et al. 1998	n=108
72.1 ± 3.8	NS	Sed	24.9 ± 2.5	Smith et al. 2004	n=14
73 ± 5	NS	N	31.4 ± 12.0	Sial et al. 1996	n=6
73.6 ± 14.9	NS	N	31.4 ± 5.7	Hernandez & Franke 2005	n=10

Age Range (Mean & SD)	Ethnic Group	Health Status	VO_{2Max} Estimate (mL / kg-min)	Citation	Comment
73.9 ± 6.3	NS	N	39.0 ± 6.3	Hernandez & Franke 2004	n=10
74 ± 3	NS	N	21.1 ± 6.8	Cress & Meyer 2003	n=98
76.2 ± 6.2	NS	N	19.8 ± 6.3	Arnett et al. 2008	n=29;70-92 y
79 ± 6	NS	N	16.8 ± 4.0	Cress & Meyer 2003	n=49;
81.6 ± 3.6	M	Frail	15.2 ± 2.9	Carr et al. 2006	n=155
83.0 ± 3.6	NS	Frail	16.0 ± 2.3	Ehsani et al. 2003	n=22
84 ± 4	NS	Sed	18.3 ± 3.9	Vaitkevicius et al. 2002	n=35
84.0 ± 4.2	NS	Frail	15.6 ± 2.7	Ehsani et al. 2003	n=24
84.4 ± 5.7	M	Frail	13.6 ± 2.6	Carr et al. 2006	n=28
84 ± 7	NS	Frail	12.8 ± 3.8	Cress & Meyer 2003	n=45

Abbreviations:

AA	African American (black)
ACE	Angiotensin-converting enzyme
	DD: deletion/deletion genotype
	ID: insertion/deletion genotype
	II: insertion/insertion genotype
Act	Active (but non-athletes)
Ath	Athletes
B	Both genders
Cardio	Cardiovascular problems
COPD	Chronic obstructive pulmonary disease
♀	Females
Fit	Very active healthy exercisers
Frail	Mild-to-moderate frailty
H	Healthy
Heart	Heart "failure" patients
His	HISPANIC
HRT	Hormone replacement therapy
Indiv	Data for individuals are provided
IS	Ischemic subjects ("silent")
LF	Low functioning: a combination of 5 self-reported functional measure
♂	Males
M	Mixed ethnicity or mixed fitness level
N	Normal (mostly healthy)
NLF	Not low-functioning: see LF above
NS	Not specified
O	Obese
OW	Overweight
Park	Parkinson's disease patients
PD	Peripheral disease patients
Sed	Sedentary
W	White (Caucasian)

Notes:

a. The McArdle et al. (2001) and Baumgartner & Jackson (1999) values are "standards."
b. The 1999 values are those recommended by the American College of Sports Medicine.
c. There was no statistically significant difference in Hagberg et al. (2003) in VO2.Max estimates for the HRT and non-HRT groups; only the non-HRT group data are shown.
d. The Hagberg et al. (1998) article provides VO2.Max estimates for lifestyle groups also (not presented).
e. The Sergi et al. (2009) article also provides 5th and 95th percentile values for VO2.Max. The 5th value is 71% of the median, and the 95th value is 136% of the median.

Table 2-2b. Estimates of VO_{2Max} for the elderly seen in the literature.

Age Range (Mean & SD)	Ethnic Group	Health Status	VO_{2Max} Estimate (L / Min)	Citation	Comment
	Females: Normal or Healthy				
59.4 ± 3.5	NS	N	1.45 ± 0.27	Bathalon et al. 2001	n=26
60 – 69	NS	N	1.76 ± 0.39	Tlusty 1969	n=14; 63.5 y
60 ± 4	W	H	1.42 ± 0.23	Hays et al. 2002	n=33
60.3 ± 3.1	NS	N	1.39 ± 0.23	Bathalon et al. 2001	n=34
61 ± 3	NS	N	1.7 ± 0.3	Hagberg et al. 2003	n=9
61 ± 8	NS	N	1.7 ± 0.3	Arciero et al. 1993a	n=75
62 ± 6	NS	N	1.51 ± 0.24	Sheldahl et al. 1996	n=9
62 ± 7	NS	N	1.50 ± 0.17	Sheldahl et al. 1996	n=11
63.3 ± 2.9	NS	N	1.45 ± 0.23	Kohrt et al. 1991	n=16
64 ± 4	NS	N	1.6 ± 0.7	Proctor et al. 2003	n=13
64 ± 5	NS	H	1.53 ± 0.18	Goran & Poehlman 1992	n=6
64 ± 8	AA	N	1.58 ± 0.56	Starling et al. 1998b	n=37
64.0 ± 3.1	NS	N	1.46 ± 0.21	Kohrt et al. 1991	n=57
65 ± 8	AA	N	1.4 ± 0.3	Carpenter et al. 1998	n=37
66 ± 6	NS	H	1.6 ± 0.3	Johnson et al. 1994	n=81
66.0 ± 5.8	NS	N	1.49 ± 0.31	Blackie et al. 1989	n=81
67 ± 6	W	N	1.4 ± 0.3	Carpenter et al. 1998	n=52
67 ± 9	W	N	1.96 ± 0.84	Starling et al. 1999b	n=35
68.7 ± 5.7	NS	N	2.17 ± 0.35	Panton et al. 1996	n=36
70 – 79	NS	N	1.40 ± 0.25	Tlusty 1969	n=14; 75 y
70.0 ± 8.1	NS	N	1.21 ± 0.25	Johnson et al. 2000	n=146
70.4 ± 3.9	NS	N	1.12 ± 0.21	Sergi et al. 2009	n=81
> 80	NS	N	0.9 ± 0.16	Tlusty 1969	n=7; 81 y
	Females: Sedentary, Overweight, or Obese				
59 ± 6	AA	O	1.6 ± 0.2	Nicklas et al. 2003	n=19
60 ± 5	AA	O	1.6 ± 0.2	Nicklas et al. 2003	n=57
60.8 ± 4.7	NS	Sed	1.32 ± 0.12	Hughes et al. 1995	n=6
61 ± 2	NS	O	1.6 ± 0.1	Tanaka et al. 1998	n=9; Sed
62 ± 2	NS	Sed	1.5 ± 0.1	Tanaka et al. 1998	n=9
62 ± 6	W	Sed	1.4 ± 0. 3	Hagberg et al. 2003	n=9; HRT
63.2 ± 5.4	NS	O.OW	1.60 ± 0.27	Nicklas et al. 1997	n=29
64 ± 4	NS	Sed	1.6 ± 0.4	Tanaka et al. 1997	n=16
64 ± 4	NS	Sed	1.46 ± 0.24	Ogawa et al. 1992	n=14
64 ± 4	W	Sed	1.5 ± 0.4	Schiller et al. 2001	n=18
64 ± 5	NS	O,OW	1.51 ± 0.30	Nicklas et al. 1995	n=29
64.1 ± 6.9	NS	O,OW	1.50 ± 0.26	Nicklas et al. 1997	n=28
64.4 ± 3.2	M	Sed	1.39 ± 0.19	Turner et al. 1999	n=10
65 ± 4	His	Sed	1.5 ± 0.2	Schiller et al. 2001	n=5
66 ± 6	W	Sed	1.4 ± 0.3	Hagberg et al. 2003	n=10; no HRT
70.3 ± 4.7	NS	Sed	1.21 ± 0.20	Hughes et al. 1995	n=6

Age Range (Mean & SD)	Ethnic Group	Health Status	VO_{2Max} Estimate (L / Min)	Citation	Comment
75.3 ± 4.6	NS	Sed	1.47 ± 0.89	Kent-Braun & Ng 2000	n=9
	Females: Active or Athlete				
61 ± 8	NS	Ath	2.0 ± 0.3	Proctor et al. 1998	n=8
64 ± 7	W	Act	1.7 ± 0.3	Hagberg et al. 2003	n=11; no HRT
65 ± 3	W	Ath	2.2 ± 0.3	Hagberg et al. 2003	n=9; HRT
65 ± 3	W	Ath	2.1 ± 0.3	Hagberg et al. 2003	n=12; no HRT
66 ± 4	NS	Ath	1.8 ± 0.4	Tanaka et al. 1997	n=13
	Females: Health Issues				
70 ± 3	M	PD	1.12 ± 0.34	Ryan et al. 2000	n=109
	Males: Normal or Healthy				
59.4 ± 3.6	NS	Ex-Ath.	2.60 ± 0.42	Saltin & Grimby 1968	n=5
60 – 69	NS	N	1.87 ± 0.44	Tlusty 1969	n=25; 65 y
62 ± 6	NS	N	2.60 ± 0.24	Sheldahl et al. 1996	n=9
63.7 ± 3.1	NS	N	2.28 ± 0.35	Kohrt et al. 1991	n=53
64 ± 3	NS	N	2.7 ± 0.3	Arciero et al. 1993b	n=89
64 ± 5	NS	N	2.67 ± 0.26	Tankersley et al. 1991	n=7
64 ± 5	NS	H	3.11 ± 0.68	Kenney & Ho 1995	n=6
64 ± 7	AA	N	1.9 ± 0.6	Carpenter et al. 1998	n=28
64 ± 7	AA	N	1.74 ± 0.60	Starling et al. 1998b	n=28
64.2 ± 9.4	NS	Ex-Ath.	3.26 ± 0.70	Pollock et al. 1987	n=13
64.8 ± 3.6	NS	N	2.20 ± 0.33	Kohrt et al. 1991	n=19
65 ± 2	NS	H	2.1 ± 0.2	Scheuermann et al. 2002	n=8
65.5 ± 4.5	NS	N	2.37 ± 0.40	Spina et al., 1997	n=8
65.8 ± 5.4	NS	N	2.43 ± 0.44	Blackie et al. 1989	n=47
66 ± 6	NS	H	2.6 ± 0.6	Johnson et al. 1994	n=56
66.0 ± 5.9	W	N	2.67 ± 0.76	Starling et al. 1998a	n=44
67 ± 6	W	N	2.27 ± 0.88	Starling et al. 1998a	n=32
68 ± 6	NS	H	2.31 ± 0.67	Goran & Poehlman 1992	n=7
68.6 ± 5.1	NS	N	1.38 ± 0.31	Panton et al. 1996	n=19
68.7 ± 8.1	NS	N	1.78 ± 0.46	Johnson et al. 2000	n=152
70 – 79	NS	N	1.55 ± 0.40	Tlusty 1969	n=13; 75 y
70 ± 7	W	N	2.1 ± 0.5	Carpenter et al. 1998	n=47
70 ± 7	NS	N	2.5 ± 0.5	Toth et al. 1997a	n=46
71.6 ± 2.4	NS	N	2.12 ± 0.33	Sabapathy et al. 2004	n=9
74.7 ± 3.5	NS	N	1.78 ± 0.38	Papadakis et al. 1996	n=26
75.2 ± 4.5	NS	N	1.71 ± 0.37	Papadakis et al. 1996	n=26
> 80	NS	N	1.14 ± 0.16	Tlusty 1969	n=2; 85 y
	Males: Sedentary, Overweight, or Obese				
60 ± 5	NS	Sed,O	2.7 ± 0.6	Katzel et al. 1995	n=26
61 ± 4	NS	Sed	1.7 ± 0.3	Van Pelt et al. 1998	n=19

Age Range (Mean & SD)	Ethnic Group	Health Status	VO_{2Max} Estimate (L / Min)	Citation	Comment
61 ± 8	NS	Sed,O	2.7 ± 0.4	Katzel et al. 1995	n=73
61 ± 9	NS	Sed,O	2.7 ± 0.5	Katzel et al. 1995	n=71
61.1 ± 6.2	NS	Sed	2.73 ± 0.48	Katzel et al. 2001	n=42
61.4 ± 5.2	NS	Sed	2.73 ± 0.52	Rogers et al. 1990	n=14
61.8 ± 5.3	NS	Sed	2.34 ± 0.40	Thomas et al. 1985	n=44
62.5 ± 3.4	NS	Sed	2.28 ± 0.47	Thomas et al. 1985	n=45
63 ± 3	NS	Sed, OW	2.6 ± 0.6	Ferrara et al. 2006	n=9
63 ± 3	NS	Sed, OW	2.6 ± 0.4	Ferrara et al. 2006	n=13
63 ± 3	NS	Sed	2.24 ± 0.33	Ogawa et al. 1992	n=13
63 ± 5	NS	Sed,O	2.3 ± 0.5	Goldberg et al. 2000	n=26
63 ± 7	NS	Sed	2.5 ± 0.7	Goldberg et al. 2000	n=12
64 ± 3	NS	Sed	2.36 ± 0.09	Ehsani et al. 2003	n=10
64.8 ± 8.0	NS	Sed	2.3 ± 0.24	Hughes et al. 1995	n=4
65 ± 2	NS	Sed	2.5 ± 0.2	Ho et al. 1997	n=6
66 ± 5	NS	Sed	2.35 ± 0.22	Hagberg et al. 1988	n=10
66.4 ± 5.6	M	Sed	2.33 ± 0.33	Turner et al. 1999	n=11
66.8 ± 1.8	NS	Sed	2.18 ± 0.16	Hughes et al. 1995	n=4
75.7 ± 4.7	NS	Sed	2.38 ± 1.71	Kent-Braun & Ng 2000	n=9
	Males: Active, Fit, or Athlete				
60 – 67	NS	Ath	2.68 ± NS	Saltin & Grimby 1968	n=4
60.0 ± 8.6	NS	Ath	3.53 ± 0.40	Pollock et al. 1987	n=11
60.2 ± 8.8	NS	Ath	3.5 ± 0.5	Pollock et al. 1997	n=21
62.0 ± 8.9	NS	Ath	3.68 ± 0.50	Rogers et al. 1990	n=15
62.3 ± 2.9	NS	Ath	3.1 ± 0.7	Hawkins et al. 2001	n=13: visit #1
63 ± 4	NS	Ath	3.14 ± 0.43	Ogawa et al. 1992	n=14
63.4 ± 6.5	NS	Ath	3.45 ± 0.39	Katzel et al. 2001	n=42
64 ± 6	NS	Ath	3.0 ± 0.3	Proctor et al. 1998	n=8
66 ± 3	NS	Fit	3.25 ± 0.25	Tankersley et al. 1991	n=6
65 ± 3	NS	Ath	3.22 ± 0.36	Hagberg et al. 1988	n=10
65 ± 4	NS	Ath	3.49 ± 0.58	Peiffer et al. 2008	n=8
66 ± 8	NS	Ath	3.3 ± 0.4	Goldberg et al. 2000	n=18
67 ± 4	NS	Act	2.08 ± 0.37	Sagiv et al. 1989	n=20
68 ± 4	NA	Act	2.12 ± 0.44	Sagiv et al. 1989	n=20
68.4 ± 9.8	NS	Fit	2.74 ± 0.79	Trappe et al. 1996	n=10
70.4 ± 3.2	NS	Ath	2.9 ± 0.7	Pollock et al. 1997	n=21;followup
71.1 ± 3.2	NS	Ath	2.4 ± 0.7	Hawkins et al. 2001	n=13; visit #2
76.0 ± 4.8	NS	Ath	2.9 ± 0.8	Hawkins et al. 2001	n=8: visit #1
82.8 ± 4.0	NS	Ath	2.0 ± 0.6	Hawkins et al. 2001	n=8;visit #2
	Males: Health Problems				
62 ± 8	NS	Park	1.3 ± 0.6	Toth et al. 1997b	n=16
63.3 ± 6.5	NS	COPD	1.43 ± 0.39	Mador et al. 1995	n=6
64 ± 3	NS	Heart	2.05 ± 0.21	Sheldahl et al. 1996	n=9
65.9 ± 6.0	NS	COPD	0.7 ± 0.2	Montes de O. et al. 1996	n=25; severe
68 ± 6	NS	Heart	1.96 ± 0.22	Sheldahl et al. 1996	n=8

Age Range (Mean & SD)	Ethnic Group	Health Status	VO_{2Max} Estimate (L / Min)	Citation	Comment
69 ± 3	NS	Heart	1.91 ± 0.23	Sheldahl et al. 1996	n=11
	Both Genders				
60 – 69	NS	N	1.93 ± 0.58	Heil et al. 1995	n=66
60 – 69	NS	N	1.77 ± 0.44	Heil et al. 1995	n=8
60 – 83	NS	Sed	1.70 ± 0.26	Sidney & Shephard 1978	n=12
60 – 83	NS	Sed	2.09 ± 0.53	Sidney & Shephard 1978	n=8
60 – 83	NS	Sed	1.96 ± 0.64	Sidney & Shephard 1978	n=14
60 – 83	NS	Sed	1.96 ± 0.32	Sidney & Shephard 1978	n=8
61 ± 10	NS	COPD	1.2 ± 0.5	LoRusso et al. 1993	n=62
62 ± 7	NS	COPD	1.26 ± 0.43	Larson et al. 1999	n=12
63 ± 3	NS	N	1.9 ± 0.4	Seals et al. 1984	n=24
63.5 ± 3.0	NS	N	1.71 ± 0.20	DeVito et al. 1997	n=11
63.6 ± 2.7	NS	N	1.89 ± 0.55	Kline et al. 1987	n=34
64.2 ± 9.3	NS	N	1.65 ± 0.20	DeVito et al. 1997	n=5
64.4 ± 2.5	NS	N	2.14 ± 0.73	Kline et al. 1987	n=36
64.8 ± 6.6	NS	N	1.55 ± 0.50	Hays et al 2006	n=11
65 – 80	NS	Sed	1.81 ± 0.21	Bell et al. 1998	n=9
65 ± 6	NS	N	2.1 ± 0.6	Scheuermann et al. 2002	n=8
65.3 ± 4.7	NS	Sed	2.16 ± 0.61	Woods et al. 1998	n=33
66 ± 5	NS	COPD	1.38 ± 0.38	Larson et al. 1999	n=13
66 ± 5	NS	COPD	1.14 ± 0.38	Larson et al. 1999	n=14
66.2 ± 4.2	NS	Sed	1.8 ± 0.5	Stein et al. 1999	n=16
67 ± 8	NS	N	0.77 ± 0.35	LoRusso et al. 1993	n=20;severe
67.5 ± 7.3	NS	H	1.62 ± 0.45	Hays et al.2006	n=11
68 ± 6	NS	COPD	1.26 ± 0.45	Larson et al. 1999	n=14
68.8 ± 6.1	NS	Heart	1.06 ± 0.25	Maldonado-M. et al. 2005	n=47
69 ± 8	W	N	1.72 ± 0.56	Startling et al. 1998a	n=99
69.4 ± 5.2	NS	Heart	1.08 ± 0.34	Maldonado-M. et al. 2006	n=50
69.5 ± 11.0	NS	N	1.20 ± 0.30	Barry et al. 1966	n=5
70 – 79	NS	N	1.93 ± 0.58	Heil et al. 1995	n=40
70 – 79	NS	N	1.77 ± 0.44	Heil et al. 1995	n=7
70 – 79	NS	N	1.59 ± 0.55	Hagberg et al. 1989	n=16
70 – 79	NS	N	1.68 ± 0.50	Hagberg et al. 1989	n=19
70 – 79	NS	N	1.51 ± 0.57	Hagberg et al. 1989	n=12; no HRT
72.6 ± 9.5	NS	N	1.08 ± 0.28	Barry et al. 1966	n=3
83.0 ± 3.6	NS	Frail	1.18 ± 0.38	Ehsani et al. 2003	n=22
84 ± 4	NS	Sed	1.23 ± 0.37	Vaitkevicius et al. 2002	n=35
84.0 ± 4.2	NS	Frail	1.09 ± 0.29	Ehsani et al. 2003	n=24

Abbreviations:

AA	African American (black)
Act	Active (but non-athletes)
Ath	Athletes
B	Both genders
COPD	Chronic obstructive pulmonary disease
♀	Females
Fit	Very active healthy exercisers
Frail	Mild-to-moderate frailty
H	Healthy
Heart	Heart "failure" patients
HRT	Hormone replacement therapy
♂	Males
M	Mixed ethnicity or mixed fitness level
N	Normal (mostly healthy)
NS	Not specified
O	Obese
OW	Overweight
Park	Parkinson's disease patients
PD	Peripheral disease patients
Sed	Sedentary
W	White (Caucasian)

A number of researchers do not believe that VO_{2Max} is an appropriate indicator of fitness or an elder's ability to undertake physical work, because many older people cannot attain **true** VO_{2Max} according to commonly accepted criteria (White et al., 1998). In fact, they state that only "motivated" subjects, <50% of their sample, could attain a classically-defined VO_{2Max}[5]. Thus, there are issues associated with use of the metric itself and what it indicates in the elderly.

Training (fitness improvements), on the other hand, improves exercise performance and VO_{2Max} estimates using most metrics of maximal oxygen consumption. Saltin & Grimby (1968) state that $VO_{2.Max}$ is 40% higher in elderly endurance competitors than in sedentary individuals of the same age. In fact, endurance training impacts remain long after exercise stops. Ex-athletes who have not performed in endurance events for at least 10 years before being tested, still had $VO_{2.Max}$ rates 20% higher than their sedentary competitors (Saltin & Grimby, 1968). The effect that lifestyle has on $VO_{2.Max}$, especially activity level, has been extensively studied by Hagberg and colleagues; they also looked

[5] The 3 criteria are: hitting a plateau in oxygen consumption with increasing work rate (defined to be a leveling or decrease in VO_{2Max} over 3 consecutive minute averages recorded at 10-s intervals), a respiratory exchange ratio (RER) of ≥ 1.10, and a heart rate within 10 beats of the subject's age-predicted HR_{MAX} (White et al., 1998). RER approximates the "true" non-protein respiratory quotient of metabolism under a steady-state condition (Astrand & Rodahl, 1986). It is measured as the ratio of CO_2–to-O_2 uptake of the lungs, which is obtained during the VO_{2Max} testing protocol.

at differences in $VO_{2.Max}$ in menopausal women due to lifestyle and selected genotypes (Hagberg et al., 1998).

A *derived* VO_2 metric is VO_{2RES}, which is equal to VO_{2MAX} - VO_{2REST}. For many physiological relationships, VO_{2RES} shows a more linear and stronger relationship (higher R^2) with other "reserve" metrics (heart rate reserve [HR_{RES}] and $METS_{RES}$) than absolute values of the same variable (McCurdy & Graham, 2004b). It is anticipated that NERL will be developing new physiological relations based on the reserve metric approach for use in exposure modeling efforts.

Peak Expiratory Flow Rate (PEFR) is a less reliable indicator of maximal airway functioning than $VO_{2.Max}$, but is easier and less expensive to measure. This physiological measure has been shown to positively reflect aspects of a subject's fitness level, being higher in elders who take frequent walks, work in the garden, and sweat at least once a month (Cook et al., 1989). PEFR also is positively associated with such things as cognitive functioning (Cook et al, 1989). There are alternative measures used to describe respiratory functioning in the elderly. For a review of some of them, see Enright et al., (1994, 1997). At the current time, our exposure models do not use PEFR or any of the alternatives as indicator variables of fitness or lung/airway function in the modeled population.

2.E Maximum ventilation (breathing) rate (V_{EMax})

The exercise physiology literature for the elderly does not focus much on $V_{E.Max}$, an important parameter in our exposure models. To physiologists, VO_{2Max} is the preferred ventilation metric of choice, as it is more directly related to metabolic processes than maximal minute ventilation, but to exposure assessors $V_{E.Max}$ is the metric that determines how much of a pollutant enters the respiratory system. McArdle et al. (2001) states that $V_{E.Max}$ varies with age; at 80 it is 40% of what it was at age 30 (p. 877). The data that could be found on $V_{E.Max}$ in the elderly appear as Table 2-3.

$V_{E.Max}$ for exposure modeling purposes is estimated from VO_{2Max} values using equations contained in Graham & McCurdy (2005). The equations have the following form:

$$Ln(V_E/BM)_I = b_o + (b_1*Ln[\ VO_2/BM_i\ ]) + (b_2*[\ Age_i\ ]) + (b_3*[\ Gender_i\ ]) + e_w + e_B$$

The within- and between- residuals (e_w and e_B) are sampled from a random normal distribution of mean=0 and the standard deviations noted below (N { 0, σ}). Gender = 1 ♀ and -1 ♂.

The equation for $V_{E.Max}$—as well as for activity-specific V_E estimates—for individuals aged 61+ in Graham & McCurdy (2005) is:

$$\text{Ln}\,(V_E\,BM^{-1})_{61+} = 2.449 + (1.044 * \text{Ln}[\,VO_2\,BM^{-1}]) + (0.268 *[\,\text{Age}\,]) + (0.030 * [\,\text{Gender}\,]) + e_w\,(0.068) + e_B\,(0.106)\quad R^2 = 0.89;\ p=0.003$$

Where :

e_B: Between-individual variability (inter-individual) residual
e_W: Within-individual variability (intra-individual) residual

A less complicated, more direct $V_{E.Max}$ equations for females and males are seen in Tlustý (1969):

$$V_{E.Max}\ ♀ = 120.6 - (1.103 * \text{Age}) \qquad R^2 = 0.42$$

$$V_{E.Max}\ ♂ = 130.6 - (1.007 * \text{Age}) \qquad R^2 = 0.25$$

There is a lot of variability in $V_{E.Max}$ estimates seen in the literature. The values in Table 2-3 show large differences by age, gender, and lifestyle (fitness level). There also is a large coefficient of variation (COV) among the subgroups, even when they are defined by a single gender and lifestyle or health grouping. These COV's are in the 15-28% range. When the genders are combined (in the "Both" group), the COV's increase to 30-40% or so, with a few at the 20% and 50% levels. Undoubtedly there are large intra-individual differences in daily $V_{E.Max}$ estimates also, but there are no data on this point.

Table 2-3. Estimates of $V_{E.Max}$ for older adults

Age Range (Mean ± SD)	Health Status	VEmax Estimate (L / min)	Citation	Comment
	Females: Normal, Healthy, or Not-specified			
60 – 69	NS	56 ± 14	Blackie et al. 1991	n=20
62 ± 6	N	59.2 ± 9.9	Sheldahl et al. 1996	n=9
62 ± 7	N	58.3 ±10.3	Sheldahl et al. 1996	n=11
65.5 ± 7.8	N	42.6 ±16.5	Carter et al. 1994	n=16
67 ± NS	N	47.0 ±12.2	Hollenberg & Tager 2000	n=579
70 – 79	NS	48 ± 12	Blackie et al. 1991	n=20
	Females: Sedentary or Health Issues			
63.7 ± 5.8	COPD	26.1 ± 7.2	Carter et al. 1994	n=58; severe
64 ± 4	Sed	64.7 ±16.4	DeVito et al. 1997	n=16
64.8 ± 6.4	COPD	39.9 ± 8.2	Carter et al. 1994	n=23; mild
65.0 ± 5.2	COPD	33.9 ± 8.2	Carter et al. 1994	n=42; moderate
75.2 ± 4.6	Sed	58.7 ± 9.6	Kent-Braun & Ng 2000	n=9
	Females: Athletes			
64.6 ± 3.9	Ath	80.3 ± 9.0	Hawkins et al. 2001	n=9;visit #1
66 ± 4	Ath	86.7 ±20.2	Tanaka et al. 1997	n=13
73.2 ± 5.7	Ath	61.2 ±13.5	Hawkins et al. 2001	n=9;visit #2
	Males: Normal, Healthy, or Non-specified			
60 – 67	Ex-Ath.	83.2 ± 7.3	Saltin & Grimby 1968	n=5;10 y no training
60 – 69	NS	83 ± 14	Blackie et al. 1991	n=20
60.0 ± 4.7	N	71.3 ±13.4	Carter et al. 1994	n=13
62 ± 6	N	102.4±15.9	Sheldahl et al. 1996	n=9
64.2 ± 9.4	Ex-Ath.	144 ± 25	Pollock et al. 1987	n=13
68 ± NS	N	75.8 ± 21.6	Hollenberg & Tager 2000	n=419
68.4 ± 9.8	Fit	87.5 ± 11.7	Trappe et al. 1996	n=10
70 – 79	NS	66 ± 12	Blackie et al. 1991	n=11
	Males: Sedentary or Health Issues			
61.4 ± 5.2	Sed	95.8 ± 22.1	Rogers et al. 1990	n=14
63.3 ± 6.4	COPD	48.9 ± 14.5	Mador et al. 1995	n=62
64 ± 3	Heart	68.0 ± 9.3	Sheldahl et al. 1996	n=9
65.3 ± 6.5	COPD	51.5 ± 18.5	Carter et al. 1994	n=32; mild
66 ± 5	Sed	85 ± 11	Hagberg et al. 1988	n=10
66.3 ± 6.2	COPD	48.3 ± 14.2	Carter et al. 1994	n=57; moderate
66.3 ± 6.3	COPD	37.1 ± 11.4	Carter et al. 1994	n=176; severe
68 ± 6	Heart	68.2 ± 6.8	Sheldahl et al. 1996	n=8
69 ± 3	Heart	74.6 ± 10.3	Sheldahl et al. 1996	n=11

Age Range (Mean ± SD)	Health Status	VEmax Estimate (L / min)	Citation	Comment
75.7 ± 4.7	Sed	98.3 ± 21.9	Kent-Braun & Ng 2000	n=9
	Males: Athletes			
60.0 ± 8.6	Ath	148 ± 18	Pollock et al. 1987	n=11
60.2 ± 8.8	Ath	151.4±20.0	Pollock et al. 1997	n=21
61 ± 8	Ath	98 ± 11	Proctor et al. 1998	n=8
62.0 ± 8.9	Ath	116.2±17.8	Rogers et al. 1990	n=15
62.3 ± 2.9	Ath	84 ± 14	Hawkins et al. 2001	n=13;visit #1
64 ± 6	Ath	135 ± 25	Proctor et al. 1998	n=8
65 ± 3	Ath	106.9±27.4	Hagberg et al. 1988	n=10
70.4 ± 8.8	Ath	117.3±24.7	Pollock et al. 1997	n=21;followup
71.1 ± 3.2	Ath	88.0 ± 27.4	Hawkins et al. 2001	n=13;visit #2
76.0 ± 4.8	Ath	93.9 ± 27.4	Hawkins et al. 2001	n=8;visit #1
82.8 ± 4.0	Ath	73.8 ± 23.2	Hawkins et al. 2001	n=8;visit #2
	Both Genders			
61 ± 10	COPD	49 ± 21	LoRusso et al. 1993	n=62
63 ± 3	N	67.2 ± 16.4	Seals et al. 1984	n=24
63.5 ± 3.0	N	50.0 ± 10.0	Lost citation	n=11
64 ± 7	COPD	44.2 ± 14.1	Singh et al. 1994	n=10
64.2 ± 4.0	N	53.8 ± 6.0	DeVito et al. 1997	n=5
65.1 ± 2.9	N	60.5 ± 25.7	Meredith et al. 1989	n+10
67 ± 8	COPD	34 ± 18	LoRusso et al. 1993	n=20; severe
69.1 ± NS	N	69.2 ± 15.4	James et al. 1997	n=10
70 – 79	N	51.1 ± 18.8	Hagberg et al.1989	n=16
70 – 79	N	57.3 ± 15.0	Hagberg et al.1989	n=19
70 – 79	N	53.5 ± 22.6	Hagberg et al.1989	n=12

Abbreviations:

Ath	Athlete
B	Both genders
COPD	Chronic Obstructive Pulmonary Disease
Heart	Heart disease or coronary artery disease
♀	Females
♂	Males
N	Normal health
n	Sample size
NS	Not specified (unknown)
Sed	Sedentary

2.F Ventilatory equivalent (VQ)

Even though VQ no longer is used in the APEX and SHEDS models, because of its historic importance in EPA's exposure work, what scant data could be found on this physiological parameter in the elderly is discussed here. Hagberg et al. (1989) presents VQ at maximum exertion (VQ_{MAX}) data on three 70-79 y old groups of mixed (both) genders. Assignment of an individual to one of the 3 groups was done on a random basis, without regard to the VQ of the sub-sets. VQ_{MAX} at $VO_{2.Max}$ for the 3 groups was: 32.2 ± 4.4, 34.6 ± 4.2, and 35.5 ± 6.6. Large COV's for the groups indicates that there is substantial variability in VQ data: 13.7%, 12.1%, and 18.5%, respectively. Statistical testing of the means or the SD's was not presented. The high variability in VQ is but one of the reasons this parameter is no longer used in APEX/SHEDS exposure/intake dose models.[6]

Panton et al. (1996) provide VQ_{MAX} estimates for 68.6 ± 5.7 y old females and 68.7 ± 5.1 males. The VQ_{MAX} estimates are 41.3 ± 7.7 and 39.8 ± 8.7, respectively. Besides the absolute values being relatively high, the COV's are quite large, being 18.6% for females and 21.8% for males. This magnitude of cross-sectional variability is rarely accounted for in human exposure/intake dose rate models.

Additional VQ_{MAX} data for elderly males are provided in Hagberg et al. (1988). The VQ_{MAX} for sedentary subjects aged 66 ± 5 was 36 ± 4; the VQ_{MAX} for athletes aged 65 ± 3 was 33 ± 4 (n=10 for both groups). These differences were not significantly different using ANOVA and author-identified "appropriate contrasts."

VQ is also a marker of the "ventilatory threshold" (V_T) which is another term often used for the aerobic threshold (where V_E increases, but VO_2 does not, for an increase in work undertaken). V_T in the elderly is about 50-60% of $VO_{2.Max}$, a higher proportion than seen in young adults (Thomas et al., 1985). V_T is correlated in a U-shaped fashioned with $VO_{2.Max}$. V_T seen in elderly males in another study was between 56-61% of $VO_{2.Max}$, regardless of the subject's fitness level (Takeshima et al., 1996).

2.G Heart rate (HR) and HR_{MAX}

Heart rate in an individual associated with a particular work load and HR_{MAX} itself are other physiological traits that are largely inherited from a person's parents (McArdle et

[6]Firstly, VQ is not measured often, so there is a lack of empirical data on the parameter. Secondly, VQ is not stable over time in an individual, or among individuals of the same age/gender cohort. Most importantly, VQ varies non-linearly with VO_2 and the increasing slope of V_E with VO_2 was not explicitly acknowledged in EPA's older models. The older exposure/intake dose rate model runs also systematically underestimated VQ at higher levels of energy expenditure/oxygen consumption (a VQ of 27 often was used, but values as high as 40 often are recorded), which biased estimated V_E rates downward.

al., 2001).[7] There are numerous $VO_{2\,Max}$ prediction equations based on HR_{MAX}, either by itself or in conjunction with other independent variables (such as age, gender, and fitness level), and there seems to be a relatively tight linear relationship between heart rate reserve (HR_{RES}), which is HR_{MAX} - HR_{REST}, and VO_{2RES}.

HR_{Max} declines with age, closely related to activity level and fitness of an individual. The following estimated mean HR_{Max} values are provided in Sharkey (1984) for elderly males of differing fitness levels:

Age	Below Average	Average Fitness	Above Average
60	158	172	175
65	152	169	173
70	147	165	170

The average COV for these estimates is about 8% or so, which is low for cross-sectional data in general. Since the resting heart rate (HR_{REST}) *decreases* for fit people, often quite dramatically, the impact of fitness level on HR_{RES} is even larger than the above age-related HR_{Max} declines might suggest. All of these factors affect the "stroke volume" of the heart, blood flow and distribution among body organs, and the "oxygen extraction efficiency" from the blood (McArdle et al., 2001).

One general HR_{Max}-to-age relationship seen often in the literature is: $HR_{Max} = 220 - Age$ (y). However, this approximation does not apply to fit individuals, which show a smaller HR_{Max} reduction with age than predicted by this formula (McArdle et al., 2001). The decrease in HR_{Max} in the elderly can be reversed to some extent by training.

Because the absolute HR-to-VO_2 relationship for given workloads are highly individualistic and are greatly affected by how the work is performed (arm work versus leg or whole-body work), we do not use HR metrics in our intake dose modeling procedures. They are mentioned here because of the hypothesized relationships among HR, cardiovascular disease in the elderly, and particulate matter concentrations often seen in the epidemiological literature (e.g., Pope & Dockery, 2006; Zanobetti & Schwartz, 2009). Literally hundreds of citations could be provided on this point, but the point remains that neither APEX or SHEDS uses HR as a physiological input variable due to the highly individualistic nature of its relationship to other important physiological parameters.

[7] Maximum heart rate shows about an "86% genetic determination" (McArdle et al, 2001; p. 236). In another place in the same book, they state that heritability explains about 50% of variability in HR_{MAX}, so obviously there is an "unsettled" relationship between genetics and maximum physiological parameters.

2.H Height (HT)

Height (HT) in meters is an input to our BMR-estimating equation, but plays no role in the physiological modeling procedures used in our exposure models. In longitudinal studies of height measurements in the elderly, HT decreases at an accelerating rate after about 45 y, especially in females (Sorkin et al.,1999). In one longitudinal study of 1,068 males and 390 females, the following decreases were measured in cm y^{-1}:

Age Group (y)	60-69	70-79	80-89	90-94
Females	-0.22	-0.29	-0.47	-0.34
Males	-0.14	-0.19	-0.31	-0.58

It should be noted that the sample size for both genders in the 90-94 y group is only 3 individuals with a short "follow-up" longitudinal period also. Gender difference in the slopes are statistically significant for all age groups <90 y (and >50 y; not shown).

Additional information is available on height/age change rates, but is not reviewed here.

2.I Concluding comments for this Section

Attention has been given to the types of anthropogenic and physiologic variables used in the APEX and SHEDS models. As mentioned, there is a lot of variability in the elderly for some of the important physiological variables discussed. In general, "older individuals possess impressive plasticity in physiologic, structural, and performance characteristics...even into the 9th decade of life" (McArdle et al., 2001: 879-880). In particular, when modeling air intake dose rates in exposed individuals, it is important to address differences in fitness in the elderly. Information on fitness is very difficult to determine *a priori*; it may have to be simulated based on the PAI data in CHAD. That subject will be addressed below under "Physical Activity."

There are other physiological considerations that apply to exposure modeling, since they affect the ability to participate in exercise and or travel outside of the home. These include muscle mass, heart rate, strength, mobility, and the like.[8] Heart rate change is one physiological component that has been shown to be associated with environmental exposures, especially to small-sized particulate matter (Stein et al., 2009; Schlesinger et al., 2006). For instance, Adar et al. (2007) states that HR variability is negatively associated with fine particulate exposure in 44 elderly subjects wearing an ECG, both for short-term and daily exposures. Exposure to fine particulates reduces parasympathetic tone. While HR change due to age is not a factor in APEX or SHEDS yet, it could be

[8] Organ mass in the elderly--particularly the brain, kidneys, liver, and spleen—decreases with age, but heart mass has less of a change (He et al. 2009). The clinical importance of this decrease is not understood at the present time.

added. As discussed, exercise scientists treat HR rather superficially, normally using the very broad $HR_{Max} = 220 - Age\ [y]$ equation to relate heart rate to age. This relationship would have to be made more rigorous if heart rate impacts associated with fine particulates or any other environmental pollutant are to be explicitly modeled.

Physiologic variables of secondary interest do affect some of the major parameters discussed above, but often the relationships among them are tenuous and difficult to quantify. Additional research on these topics would need to be undertaken if they are to be added to our exposure models. BMI, for instance, while not used directly in the models mentioned (its two constituents—BM and HT are used) is an important metric of concern from a health effects perspective (Stevens et al., 1998). A report undertaken as part of EPA's Aging Initiative by Abt Associates (Marriott et al., 2008) provides information about BMI in the elderly population. The proportion of the elderly who are overweight hovers around 35-42% for all five-year age groups between 65 and 85, while those categorized as obese decreases from 38% to 17% for the same age classes (Marriott et al., 2008; p. 6). An overweight elderly population is a relatively new phenomenon. Since being overweight or obese (especially) affects intake dose rates, these conditions probably also affect heath effects associated with airborne exposures.

A quick update of elderly BMI data was conducted in late 2009 (CDC, 2009) for this report. CDC provided the following age-adjusted percentage estimates by body weight categories based on four BMI cutoffs (in kg m^{-2}): underweight (BMI < 18.5); healthy weight (18.5 ≤ BMI < 25.0); overweight (25.0 ≤ BMI < 30.0); obese (BMI ≥ 30.0).

Weight Categorical Descriptors
(Percent of age group population and [standard error])

	Underweight	Healthy	Overweight	Obese
65 – 74 y	1.1 (0.2)	30.2 (1.1)	38.3 (1.2)	30.4 (1.1)
≥ 75 y	3.5 (0.5)	42.0 (1.3)	37.5 (1.3)	16.9 (1.0)

These CDC estimates are similar to those provided above by Abt Associates. When undertaking an exposure analysis, subjects who provided diary data in CHAD could be assigned to the above categories and modeled accordingly. However, doing so requires that one or more of the physiological parameters in APEX or SHEDS would have to be distinguished somehow on the categories used, and no published parameter relationship has been identified to do so. Perhaps that type of information will become available in the future. Thus, at the present time BMI can only be used descriptively and not as an operative variable in EPA's elderly exposure modeling efforts.

3. Energy Expenditure, Total Daily Energy Expenditure, and Physical Activity Index

Abstract

Topic: This chapter discusses physical activity in the elderly from an energy-expenditure perspective.
Issue /Problem Statement: Energy expenditure (EE) decreases with age, and thus exposure model algorithms that base intake doses on EE-derived ventilation rates should be validated with age-specific EE data.
Data Available: The literature covering different mean energy expenditure metrics in the elderly is relatively data-rich, and these data are mostly useful in validating EPA's physical activity algorithms. Activity-specific energy expenditure data in the elderly, however, are scarce.
Research Needs: The identification or collection of activity-specific EE and METS data in older people is needed. The ventilation algorithms in EPA's exposure models should be refined to account for age-dependent changes in both maximal and activity-specific EE.

3.A Overview & TDEE

Because of the commonly identified systematic biases associated with estimates of energy *intake* (EI, in kilocalories), energy *expenditure* metrics are used in the APEX or SHEDS-Air models. Discussions of problems in estimating EI in the elderly are contained in Johnson et al. (1994), Tooze et al. (2007), and Young et al. (1992). Basically, EI has been shown to be under-reported by approximately 40% of the respondents, particularly in the low-income elderly subpopulation (Tooze et al., 2007). The most accurate estimate of daily EI in subjects of any age is to measure "total daily energy expenditure" (TDEE) in an individual. This is because daily EI is equivalent to TDEE given that condition that a person is neither losing or gaining weight. For some persons, this assumption generally is valid from a practical perspective; i.e., they may be minimal changes in body weight within a relatively short time frame: perhaps a year or less, generally the longest time period of analyses used in EPA's exposure modeling assessments. This assumption of stable weight may not be applicable for people having certain health conditions or for children and adolescents. There subsequently will be greater uncertainty in representing their body weight and attendant energy expenditures than for weight-stable persons. It would be very difficult to model intake dose rates for weight-changing individuals given the importance that BM plays in many of the physiological relationships found in APEX and SHEDS, so EPA modelers so far have assumed that BM of a simulated individual does not change for the year modeled (McCurdy et al., 2000). This restriction can be lifted at the expense of a considerable increase in model running time and assumptions regarding the time trajectory of weight changes, so modeling exposures and intake dose for a weight-changing individual is a practical matter, not a conceptual issue.

TDEE is estimated using a variety of techniques (Goldsmith et al., 1967; Schultz et al., 1989), but the doubly-labeled water (DLW) method is considered to be the most widely accepted (the "gold standard") for TDEE measures (Sawaya et al., 1995, 1996; Starling et al., 1998a,b). The DLW method actually provides estimates of EE for a multi-day period, but they are averaged over the number of elapsed days since drinking the isotope-

labeled water to obtain a daily average estimate.[9] In the APEX and SHEDS models, TDEE is calculated as the sum of activity-specific EE's obtained by multiplying activity-specific METS by the time spent in each activity (McCurdy, 2000). See Section 2 for more information on these parameters.

$TDEE_i = \Sigma (EE_A)$, where $EE_A = METS_A * time_A * BMR_i$

The units of $TDEE_i$, EE_A, and BMR_i are kilocalories (kcal; but popularly called Calories [C] in this country). $METS_A$ is a unitless metric. All of the energy (kcal) values are converted using the "U" parameter within the exposure models to oxygen consumption (VO_2) associated with the activity's energy expenditure. The units of VO_2 are either L min^{-1} or mL kg^{-1} min^{-1}.

The main source of $METS_A$ estimates is from the Ainsworth et al. (1993, 2000) *Compendium*. Additional $METS_A$ data are found in Jetté et al. (1990). Many articles can be found on activity-specific estimates and how they were developed, but not in the elderly. See Section 3.B.

$TDEE_i$ can also be obtained from multiplying the simulated person's Physical Activity Index (PAI_i) by BMR_i. Basically, PAI is the subject's daily-averaged METS for all activities undertaken in the day. This approach essentially follows the "factorial method" used by exercise physiologists and clinical nutritionists to estimate TDEE in individuals (Roberts & Rosenberg, 2006). There are scores of prediction equations relating TDEE in the elderly to both BMR and BM; see Carpenter et al. (1995) for a survey of over 20 such equations. The "pooled mean" COV for PAI for elderly males is 22.5% (versus 12.3% for all age groups). Thus, there is considerable relative variability within the elderly population, probably due to variability in health status and physical/mental functioning. See Section 6 for more information on that topic.

There are numerous articles on energy requirements of various population groups, including the elderly, mostly oriented toward minimum food intake needed to survive. There also are articles on energy requirements needed to "thrive" and to avoid nutrition-related health problem. Roberts (1996) is a comprehensive article of that type. Probably the single-most relevant review of TDEE in the elderly is Roberts & Rosenberg (2006). They state that TDEE usually is divided into 3 major categories: basal metabolism (see Section 2), physical activity,and the thermic effect of feeding. The thermic effect of feeding generally is about 10% of TDEE, and is never directly measured (Rogers & Rosenberg, 2006). Essentially it is treated as a fixed component of TDEE, and for this reason, we also ignore it here. Thus, the category of TDEE that is most important from an exposure and dose modeling perspective is physical activity (PA).

[9] Although DLW is considered to be the most accurate means of estimating multiple-day EE, calculating DLW involves using specific regression-based equations and assumptions involving fractionated water loss, the rate of carbon dioxide production per litre of oxygen consumed (the Weir equation), and the respiratory quotient (Surrao et al. 1998). Thus, the DLW measure itself is not without uncertainty. Note that the time period used in a DLW study usually is 7 days, but it varies between 5-14 days in different studies.

Section 5 below focuses entirely on physical activity (PA) in the elderly, and *types* and amount of time spent in it. In this Section, specific types of PA of interest are discussed from an *energy expenditure perspective*, that is described by oxygen consumption, METS, or kcal—all on a per unit time (minute) basis. When aggregated over a day, total EE from physical activity is known as PAEE (physical activity energy expenditure); Table 3-1 provides estimates of elderly PAEE seen in the literature.

In our modeling efforts, we use TDEE to check on how realistic are the intake dose rate output distributions in APEX and SHEDS that are developed from the highly disaggregated physiological processes depicted in Figure 2-1. If there is systematic error associated with the use of and parameterization of the variables depicted in the modeling logic, the subsequent exposure and dose estimates would likely be biased. Calculating TDEE in the model simulations and comparing them to distributions found in literature values provides an independent—albeit indirect—check on the intake dose modeling calculations. Thus, TDEE plays an important role in our modeling efforts, and has been used by OAQPS to evaluate APEX model performance. Estimates of TDEE in the elderly population appear as Table 3-1.

Table 3-1. Estimates of TDEE, PAEE, and/or PAI for the elderly.

Age Range (y)	Mean Age (y)	Sam. Size (n)	Gen.	TDEE (kcal/d)	PAI (-)	Reference	Comment
	Normal Weight Individuals						
60 - 69		48	♀	2042 ± 343	1.69	Roberts & Dallal 2005	SD for PAI: 0.31
		14	♂	2397 ± 437	1.61	Roberts & Dallal 2005	SD for PAI: 0.18
70 - 79		14	♀	1888 ± 295	1.55	Roberts & Dallal 2005	SD for PAI: 0.26
		30	♂	2407 ± 374	1.62	Roberts & Dallal 2005	SD for PAI: 0.25
80 - 89		6	♀	1382 ± 152	1.21	Roberts & Dallal 2005	SD for PAI: 0.09
		4	♂	1700 ± 239	1.17	Roberts & Dallal 2005	SD for PAI: 0.15
90 - 97		9	♀	1356 ± 166	1.17	Roberts & Dallal 2005	SD for PAI: 0.13
		6	♂	1935 ± 156	1.38	Roberts & Dallal 2005	SD for PAI: 0.17
	Overweight Individuals						
60 - 69		46	♀	2061 ± 294	1.52	Roberts & Dallal 2005	SD for PAI: 0.23
		30	♂	2851 ± 420	1.71	Roberts & Dallal 2005	SD for PAI: 0.29
70 - 79		19	♀	1868 ± 402	1.51	Roberts & Dallal 2005	SD for PAI: 0.28
		34	♂	2624 ± 461	1.55	Roberts & Dallal 2005	SD for PAI: 0.27
80 - 89		6	♀	1748 ± 464	1.41	Roberts & Dallal 2005	SD for PAI: 0.37
		6	♂	2294 ± 357	1.47	Roberts & Dallal 2005	SD for PAI: 0.16
90 - 97		7	♀	1766 ± 292	1.33	Roberts & Dallal 2005	SD for PAI: 0.22
		2	♂	1863 ± 46	1.29	Roberts & Dallal 2005	SD for PAI: 0.13
55-65	60.8 ±3.1	29	♀	2229 ± 325	1.81	Vinken et al. 1999	H; SD for PAI:0.23
	61 ± 4	28	B		1.65	Meijer et al. 2001	H; PAI Range:1.4-2.0
	61 ± 4	9	B		1.72	Meijer et al. 2001	H; not retired subset
32 - 82	61.2±15.3	27	♂	3071 ± 351		Seale 2002	Overweight

	62 ± 8	16	♂	2214 ± 460		Toth et al. 1997a	Parkinson's disease
41 - 80	62.1±11.9	27	♀	2282 ± 167		Seale 2002	Overweight
56 - 70	64 ± 5	6	♀	2092 ± 231	1.42	Goran & Poehlman 1992	H; PAI: 1.3-1.8
52 - 79	64 ± 7	37	♀	2090 ± 411	1.51	Starling et al. 1998a	AA; SD for PAI: 0.25
52 - 79	64 ± 8	28	♂	2772 ± 556	1.71	Starling et al. 1998a	AA; SD for PAI: 0.32
57 - 70	65 ± 5	7	♂	2675 ± 394	1.50	Goran & Poehlman 1992	H: PAI: 1.3-2.1
61 - 77	66.8 ± 3.7	15	B	1764 ± 531		Hunter et al. 2000	Healthy
60 - 77	67 ± 4	13	♀	1447 ± 162		Treuth et al. 1996	Healthy
	67 ± 5	13	B	2349 ± 545		Toth et al. 1997c	Non-cathectic HP
NS	67.6 ± 4.1	10	♀	2065 ± NS	1.66	Roberts 1996	Note 2 (P&W 1995)
60-81	67.8 ± 6.1	20	♂	2580 ± 566	1.74	Vinken et al. 1999	H; SD for PAI:0.27
	69 ± 6	50	B	2543 ± 449		Toth et al.1997	Healthy controls
NS	69 ± 7	15	♂	2495 ± 352	1.75	Roberts 1996	Note 2 (Roberts 1992)
56 - 90	69 ± 8	99	B	2379 ± 556	1.68	Starling et al. 1998a	SD of PAI: 0.28
NS	70.0 ± 6.9	9	♂	2349 ± 300	1.72	Roberts et al. 1996	H; PAI SD: 0.69
NS	71 ± 5	16	♂	2412 ± NS	1.51	Roberts 1996	Note 2 (P&W 1995)
66 - 81	71.2 ± 5.0	20	B	1840 ± 395		Leaf & Reuben 1996	Sedentary; note 1
	71.5 ± 4.8	21	♀	2213 ± 429		Ades et al. 2005	Normal (control)
	72.9 ± 6.1	21	♀	2207 ± 402		Ades et al. 2005	CHD & limitations
NS	73 ± 3	10	♀	2201 ± 354	1.80	Roberts 1996	Note 2 (Reilly 1993)
NS	73 ± 3	13	♀	2103 ± 837		Rutgers et al. 1997	Healthy
`	73 ± 6	12	B	1870 ± 347		Toth et al. 1997	Cachectic HP
67 - 82	73.5 ± 4.2	13	♀	2256 ± 215		Seale et al. 2002b	Overweight
NS	74 ± 2	10	♀	1852 ± 214	1.62	Roberts 1996	Note 2 (Sawaya 1993)
68 - 80	74.0 ± 4.4	10	♀	1813 ± 215	1.59	Vinken et al. 1999	H; SD for PAI:0.18
67 - 82	74.1 ± 4.1	14	♂	2971 ± 390		Seale et al. 2002b	Overweight
70 - 79	74.1 ± 3.2	67	♀	1904 ± 369	1.69	Blanc et al. 2004	B; PAI SD: 0.24
70 - 79	74.2 ± 2.7	39	♀	2106 ± 263		Manini et al. 2009	Active; normal
70 - 79	74.5 ± 3.3	43	♂	2788 ± 293		Manini et al. 2009	Active; normal
71 - 79	74.6 ± 3.1	40	♀	1839 ± 175		Manini et al. 2009	Normal
70 - 79	74.8 ± 2.8	77	♀	1885 ± 286	1.65	Blanc et al. 2004	B; PAI SD: 0.21
70 - 79	74.8 ± 2.9	72	♂	2324 ± 436	1.71	Blanc et al. 2004	W; PAI SD: 0.22
70 - 79	75.1 ± 3.2	72	♂	2521 ± 396	1.74	Blanc et al. 2004	W; PAI SD: 0.22
70 - 79	75.1 ± 3.1	43	♂	2395 ± 214		Manini et al. 2009	Normal
70 - 79	75.2 ± 2.7	43	♂	2044 ± 280		Manini et al. 2009	Less active; normal
70 - 79	75.5 ± 3.2	40	♀	2199 ± 335		Manini et al. 2009	Less active; normal
76 - 88	82 ± 3	23	♂	1657 ± 209	1.50	Fuller et al. 1996	W: PAI SD: 0.2
				TDEE/BM (kcal/kg-d)			
NS	65 ± 5	16	♂	38 ± 14		Tanaka et al. 2002	Sedentary
76 - 88	82 ± 3	23	♂	30.8 ± 4.9	1.50	Fuller et al. 1996	White; normal
				PAEE (kcal/d)			
52 - 79	64 ± 8	37	♀	207 ± 211	1.51	Starling et al. 1998b	SD for PAI: 0.25
52 - 79	64 ± 7	28	♂	410 ± 320	1.71	Starling et al. 1998b	SD for PAI: 0.32
	67 ± 4	15	♀	682 ± 325		Treuth et al. 1996	
48 - 94	67 ± 9	32	♀	1211 ± 429		Starling et al. 1999	Whites
48 - 94	66 ± 11	35	♂	874 ± 244		Starling et al. 1999	Whites

56 - 90	69 ± 8	99	B	719 ± 377	1.68	Starling et al. 1998a	
	71.5 ± 4.8	21	♀	547 ± 360		Ades et al. 2005	Normal (control)
	72.9 ± 6.1	21	♀	498 ± 314		Ades et al. 2005	CHD & limitations
70 - 79	74.2 ± 2.7	39	♀	805 ± 206		Manini et al. 2009	Active; normal
70 - 79	74.5 ± 3.3	43	♂	1079 ± 183		Manini et al. 2009	Active; normal
71 - 79	74.6 ± 3.1	40	♀	436 ± 61		Manini et al. 2009	Normal
70 - 79	74.6 ± 3.2	67	♀	620 ± 272	1.69	Blanc et al. 2004	AA; note 3
70 - 79	74.8 ± 2.10	72	♂	865 ± 284	1.74	Blanc et al. 2004	B
70 - 79	74.8 ± 2.8	77	♀	584 ± 197	1.65	Blanc et al. 2004	W
70 - 79	75.1 ± 3.2	72	♂	775 ± 313	1.71	Blanc et al. 2004	AA
70 - 79	75.1 ± 3.1	43	♂	737 ± 83		Manini et al. 2009	Normal
70 - 79	75.2 ± 2.7	43	♂	467 ± 115		Manini et al. 2009	Less active; normal
70 - 79	75.5 ± 3.2	40	♀	350 ± 66		Manini et al. 2009	Less active; normal

Abbreviations:

AA	African-American (black)
B	Both genders
CHD	Coronary heart disease
♀	Females
H	Healthy
HP	Heart patients
♂	Males
NS	Not specified
SD	Standard deviation
W	White (Caucasian)

Notes:

1. Data were provided for a 48 h period; the TDEE estimate is 1/2 of it. The authors provide data for individuals and group means. The weighted means are estimated to be: ♀=1781(n=15) and ♂=2018 (n=5).
2. Roberts et al. 1995 is a review of previous papers on TDEE in the elderly. One of them is Roberts et al. 1992 in the references. P&W is Pannemans & Westerterp 1995 *Brit. J. Nutr.* 73: 571-581, which in not in the references. Reilly 1993 is in *Brit. J. Nutr.* 69: 21-27. Sawaya 1993 is Sawaya et al. *Amer. J. Clin. Nutr.* 62: 338-344.
3. PAEE is also supplied in units of kcal/day-kg.

We note that the intra-individual variation in TDEE is quite large. Based upon theoretical error analysis of experimental variation of the DLW method, the COV for TDEE should be about 6%, but the observed variation is double that: about 12% (Goran, 1995). With respect to cross-sectional relative variability, Black & Cole (2000) report that the "pooled mean" COV for TDEE is 11.8% for all age groups and 16.3% for male subjects 65-74 y old (Black & Cole, 2000). A longitudinal study that only presents cross-sectional data by age groups is Sunman et al. (1991). This study started in 1952, and TDEE was assessed 24 years later, when the male college graduates were in their late 60's. It was assessed again when the men were in their mid-70's. The group was divided into former athletes and "controls." The Sunman et al. (1991) mean ± SD data are reproduced here; the weekly PAEE was divided by 7 to obtain the "daily" estimate:

	TDEE (kcal day^{-1})	PAEE (kcal day^{-1})	n	Age
Athletes				
1976	1968 ± 923	232 ± 229	147	68.5 ± 7.7
1984	1850 ± 802	238 ± 226	80	75.1 ± 5.3
Controls				
1976	1992 ± 708	190 ± 227	66	69.8 ± 8.8
1984	1618 ± 660	229 ± 234	35	77.1 ± 7.1

A few cross-sectional statistics from their study of interest indicate that : (1) a much larger TDEE decline in controls (19%) than in former athletes (6%); (2) relatively large TDEE COV's exists in both groups, ranging from 36% to 47%; (3) very large COV's in PAEE occurs in both groups, being 95%-120% of the mean; and (4) the relatively narrow proportion of PAEE-to-TDEE in both groups: 9.5-14.1%. Both the TDEE and PAEE estimates are lower than many of the values contained in Table 3-1. Perhaps this is a reflection of when the study was done: in the late 1970's and early 1980's, before the rapid increase in body mass and BMI occurred in the U.S. population. It is unfortunate that the authors, Sunman et al. (1991), did not analyze their data longitudinally on a per-person basis.

TDEE decreases with age, as expected, since BMR (about 50-70% of TDEE in most adults) and PAEE both decrease with age (Roberts & Dallal, 2005). This trend holds for TDEE adjusted by BM or by LBM. Roberts & Dallal (2005) provide an extensive table of TDEE and PAI for the elderly by decades, which is included in Table 3-1. Their information comes from a National Academy of Sciences database of doubly labeled water studies, but it not otherwise identified. One important age-related phenomenon is that the elderly have greater fluctuations in total body and fat mass following under- and over-eating events relative to that of younger adults. This results in a greater imbalance between daily EI and EE due to reduced compensation from adaptive changes in energy expenditure (Roberts & Rosenberg, 2006). Older people also have a reduced ability to oxidize fat in meeting the fuel requirements of living, and thus have an increased potential to become overweight. However, there are contra-indicatory effects in post-prandial EE expenditure that minimize this problem in the elderly (Roberts & Rosenberg, 2006). The topic is complex and the data available on the subject are not definitive.

The distributional parameters of our model outputs should be evaluated to see whether or not the intra-individual variability in modeled TDEE approximates the values seen in the literature. Too narrow or overly wide modeled COV's would provide insight into the sampling procedures used in the exposure models. That has not been done to date in APEX or SHEDS modeling applications. We are not addressing full variability within and among individuals if the resultant TDEE COV's are too narrow.

3.B Activity-specific energy expenditure (EE_A) and oxygen consumption ($VO_{2.A}$)

As just mentioned, the APEX and SHEDS models use activity-specific estimates of energy expenditure (EE_A) to estimate intake dose rates via inhalation exposure. If METS-derived estimates of EE_A are simply random sampled from an approximate of METS, there is still a possibility that unrealistic estimates of activity-specific $VO_{2.A}$ and $V_{E.A}$ could result, since work cannot be maintained at a constant level for long periods of time. If work exceeds approximately 50% of VO_{2MAX}, the body uses anaerobic physiological processes to meet its energy demands. Doing so incurs an oxygen debt which ultimately reduces breathing efficiency, that is VO_2 and V_E are increased to do the same amount of work. This is known as the oxygen cost of breathing. During prolonged exercise, a person's VO_2 will approach $VO_{2.MAX}$, resulting in fatigue. Once prolonged exercise ceases, the accumulated oxygen debt has to be repaid. Therefore, both VO_2 and V_E will be higher after the work stops than the subsequent activity's nominal EE_A would dictate. This oxygen needed to repay the debt now is called "excess post-oxygen consumption (EPOC). See Hagberg et al. (1980a,b) for more information on both fatigue and EPOC.

NERL and its collaborators have developed a method to account for fatigue and EPOC in its exposure/intake dose models (Isaacs et al., 2008). Not much model adjustment is needed to address EPOC for most individuals, so the biggest impact on intake dose rate modeling is to account for fatigue by lowering both $VO_{2.A}$ and $V_{E.A}$ appropriately when sequential prolonged exercise occurs. It should be noted that EE_A—or its basis, the $METS_A$ value--is not directly adjusted; the effective change in EE_A is accounted for by an oxygen debt correction to oxygen consumption and breathing rate.

There are a number of articles presenting EE_A data for elderly cohorts, usually for walking (at different rates) and cycling. Sometimes other activities are measured, but they are quite limited in breadth. What data are available are shown in Table 3-2. When BMR and EE_A's are both supplied for an individual, METS estimates for specific activities can be calculated for them. This is how METS estimates themselves generally are calculated. However when group mean/standard deviation data are the only information presented, the subsequent METS estimates are biased and not very useful (Haveman-Nies et al., 1996).

One good example of elderly EE_A data (as VO_2) is Leaf & MacRae (1995). They tested 20 subjects (15 ♀ and 5 ♂) having a mean age of 71.2 ± 4.5 y (range: 65-81). While individual data are provided—quite rare actually—group mean data only are discussed here. The subjects walked on a treadmill at a rate of 2 ± 0.4 mi h^{-1}, where VO_2 was measured by indirect calorimetry (a face mask recording a number of respiratory parameters). Work undertaken on the treadmill was converted from ergs into EE using American College of Sports Medicine (ACSM) equations, and then into METS. The estimated group EE's worked out to be a METS of 3.4 ± 0.4 for a 2.0 ± 0.4 mph pace. They then allowed the subjects to walk outside at their own pace on a track, and the average measured speed for the group was 3.0 ± 0.4 mph, faster than the treadmill speed.

Calculated METS for this "self-selected, customary walking speed" (Leaf & MacRea, 1995; p. 101) is approximately 4.4 ± 0.5 METS. Both METS estimates are considered to be in the "moderate" exercise range of 3-6 METS for all but the very active (and younger) athletes; see Welk (2002). The METS "Compendium," states that walking at 3.0 mph on a firm, level surface expends 3.5 METS (Ainsworth et al., 1993), very close to the treadmill exercise estimate.

Malatesta et al. (2003) compared the energy cost of walking in 3 small mixed-gender samples (n=10 in each case), two of them elderly. The "G80" group was 81.6 ± 3.3 y old on average, and used 0.229 ± 0.030 mL O_2 kg^{-1} m^{-1} at their preferred walking speed of 1.14 m s^{-1} (about 1.6 mph). The "G65" group was 65.3 ± 2.5 y old on average, and used 0.205 ± 0.020 mL O_2 kg^{-1} m^{-1} of energy at their preferred speed of 1.35 ± 0.08 m s^{-1} (about 3 mph). Both groups were slower and burned more energy on average to accomplish the task - walking at their preferred speed - than the younger group (age = 24.6 ± 2.6 y; EE of 0.179 ± 0.020 mL kg^{-1} m^{-1}). Data were not presented to be able to calculate average METS for this activity, but the preferred speeds were similar to those seen in the Leaf & MacRea (1995) study.

There is one article that apportions energy expenditures of specific activities as a percentage of TDEE using the "factorial" method of estimating TDEE (Morio et al., 1997). Twelve "free-living" females and males aged 71.1 ± 2.7 y participated in a study that estimated TDEE 3 different ways: DLW, the factorial method, and a HR-to-EE relationship. The subjects were instructed to record their activities in a diary every 5 min.

The proportion of TDEE spent in the following activities was estimated for the study subjects from the factorial method are:

	Sleep	Rest	Sit	Stand	Walk	Recreation
♀	20%	3%	27%	32%	13%	5%
♂	20%	1%	28%	20%	13%	18%

The factorial method's estimates were not statistically different than the DLW estimates on average, but there was wide variability among the individual factorial/DLW comparisons (Morio et al., 1997).

3.C Activity-specific METS ($METS_A$)

There is little direct data on METS for the elderly. The METS Compendium and its update (Ainsworth et al., 1993, 2000) essentially *assume* that METS apply to both genders and all ages. The only supplied caveats to their use is (1) they represent *averages* of EE seen among individuals undertaking the same task (and do not, therefore, represent population variability inherent in undertaking the work), and (2) the estimates are "not intended to be used for adults with major neuromuscular handicaps or other conditions that would significantly alter their mechanical or metabolic efficiency" (Ainsworth et al., 1993; p. 73). The last caveat almost certainly applies to a significant portion of the elderly, although that group is not explicitly identified in the article. To accomplish a *fixed work load*, $METS_A$ should be adjusted *upward* for the elderly to indicate the increase in energy expenditure needed to accomplish that work load. In addition, $METS_{MAX}$ values are lower in the elderly. This is because the elderly have muscle atrophy, diminished balance, and less lean body mass, making them less efficient in accomplishing work than the younger people upon which most METS estimates are based. These factors increase EE_A and VO_{2A} for selected relatively-high $VO_{2.Max}$ activities for the elderly--or at least some individuals in it. Further, when considering the fact that the elderly have a relatively lower BMR, the $METS_A$ needed to accomplish the same amount of work as younger people has to higher in the elderly (or time needed to complete a fixed task has to increase). Data on the healthy elderly being able to accomplish a specific task at lower $METS_A$ than health-compromised elderly (post-myocardial infarction patients) indicates that the hypothesized needed adjustment to "standard" $METS_A$ estimates is logical for the elderly and subsets of them (Woolf-May & Ferrett, 2008).

Regardless of the precise applicability of $METS_A$ in the elderly, it has been found that elderly people who cannot exercise at a METS of 5 "generally indicates a higher mortality group" compared to those with an exercise capacity of ≥ 5 METS. (This essentially is a $METS_{Max}$ criterion.) Elders capable of exercise at METS ≥ 5 have an excellent long-term prognosis of survival, even in elderly people with coronary disease (Franklin, 2007; Franklin et al., 2003; Shaw & Mieres, 2008). Thus, $METS_A$ capability can be used as a marker of fitness in the elderly.

To better understand the topic of activity-specific elderly METS, we currently have a project with UNC's Exercise Physiology department to evaluate the appropriateness of the Compendium for use in the elderly. The reason for an increased $VO_{2.A}$ in the elderly for a particular work load seems to be that VO_2 kinetics are reduced because of slow adaptation of muscle blood flow and oxygen delivery (DeLorey & Babb, 1999; DeLorey et al., 2004, 2005, 2007).

Table 3-2. Estimates of activity-specific energy expenditure for the elderly.

Activity Descriptor	Mean Age	n	Gen	METS	Reference	Comment
Sitting	72.0 ± 4.0	28	♀	1.29 ± 0.09	Voorips et al. 1993	
Walking	72.0 ± 4.0	29	♀	4.74 ± 0.82	Voorips et al. 1993	

				Energy Expenditure (EE) Units		
Activity Descriptor	**Mean Age**	**n**	**Gen**	**EE** (kcal/min)	**Reference**	**Comment**
Lying	68 ± 5	6	♂	1.37 ± 0.15	Calloway & Zanni 1980	Healthy
Sitting	66 ± 3	13	♀	1.2 ± 0.2	Thompson et al. 1997	Overweight
Sitting	66 ± 3	14	♀	1.0 ± 0.1	Thompson et al. 1997	Overweight
Sitting	66 ± 3	13	♀	1.1 ± 0.1	Thompson et al. 1997	Overweight
Sitting	68 ± 5	6	♂	1.47 ± 0.21	Calloway & Zanni 1980	Healthy
Standing	66 ± 3	13	♀	1.3± 0.2	Thompson et al. 1997	Overweight
Standing	66 ± 3	14	♀	1.2 ± 0.2	Thompson et al. 1997	Overweight
Standing	66 ± 3	13	♀	1.2 ± 0.2	Thompson et al. 1997	Overweight
Walking @38 m/min	66 ± 3	13	♀	3.2 ± 0.8	Thompson et al. 1997	Overweight
Walking @38 m/min	66 ± 3	14	♀	2.9 ± 0.5	Thompson et al. 1997	Overweight
Walking @38 m/min	66 ± 3	13	♀	3.2 ± 0.6	Thompson et al. 1997	Overweight
Walking @64 m/min	66 ± 3	13	♀	4.3 ± 1.1	Thompson et al. 1997	Overweight
Walking @64 m/min	66 ± 3	14	♀	3.9 ± 0.5	Thompson et al. 1997	Overweight
Walking @64 m/min	66 ± 3	13	♀	4.1 ± 0.5	Thompson et al. 1997	Overweight
Walking @ 2.5 mph	68 ± 5	6	♂	4.51 ± 0.34	Calloway & Zanni 1980	Healthy

				Oxygen Consumption Units		
Activity Descriptor	**Mean Age**	**n**	**Gen**	**VO2/BM** (mL/Kg-Min)	**Reference**	**Comment**
Free level walking	60-80	21	♂	11.9 ± 1.9	Waters et al. 1983	
Free level walking	60-80	43	♀	11.8 ± 1.6	Waters et al. 1983	

				Oxygen Consumption Units		
Activity Descriptor	**Mean Age**	**n**	**Gen**	**VO2** (mL/Min)	**Reference**	**Comment**
Walking	72.0±4.0	29	♀	16	(Misplaced)	

3.D Physical Activity Index (PAI) or Level (PAL*)*

PAI in the "free-living" population (all ages) ranges from 1.2 - 2.2 (Black et al, 1996), but estimates over 2.5 are not uncommon in active people (Goldberg, 1997), including the elderly. A United Nations report recommends that the PAI for people >65 y should be at least 1.5 to "prevent accelerated changes in muscle and bone" (Dupont et al., 1996). Estimates of PAI found in the literature are summarized in Table 3-1. Most are >1.5 until the age of 80 years old, when there is a dramatic decline. A few of the group means for the younger elderly are close to being labeled "moderately active" (a PAI between 1.75-1.99) in our exposure modeling scheme (McCurdy, 2000). That also hold true for selected ethnic groups in the 70-79 y age range (Blanc et al., 2004).

Roberts et al., (1996) performed a meta-analysis of 574 DLW studies and provides the following summary data for PAI values in these elderly groups:

Females	65-74 y	1.62 ± 0.28
	75+	1.48 ± 0.23
Males	65-74 y	1.61 ± 0.28
	75+	1.54 ± 0.24

These estimates fall in the same range as those reported by Roberts & Dallal (2005) data in Table 3-1, but we note that the first author is the same for both studies.

4. Time Use & Human Activity

Abstract

Topic: This chapter discusses human activity patterns in the elderly.
Issue /Problem Statement: The pattern and distribution of time spent in different microenvironments and activities is markedly different in the elderly than in younger adults. In EPA's exposure models, microenvironment determines encountered concentration while activity determines ventilation (and possibly food intake). Thus, time use has a large impact on exposure estimates.
Data Available: There exists a data-rich literature on time-averaged location data in the elderly. There is also a moderate amount of cross-sectional event- or diary-based information available from a number of time-use databases. However, longitudinal time-use information is scant.
Research Needs: More data should be collected/identified for parameterizing EPA's longitudinal diary assembly algorithms specifically for older populations.

4.A Overview

The intent of this Section is to provide general information from the literature on time use by the elderly, their activities, and locations frequented. Specific information on these items used in our exposure models come from CHAD and other diary data. However, that information needs to be put into perspective in order to check model performance and the diaries used to estimate exposure. We attempt to do that here. Most of the available elderly time use data in the general literature are not sequentially event-based. The data are generally *time-averaged,* indicating the number of minutes, or the proportion of time, spent / day in selected activities. There is very scanty location information provided for the elderly.

EPA uses time use data in its event-based (sequential) exposure models even though it generally calls it human activity or activity-pattern data.[10] Time use data has been collected and used by many disciplines, including sociology, economics, urban and transportation planning, epidemiology, women's studies, psychology, sleep clinics, physiologists, and exposure modelers (Committee on National Statistics, 2000). There are two basic approaches to gathering *sequential* time use data: (1) the *ex post* recall interview survey ("What did you do yesterday?")[11] and (2) the contemporaneous time budget diary approach where the subject records activities as they undertake them (Åś, 1978; Gershuny & Sullivan, 1998; Niemi, 1993; Stafford, 2009). There are advantages

[10] Remember from Section 1 that an event occurs in a single location (μE), constitutes a single activity, and a single EE. If any of these factors change, then a new event occurs.
[11] Also known as the "day reconstruction method" (Kahneman et al., 2004). This method has been used to obtain time use data in 40 community-based elders with neurodegenerative disease, including Parkinson's, dementia, and Alzheimer's (and other less common mental problems). Restricted time use patterns were found for both discretionary and obligatory activities, as expected (Lomax et al., 2004). These elders, who were English, undertook mostly passive activities, such as day-time sleeping and watching TV. They rarely left their house. The same findings have been obtained for elderly stroke victims in Australia (McKenna et al., 2008). We could not find a similar US study, but the observations probably apply in this country also.

and shortcomings associated with either approach, but the diary approach usually provides more information on more events than the recall approach (McCurdy & Graham, 2003, Robinson, 1988, 1989; Robinson and Silvers, 2000). CHAD contains time use information from both types of studies.

Selected aspects of time use by the elderly has been extensively studied by sociologists, economists, and epidemiologists since the use of time reflects—among other things—functional (including working potential, interactions with others, and health impacts) capabilities of that subpopulation (Lawton, 1999; Singleton, 1999). In fact, the congruence between actual and desired time use is an important concept in elderly psychology (Calderon, 2001; Seleen, 1982). Life satisfaction is increased when the elderly can do what they want to do, without restriction or compromise. Probably that is true of everyone, but may be more important—and is more studied—in the elderly. It is called the congruence theory of life satisfaction (Seleen, 1982). Part of the congruence theory is "transport mobility" by the elderly, shown to be closely linked to independence, well-being, and quality of life (Spinney et al., 2009).

On the other hand, it often is difficult to use sociologically-oriented elderly time use data because of its emphasis on the social **context** of activities, in the first instance, and its dichotomization of most major activities into work and non-work categories, in the second. Both sociology and economics usually disaggregate time use into obligatory and discretionary activities without regard to locations (Gauthier & Smeeding, 2001; Lawton et al., 1986). Obligatory actions are paid work, eating, shopping, housework, cooking, sleeping, etc. Discretionary actions are socializing, leisure pursuits, rest and relaxation, and passive or active recreation. Travel often is assigned to one of these two general actions based on its purpose: not where it occurs. These data have limited usefulness for exposure modeling purposes.

One of the most prolific time use researchers is sociologist Dr. John Robinson now of the University of Maryland. He has worked with both EPA and California's Air Resources Board (CARB) to obtain exposure-relevant time use data, including the National Human Activity Pattern Study (Klepeis et al., 1996, 2001; Robinson, 1989; Robinson & Blair, 1995; Robinson & Silvers, 2000; Robinson et al., 1996; Robinson & Thomas, 1991; and Robinson et al., 1989). The NHAPS and California time use studies are in CHAD, and selected daily aggregated data from both are discussed below.

It should be noted that obtaining time use information is sometimes difficult for selected older people due to physical and/or cognitive difficulties, although many researchers feel that it is no more difficult to obtain reliable and valid activity data from elders than for other population subgroups (Lawton, 1999). More importantly, it is the educational and reading ability of subjects, along with health status, that gives rise to response inconsistencies. When cognitive problems arise with a particular older person, a proxy time budget is frequently obtained (Lawton, 1999). A sequential structured interview of "yesterday's events" seems to be the preferred method used to obtain activity data from the elderly (Klumb & Maier, 2007; Lomax et al., 2004). There is an "age effect" in

obtaining convergent and reliable time use information that has to be addressed when obtaining data from the very old (Klumb & Baltes, 1999).

There are many dimensions of the use of time by people that are important for exposure modeling. They are outlined below in Table 4-1. As mentioned earlier, the "event" (E) is the basis for locating a simulated person in time and space. Other important dimensions for exposure modeling are: frequency (F), duration (D), and pattern (P). Many of the other dimensions follow from the usual weekday/weekend (or workday/non-workday) arrangement of life, captured by the sequence (S) and cycle (C) dimensions. To date, except for providing seasonal or yearly estimates of exposure (related to the T and T_{TOT} metrics), EMRB has not used the other dimensions to frame output estimates from our models, but we could easily do so. OAQPS has done so in a number of past NAAQS reviews.

4.B Factors affecting time use in the elderly

Despite many cultural differences among countries, in general time use by the elderly is similar across developed countries, especially for "non-discretionary activities," such as work, sleeping, and eating (McGrath & Tschan, 2004). Time spent in these activities by the elderly has not changed much over the years (Bittman & Goodin, 2000; Gauthier & Smeeding, 2001). However, time use has changed for discretionary activities that are important in how the elderly view themselves and relate to society (Altergott, 1988).

Table 4-1. Definitions of time use metrics useful for exposure modeling.

After: J.E. McGrath and F. Tschan (2004) Temporal Matters. Washington DC: American Psychological Association.

Event (e)	An observed state/activity with a homogeneous "value" related to the subject matter; e's are numbered sequentially with a subscript (i) for each T period (e.g., e1 , e2 , …en). The class of events having a defined commonality with one or more ex's regardless of temporal sequence is designated as Ex
t	A minimum unit of time; in exposure modeling it is 1→60 minutes
e_t	Duration of an event (in minutes); in exposure modeling, **e_t** never crosses a clock hour; longer events are subdivided into two or more clock hours
T	A longer period time that is the summation of all applicable **t**'s of interest; in exposure modeling, T generally is a day. Longer time periods are also of interest designated **T_{TOT},** which is the sum of all **T's** of interest
Coupled events	A series of events that occur sequentially in a causal manner (i.e., **$e_{x=1}$** always proceeds **$e_{x=2}$**). The coupled events may consist of a sequence of events that are always temporally related to each other.
Cycle	A systematic temporal pattern showing a rise and fall in some property of an event et such that it returns to its original value recurrently. Each cycle has phase and magnitude properties. A cycle is a "rhythm" with approximately equal subject-specific values of magnitudes.
Frequency (F)	Frequency of a class of events (**E**) = number of **e_x**'s per **T**
Duration (D_x)	Total duration of **e_x**'s occurring within **T**
Location (L_t)	The location where an event occurs; the same event may occur in more than one location. Thus, there are parallel metrics for location as for events: frequency, duration, proportional duration, and sequence.
Pattern (P_x)	The temporal pattern of a series of events of the same class { **$e_{x=1/i}$, $e_{x=1/i+1}$ . . $e_{x=1/n}$** }
Proportional Duration (%D_x)	**D_x / T * 100**
Rhythm (R.e_x)	A regular pattern of **$e_{x=i}$** over time period **T**. It can be defined in terms of periodicity (sequence), frequency, or rate. It generally refers to the pattern of evenly spaced occurrence of **$e_{x=i}$**'s that are approximately equal in duration.
Sequence (S)	The order of events in a class (**$e_{x=1/1}$, $e_{x=1/2}$, … $e_{x=1/n}$**) or for all events (**e_1, e_2, …e_n**)
Trend	A temporal pattern of events of a given class **$e_{x=i}$** that shows a systematic directionality over time

Time use changes over the **life cycle** (biological lifestage) because of age (per se), disability, and health status. But it also changes due to "social" (family role) **lifestage** factors (Vadarevu & Stopher, 1996). The latter include marriage, parenthood, employment/retirement status, household income, children living nearby, and other

considerations (e.g., the "empty nest" syndrome) (McGrath & Tschan, 2004). The largest impact on time use by the elderly is caused by decreased mobility, especially in those of very advanced age (referred to commonly as the "old old"). When seniors become dependent on others for transportation and personal care, they *start* spending a large proportion of time in passive activities (Lawton, 1991).

Most elderly single-person households consist of a female living alone. Females 65+ are 4 times more likely to be widowed than males of the same age. They also are 20% more likely to be divorced. This disparity in household structure increases with age (Rosenbloom, 2004b). By 75 y, 50% of females live alone versus 23% for males. By 85 y, the proportion is 86% for females and 41% for males (2004b). These factors certainly affect time use by the elderly.

Retirement obviously affects elder's time use (Kim & Hong, 1998; Mancini & Orthner, 1982); Piekkola & Leijola, 2004; Rosenkoetter et al., 2001). They have more "leisure," among other things. This does not mean that they stay home and do nothing. Partly, this is a definition problem, in that the word leisure has many meanings that vary by age and gender (Lawton, 1999; Little, 1984). For the elderly, leisure usually means discretionary or non-obligatory activities (Lawton, 1999). One type of leisure is voluntary work. In recent years, "unpaid productive activities" (voluntary work) has increased greatly,[12] which results in the elderly being "socially productive" for years beyond their (paid/housework) working life (Altergott & McCreedy, 1993). In general, retired males spend more time in active leisure—and traveling associated with it—than females of the same age. The same is true for passive leisure. The only leisure activity that older females devote more time to than older males is "creative leisure," such as knitting, making things, and art-making (Altergott, 1988). These are statistically-significant differences.

The total amount of leisure (both active and passive) peaks at about 8 h d^{-1} for individuals in the 65-74 age range (Altergott, 1988). After that age range, active leisure decreases greatly for males, but not females. Travel for leisure does not change much with increasing age, however. Older females spend significantly more time than males of the same age in "obligatory" activities, especially housework (Altergott, 1988; Bryson, 2008; Henderson et al., 1996). These gender differences could have exposure impacts due to differences in time spent outdoors, in motor vehicles, or indoors if pollutant sources are present.

Hospitalization obviously affects locational aspects of daily living for the elderly (Boyd, 2005). Since EPA does not estimate exposures to environmental contaminants *inside* of a hospital or other health-related institutions, we ignore those locations in our analyses and do not provide any data for time use or "participation rates" for them. (They are not ignored for "free-living" individuals visiting one of these facilities, however.) It should be noted that hospitalization can affect 30% of more of elderly females (>65 y) in a given

[12] National statistics from 1993 indicated that 43% of people aged 65-74 y participate in volunteer work, while 36% of those 75+ do so (Kim & Hong, 1998).

18 month period, so the potential subpopulation size for institutionalized people is large. Hospitalization also is an independent predictor of a decline in activities of daily living (ADLs), which greatly affects an older person's ability to live alone, with numerous psychological and locational dimensions (Boyd, 2005).

Data are available from Europe and Canada to put the US time use information into perspective; see European Commission (2003); Horgas et al. (1998); the series of articles by Leech et al. (1996-2006); and the work by Zuzanek and colleagues (1988-1999). Articles can be found for other countries also (e.g., Japan; see Ujimoto, 1988-1993).

Literature on the elderly, especially when focused on people having functional limitations and the frail, distinguishes between basic activities that are needed to survive at a minimal level of independence and those that are more engaged socially. There are locational aspects of both types of activities. The more basic activities are discussed in Section 6.

4.C Time use databases

We review here some of the time use information sources that may be used to model exposures in the elderly or serve as a check on model performance regarding time use by that group. The broader time use (activity) literature in general does not provide information on where activities occur: i.e., their location, and when it does, it is not presented in a way that we can use for exposure modeling purposes (Robinson, 1977; Robinson & Godbey, 1999). In other words, it is difficult to identify habitués—people who actually inhabit a specified location of interest in most time use databases. To emphasize this point, Robinson & Thomas (1991) directly state that most activity information cannot be used to estimate where people spend time.[13] Some locational data on where the elderly spend time are contained in EPA's *Exposure Factor's Handbook*

[13] An extended quote from Robinson & Thomas (1991) succinctly highlights this issue from just one locational perspective: time spent outdoors.

> [There is an] unexpectedly wide range of activities that are performed in outdoor locations near the home. It brings home the difficultly that analysts fare in predicting locations from activities. This cross-tabulation of activities by location does show that most of the types of activities that one expects to be outdoor activities by location are, in fact, the ones most likely to be performed outdoors. Thus, among household activities (which take up more than half the time spent outdoors near the home), yard work (15%) and plant / pet care (16%) are the activities that fall mainly into the outdoor category. However, almost as much 'indoor-type' as outdoor-type housework activity is done outdoors—such as cooking outside (1%), cleaning carpets and other household objects outside (5%), putting laundry out to dry or other clothes care (2%), repairing appliances/other household objects outside (11%), and performing household management tasks outside (6%).
>
> As expected, one also finds a fair amount of outdoor time near the home …spent on sports activities (3%), on play activities with children (2%), on meals (2%), and on relaxing (3%). But more outdoor time is on hobby activities (5%), and watching TV (6%) than on any of the 'usual' outdoor activities. Six percent of home outdoor/yard time is even spent sleeping and 7% doing paid work, which further illustrates how little these 'usual outdoor' activities take up the time that people spend outdoors near the home (p. 36).

(NCEA, 1997) and are reproduced here as Table 4-2. Gender-specific data are not available.

Aggregate data on time use distributions by the elderly abstracted from various tables in the *Exposure Factor's Handbook* are provided in Table 4-3. The data are from EPA's NHAPS surveys (see Table 1-1) and are not gender-specific. Much of this information also appears in Tsang & Klepeis (1996, 1997). The information is arranged under four main categories: bathing/showering, useful for estimating dermal and inhalation to water contaminants; motor-vehicle oriented locations, useful for estimating inhalation exposures to air toxics and other gaseous pollutants; outdoors, for estimating exposures to any ambient pollutant; and potential high-exposure-generating activities.

It should be noted that the *Exposure Factors Handbook* provides time use data other than that reproduced here. The time units for those data are in hours/week, hours/month, and minutes/month and do not fit easily into the min/d units used in Table 4-3 without making the assumption that daily time is simply the monthly value divided by 29-31 days/month. As already noted, there is a wide variety of time use by the elderly on a daily basis, and assuming equal daily usage is not consistent with the longitudinal data that are available (see Section 4.E). Another caveat associated with Table 4-3 is that Tsang & Klepeis (1996) used a number of recodes for both locations (called NEWLOC) and activities (NEWACT). It is not clear from either Tsang & Klepeis (1986) or the *Exposure Factors Handbook* precisely what recodes were used to develop the activity/locations used for the distributions noted in our Table 4-3, so there is unresolved uncertainty then, regarding the breakdowns in that Table. (For more detail on the activities/locations mentioned, see Tables 27 and 28 in Tsang & Klepeis, 1996).

Regardless of the precise distributional cutpoints depicted in Table 4-3, most of the distributions are very "heavy tailed" (skewed to the right). Normally a log-normal distribution approximates that type of data, with most doers or habitués spending a little time doing the activity and a few doing it a lot. Combined with the generally low participation rates in many of the activities, only a minority of the elderly will experience exposures "at the high-end tail of the distribution." However, these are the very same people that our environmental standards are supposed to protect (Jordan et al., 1983).

We attempted to provide the same type of data seen in Table 4-3 for the California adult study (Wiley et al., 1991b), but were unable to determine the proportion of elderly "doers" or habitués from data shown in that report. Without that, a participation rate could not be determined, nor could the mean doer/habitué time be calculated. The reader is referred to Table 3.3 in Wiley et al. (1991b) for additional information on time use by persons 65+ in California, but for our purposes the data are insufficient for checking on outputs from the APEX/SHEDS exposure models.

Table 4-2. Selected activity-location data for the elderly in EPA'S *Exposure Factors Handbook*

	Mean "Doer" time for people aged 65+ (rounded)*			
	CARB Data		NHAPS Data	
Location/Activity Combination**	% Doers	(min/d)	% Doers	(min/d)
"Autoplaces" (locations containing motor vehicles)	17	53	7	57
In an internal combustion vehicle	71	89	78	80
In another type of vehicle	3	53	<0.5	277
Outdoors-physical activity	15	104	19	81
Outdoors-other	55	101	58	140
Non-residential Indoor Locations				
Restaurants/bars	26	99	28	74
Shopping & undertaking errands	46	76	50	69
Working	9	336	10	341
Residential Locations				
Working	3	195	2	297
Cooking	59	69	77	65
Other activities, including kitchen	82	119	91	119
Not defined as being in a specific location				
Physical activity	7	48	13	51
Social & cultural activities	43	114	70	122
Eating & leisure activities	98	394	97	312
Sleeping	100	502	100	509

Notes:

*Related data also appear in Robinson & Thomas (1991), which is the source of the EFH data.

**These are selected combined location and activity pairs that are called microenvironments in both papers, but this is an inaccurate use of that term as used by exposure modelers. A microenvironment is a location having a constant concentration for the period of time inhabited by a person of interest (a habitué). A doer is a person who undertakes an activity.

Table 4-3. Selected time-use data for people 65+ from EPA's *Exposure Factors Handbook*

Activity on the diary day	Doer Sample Size (n)	Percent Doers (Calc.)*	Distribution of time by selected percentiles (rounded) spent in the activity (min/day) 5 %	25 %	50 %	75 %	90 %	95 %	99%	Source *
Bathing/showering										
Taking a shower	408	30.2	5	10	10	20	30	60	60	15-21
Time spent in bathroom **after** a shower	409	30.3	0	4	5	10	20	30	45	15-23
Taking/giving a bath	139	10.3	5	10	15	20	40	60	61	15-26
Time spent in bathroom **after** a bath	133	9.9	0	5	10	15	35	35	60	15-28
Total time spent in the shower or bath	567	42.0	5	10	15	20	30	30	60	15-30
Total time in bathroom after either/both	548	40.6	0	4	10	15	20	30	60	15-32
Motor-vehicle oriented locations										
Gas/service station (cumulative)	16	1.2	5	10	18	55	180	240	240	15-106
Ditto, per visit	67	5.0	3	5	10	15	15	40	120	15-39
Outdoors at a gas/service station	16	1.2	5	10	18	55	180	240	240	15-106
Alongside of a road with heavy traffic	31	2.3	2	4	20	45	60	121	121	15-43
Outdoors: near street/neighborhood	122	9.0	2	20	40	75	120	190	270	15-104
Outdoor in a parking lot	13	1.0	1	10	25	60	180	465	465	15-105
Waiting at a bus/train stop	11	0.8	5	20	30	40	45	45	45	15-128
Inside a vehicle in heavy traffic	139	10.3	5	15	30	60	121	121	121	15-44
Traveling in a car	812	60.2	10	30	60	110	165	225	405	15-121
Traveling in a truck/pickup	90	6.7	12	30	49	105	185	265	453	15-122
Traveling in other trucks	9	0.7	18	25	60	99	186	186	186	15-124
Traveling in a bus	27	2.0	20	45	73	130	435	460	570	15-125
Traveling on a train/subway/rapid transit	9	0.7	10	10	24	120	690	690	690	15-129
Inside a vehicle (cumulative)	907	67.2	10	35	60	120	190	258	460	15-133
In a parking garage/indoor lot	18	1.3	0	3	5	15	45	90	90	15-45
Traveling: bike, skateboard, roller skates	7	0.5	23	25	35	110	205	205	205	15-127
Outdoors										
Walking to car: driveway/parking lot	373	27.7	0	2	5	10	15	30	88	15-46
Other outdoor time (walk or run)	143	10.6	2	15	30	60	121	121	121	15-47
Other outdoors	128	9.5	12	45	95	203	420	510	610	15-140
Outdoor cleaning	164	12.2	30	60	120	173	300	350	510	15-72
Construction site	6	0.4	60	300	460	540	560	560	560	15-107
Outdoor playing (cumulative)	4	0.3	30	45	60	60	60	60	60	15-80

	Doer Sample	Percent Doers	Distribution of time by selected percentiles (rounded) spent in the activity (min/day)							
Playing on grass	3	0.2	30	30	121	121	121	121	123 1	15-64
School or playground	7	0.5	5	30	60	95	150	150	150	15-108
Park or golf course	55	4.1	20	30	120	300	510	570	735	15-109
Pool, lake, or river	25	1.9	30	60	115	277	480	510	525	15-110
Farm	17	1.3	5	50	85	160	360	495	495	15-112
Outdoor recreation (cumulative)	32	2.4	5	30	171	375	495	600	735	15-86
Outdoors at home or in yard	401	29.7	10	45	90	180	302	465	660	15-120
Outdoors-at-home (cumulative)	502	37.2	5	36	110	210	375	485	735	15-132
Outdoors near-a-vehicle	342	25.4	4	10	30	60	120	205	510	15-134
Potential high-exposure activities/locations										
Near frying, grilling, or "bar-b-queing"	96	7.1	3	5	10	20	30	120	121	15-34
In a bar/nightclub, restaurant	270	20.0	20	45	63	100	178	255	520	15-139
Smokers are present	340	25.2	30	100	240	540	798	880	120 5	15-141

Notes:

* The Table number in the EHF containing the data from the NHAPS survey. Data from other sources are included in the Handbook, but are not reproduced here.

**Calculated (calc.) using a total number of elderly 65+ (1,349) given in Tsang & Klepeis, 1996.

4.C.1 The CHAD database

CHAD has been introduced in Section 1. A lot of the early material in CHAD is associated with Dr. John Robinson, since he was funded by EPA to investigate the relationships between time use and potential exposures to smoking and environmental contaminants (Robinson, 1988; Robinson & Thomas, 1991; Thomas & Behar, 1989). This published work, however, is very general with respect to the elderly, who rarely are discussed as a separate sub-group. This is also true of Robinson (1977) and Robinson & Godbey (1999). The actual diaries that come from the EPA-funded study, called NHAPS, are part of CHAD (see Table 1-1), as is his California (CARB) data (Robinson et al., 1989; Wiley et al., 1991a, b). Therefore, individual diary data from these studies can be part of our current modeling work, if desired. Aggregate data from NHAPS have been extensively discussed by others (Kleipis et al., 1996, 2001; Shadwick et al., 1999; Tsang & Kleipis, 1996, 1997)

The CHAD database includes 5,742 person-days of diary data for people aged 60 or older, 38% of it being a single-day per individual. See Table 4-4. This is not a large data set to represent the wide range of activities in the elderly. Approximately 3,400 of those

days were added as part the Aging Initiative program, a tangible result of NERL's Aging Initiative work. Additional diary days of data are being pursued.

Table 4-4. Activity diaries in CHAD for the elderly.

Age range	Total# ofdiary days	Number of diary-days (DD) available per individual: One	Two	3 or 4	5 to 9	10+	Percent With only 1 day
Females							
60-64	647	372	18	18	1	7	57.5
65-69	589	331	12	9	2	14	56.2
70-74	681	296	2	9	2	25	43.5
75-79	592	186	0	4	3	25	31.4
80-84	345	129	0	4	3	13	37.5
85-89	201	38	0	5	2	11	18.9
≥ 90	19	13	0	0	0	1	68.4
Total	3074	1365	32	49	13	96	44.4
Males							
60-64	342	266	6	16	0	1	77.8
65-69	1083	218	6	10	1	6	20.1
70-74	362	156	1	7	1	12	43.1
75-79	384	107	0	3	7	18	27.9
80-84	260	53	0	3	3	18	20.4
85-89	193	20	0	1	3	11	10.4
≥ 90	44	12	0	0	0	2	27.3
Total	2668	832	13	40	15	68	31.2
Grand Total	5742	2197	45	89	28	164	38.3
Unknown Gender							
≥ 90	1	1					

As NERL staff has analytically shown, there are contextual factors that affect time use by the elderly and others, such as day of the week, seasons of the year, special times of the year, social class, educational levels, etc. (Graham & McCurdy, 2004; McCurdy & Graham, 2003). Overall in the CHAD database, people >64 y old spend about 65 min/d outdoors, but variability in this population group is large: the coefficient of variation (COV) is 120% for "habitués": those people who actually go outdoors. Only 57% of the elderly went outside on the day(s) they were surveyed. Both the time spent outdoors and the "participation rate" by the elderly are lower than that for adults and children, on average, but the differences aren't large even though they are statistically significant at $p=0.05$. When gender differences in the time spent outdoors are investigated, elderly females are outside less than males (60 v. 118 min/d on average) and this difference is significant ($p<0.001$) (Graham & McCurdy, 2004). The elderly spend less time in motor vehicles (86 min/d on average) than other adults--about 105 min/d--and also have a lower participation rate for that location (Graham & McCurdy, 2004).

4.C.2 The American Time Use Survey (ATUS)

A potentially good source of elderly diary data is the Bureau of Labor Statistics' (BLS) American Time Use Survey (ATUS). There is one day of data per person in the Survey. See Abraham et al. (2006), Hamermesh, et al. (2005); Herz & Devens (2001), Krantz-Kent & Stewart (2007), Russell et al. (2007), and Schwartz (2002) for information on this database. This survey is large and on-going, with between 12, 250 and 14,000 person-days of information being obtained each year since 2004[14]. Approximately 17% of the diary-days in ATUS are for people aged 65+. There are some structural problems with the ATUS data from an exposure modeling perspective, but NERL has conditional plans to address them and attempt to use the database for our work (George & McCurdy, 2010). Until that effort is undertaken, we cannot utilize the ATUS data in our models. Some papers that have been published using the ATUS data are discussed below under "Specific Examples" (Section 4.D).

4.C.3 Other databases

Another large activity pattern study is the Multinational Time Use Study (MTUS). There are many articles and books describing this Study (Gershuny, 2000, 2004, 2005, 2009), and its "raw" data are available on the web to registered users. While the U.S. is included in this essentially historic time use database, the published papers describing it do not focus on the elderly or even provide descriptive information on time use patterns for them. The same comment applies to the American Heritage Time Use Study (Allard, et al., 2007; Merz & Stolze, 2008; Tudor-Locke, et al., 2007), which contains data only on time use patterns of US citizens.

4.C.4 On vacations and out-of-region time

There is no exposure model that correctly handles time spent by a modeled population outside of their region, either on vacation (short-term or long) or during work or leisure travel by the modeled subjects. Modeled subjects never leave the analyzed region, in other words. The main reason for this is a lack of time use data for vacations and for multi-day travel, mostly because the *ex post* survey is done at the home location. If no one is there, they cannot be surveyed. If a diary is used to obtain sequential time use data, many subjects object to using it on vacation and become non-compliant (even in our EPA-sponsored studies!). Even if vacation time use data are collected, there usually is not any way to determine if a person is away from home in the CHAD or other databases except by deduction: if a person sleeps in a hotel or motel, then he or she probably is outside of the "home" region. Even that may not hold for all circumstances, and sleeping

[14] ATUS began in 2003 with 20,720 *ex post* diaries, but the number per year fell after that. The number of diaries per year are: 2004: 13,973; 2005: 13,038; 2006: 12,943; 2007: 12,248; and 2008: 12,723. Thus, there are 85,645 days of diary days available for the 2003-2008 time period: the largest and most recent source of U.S. time use data available for analysis from any source.

in “another’s home” (a code used in many studies, but not in ATUS) could occur anywhere.

Assuming a person is in their own region all the time will over-estimate exposures to pollutants particular to that region, of course. (And exposures experienced in another region are completely ignored.) While this is a problem with all exposure modeling efforts, it may be a particularly important one for the retired elderly since many of them spend significant time away from their primary residence (Stalvey et al., 1999). They visit children (locally or in another region), “temporarily migrate” to another area, or just “travel around.” See Section 4.D.2 for instance.

It is difficult to both model vacation/out-of-region behavior and obtain data to go about doing so. One interesting article that quantifies the size of temporary migration is Smith & House (2006). Their focus is on the elderly in Florida. From a random-probability telephone survey of elderly persons (55+ y old) people in Florida over a 3 year period, they identified people who spent one month or more / year from out-of-state. They were called “temporary residents” if they were non-permanent Florida residents. Non-residents who spent <1 month in Florida were excluded. They classified the residents as “stayers” if they spent <1 month out-of-state or “sunbirds” if they left during the hot months (or any other time of the year). Snowbirds were those temporary residents who came into the state during the winter months. The number of temporary residents in Florida was very large and seasonal, as expected, and most were elderly (Smith & House, 2006).

How should exposure modelers capture this time use phenomenon? How can a risk assessment account for doses received or not received outside of the modeling area-of-interest? These questions are not addressed in any published environmental exposure/dose/risk assessment report. These questions are something to be aware of, and all health risk assessments should contain caveats regarding these essentially time use issues.

4.D Examples of 24-h time use data

Time use data for the elderly include different emphases, age/gender combinations, and formats. Therefore, it is difficult to summarize the information succinctly. Selected data from US studies with *multiple* categories of time use are summarized here. Articles that present useful data for only one activity-type of importance to exposure modeling are reviewed under the specific categories that follow. Locational information for multiple- or single-categories of time use is only occasionally provided, however. **Participation rate** is the percent of the sample actually undertaking a specific activity on the sampled day, and these people are called a *habitué* when location considerations are being discussed and a *doer* when a specific activity is undertaken.

Czaja (1990) provides mean estimates of the time spent in various activities in a 24-h day, which are reprinted here as Table 4-5. The Czaja (1990) data are reproduced (in more readable form) from Moss & Lawton (1982), so the data are not very current. The estimates probably are similar to those cited below under Lawton et al. (1986) since the mean age of the sample is the same (76.2 y). The time use data are from 426 people living independently and from 164 people living with others or in a facility. Czaja (1990) provides the location ("environmental context") for waking hours only, and 82% of all waking-time activities occur in the home or yard.

Gørtz (2006) provides data on US elderly time use, but combines 31 activity types into 6 major categories, none of which are particularly useful from an exposure modeling perspective. Therefore, no information is abstracted from this study.

Kelly et al. (1986) provide graphical—and at a small scale, at that—data on the percentage of elders aged 65-74 and 75+ that participate in various activities that are of interest to us: overall activity level, travel, exercise and sport, and outdoor recreation. Due to its format, specific statistics from this paper are not abstracted here. As expected, participation in all of these items decreases with age for both genders. Females participate less than males, except for "overall activity level" and "travel," where 75+ females participate more frequently than 75+ males.

Knipscheer et al. (1988) provide information on time use (h/d) in the elderly, disaggregated into two age groups of interest to us: 65-74 y and 75+ y. Their data, however, are not very useful; for one thing there is no locational information, and the activities are grouped into "productive" and "nonproductive" categories. Productive activities include house work, helping others, volunteering, and "going out." Nonproductive activities are leisure, mass media, TV news watching, and newspaper reading (Knipscheer et al., 1988).

The most promising-sounding article on elderly time use is entitled "How do older Americans spend their time?" (Krantz-Kent & Stewart, 2007). It is based on data from the 2003 and 2004 ATUS surveys. It provides complete daily data for a number of activities and work status—but none on locations—by gender for two age categories that we are interested in: 65-69 and 70+ (other age groupings are included also). We cannot get very much useful exposure information from the article, however, since travel is assigned to its purpose: travel for a large number of household-related purposes is assigned to "household work" and travel for (paid) work is assigned to working. The household travel category is particularly troublesome, since it includes travel for obtaining governmental and civic services, consumer purchases, obtaining professional and personal care, and a number of other purposes (including "not elsewhere classified"). Participation rate data to determine "doer" time also are not provided. Probably the most useful information contained in the article is the differences in time use spent in selected activities by employment status: employed full time, employed part time, and not employed.

Table 4-5. Time spent per day in selected activities (from Czaja et al. 1990).

Activity	Time Spent in the Listed Activity (minutes per 24 h day) Independent. Subjects	Impaired Subjects
1. Obligatory activities		
Personal & health care	53	71
Eating	77	77
Cooking	69	45
Helping others	10	7
Housework	68	38
Shopping	22	13
2. Discretionary activities		
Social interaction	112	110
Religious activities (non-service)	10	7
Reading	59	52
Watch TV	205	210
Listen to radio	28	33
Recreation & hobbies	44	32
Rest & relaxation	128	200
Sleep	456	452
3. "Gap" & minor	26	40
Summation	1367	1387
Unknown mean time	73	53

Notes:

"Impaired subjects" are recipients of in-home services (n=91) or are people awaiting entry to a long-term care facility. Impaired subjects is the heading used in Czaja (1990), but not in the source article: Moss & Lawton (1982).

The means are "statistically adjusted" to account for age, gender, education, ethnicity, income, and household consumption (Moss & Lawton, 1982).

For the “leisure and sports” category, the following mean hours/”average” day information is provided for elderly females and males (Krantz-Kent & Stewart , 2007). The category is broad, including socializing, communicating, watching TV, sports, exercise, recreation, relaxing and thinking, and reading. Most of these activities are quite passive, and have low energy expenditures—usually resulting in a low dose rate even if an exposure occurs.

	Females (h/d)			Males (h/d)		
	60-64	65-69	70+	60-64	65-69	70+
Employed full-time	3.8	4.0	3.6	4.1	5.7	7.6
Employed part-time	4.4	4.9	6.1	3.9	6.0	8.1
Not employed	6.1	6.5	7.2	4.1	5.9	8.1

Another ATUS-based paper is by Waidmann et al. (2006). It provides information from 2003-2005 "waves" of the survey. They aggregated data for everyone 65 and over, with a sample size of 7,932 for the 3 years. The participation rate and doer time from their study follows (from their Tables 4 & 5). The travel time estimates are lower than those provided by Gossen & Purvis (2006); see the "Travel Section" (4.D.1) for more information on that activity.

Activity	Participation Rate (%)	Time Spent (min/d)
Travel	72.4	77
Cleaning	33.2	84
Work/volunteering	18.3	282
Physical recreation	17.9	76

Lawton et al. (1986) provide participation rate and time "allocations" for selected activities and a few general locations. The sampled mean age was 76.2 y; the standard deviation (SD) was not provided. "Recreation" is one of the discretionary activities depicted, and 35% of the 535 people sampled from a wide variety of housing types participated in it. "Doer" time was 118.2 min/d. The category is not well-defined, and probably includes both active and passive leisure. (If it were entirely active, it would have been reviewed below in "physical activity.") They also report travel as an activity, and 50% of the people participated for a doer time of 67.8 min/d. These values both are reasonably consistent with those shown in Table 4-3 ("inside a vehicle, cumulative").

With respect to locations—called "environmental contexts" by Lawton et al. (1986)—the choices were: "at home," "in yard," and "away from home." Travel locations probably were included in that last category. The most useful coded location from an exposure modeling perspective is time spent in the yard: 41% of the elders expended 148.1 min/d on average in that location (Lawton et al., 1986). These are quite high numbers and could lead to high exposures to ambient pollutants. Lawton's estimates are quite close to "cumulative outdoor-at home" time shown in Table 4-3, where 37.2% of the elderly do so on any one day for a median of 110 min/d.

Linn et al. (1999) provide time use data on 30 COPD subjects aged 56-83 y old enrolled in a study of heath effects associated with living in a city with high particulate

concentrations. The subjects maintained a paper diary for 4 consecutive days on two occasions; the minimum time block used in the paper diary was 20 minutes. Most of the subjects spent the majority of time indoors and were sedentary. "Physical activity time was appreciable, but was of low intensity, as judged either from diary reports or from recorded heart rates" (Linn et al., 1999; p. PM-113). Selected data from their paper follows (their Tables 4 & 5).

	Group mean time spent in the categories shown			
	Midnight - 6 am	6 am - Noon	Noon - 6 pm	6 pm- Midnight
% clock h away from home	0.5	7.5	23.5	7.0
Min/time period outdoors	0.4	19	45	10
Min/time period in vehicles	0.2	10	27	8
Min/time period active	4.8	72	95	24

Note: "Active" time use was based on a self-described qualitative term that used a 0-100 visual analog scale developed by Linn et al. (1999). The subjects looked at the scale and "coded" each activity according to their impression of how much work (energy expenditure) they expended in undertaking it. There are a number of similar scales used in the exercise physiology literature (e.g., the Borg et al. articles), and the Linn et al. (1999) scale data are not consistent with them. It is difficult to know what to do with the Linn et al. (1999) data.

The percent (%) of clock h away from home in Linn et al. (1999) includes those diary *hours* with one or more 20-minute period that was coded away from home. Therefore, it includes partial and whole hourly blocks of time. There is uncertainty about just how much clock time the whole/part blocks relates to exactly. The authors also provide the following locational data in their Table 5 (p. PM-113). The monitored week is a four-day time period with concomitant personal particulate and home monitoring data. Coded time use information is available for it and a "reference" week, that was not monitored (Linn et al., 1999). The time spent in both locations was shown to be statistically significantly different using a repeated-measures ANOVA. The main effects of *week* and *order* were non-significant for all items, but the interaction terms were statistically different at $p<0.05$.

	Group mean time/activity data for two time periods	
	Monitored Week	Reference Week
Min/d outdoors	62.4	86.4
Min/d in vehicles	36.0	55.2

The Linn et al. (1999) data were included in the Frazier et al. (2009) analysis of intra- and inter-individual variability in time spent in 3 general locational categories. That analysis was sponsored by NERL, and so also should be considered to be an output of our Aging Initiative program. Its findings are discussed in section 4.E below.

Wayne Ott (1989) provides an early description of time use data in modeling exposures, but the elderly are not a prominent subgroup of concern in his article.

Pruchno & Rose (2002) provide selected summary information on time use by a group of frail elders in Cleveland Ohio. Some of the 123 people included lived in a nursing home (n=45), while others lived in an assisted living facility (n=51) or "in the community" with the support of home health services (n=27). They all participated in a 1-day "yesterday" interview using 15-min blocks, but age of the participants was not provided. The data provided in the article are in both the obligatory/discretionary dichotomy favored by transportation planners (and some geographers) and by sociologists. They also use an "environmental context", but the only category of interest in it to us is "time away from home." That datum and travel time estimates from Table 1 in Pruchno & Rose (2002) follow.

Mean Minutes/Day Spent by the Frail Elderly
And Participation Rate by Housing Type

	Nursing Home	Assisted Living	Home (Assisted)	Stat. Sign. Differences
Travel time	11	26	32	Cols. 1 & 3
Participation %	17.8	43.1	55.6	Not tested
Away from "home"	36	95	145	Cols. 1 & 3
Participation rate	17.8	43.1	63.0	Not tested

As can be seen, time use by the frail elderly is different for the diverse housing types, sometimes significantly so. The participation rate data are particularly informative, and indicate that most of the people who are away from home also travel, but that time spent in the two categories is quite different. See the discussion of time use by health-compromised elderly in the Frazier et al. (2009) paper described in Section 4.E.

A paper by Vadarevu and Stopher (1996) is interesting as it emphasizes the importance of "life cycle" in affecting individual and family activities. They use the term in the way that we have defined "life stage," and we will use the latter term here. One of their life stage groups is "older families." While participation rate in "mandatory" activities is similar among the five life stage groups depicted—except the unemployed adult group—there are big differences among them for "optional" activities, such as social engagements, recreation, eating out, etc. Elderly families socialize almost twice as much (not significant based on an ANOVA analysis) as the other life stage groups and about 4 times as much for recreation (significant at p=0.01). Time (h/d) spent in recreation also

is significantly different (against the population mean, using a z statistic from multiple pair-wise comparisons (Vadarevu & Stopher, 1996). Some of the differences found in the older family life stage group undoubtedly are due to most of them not working compared to the other groups (except for non-working adults—unemployed and retired, of course).

Verbrugge et al. (1996) provide time use and other information from the Baltimore Longitudinal Study of Aging (BLSA), one of the most important studies of the elderly in this country. They provide estimates of variability in time use due to cross-sectional versus longitudinal (within individual) effects, so data from the paper are provided below under Section 4.E.

There are a few articles on the time use of nursing home residents, but since that location is so specific and may never be a focus of EPA exposure modeling, it is mentioned only in passing in this review. However, one article is of interest. Smith et al. (1986) asked 60 people aged 78 y on average (range: 65-99) living in a nursing home to keep an activity diary for two days separated by 2 weeks. Locations were not recorded. The sample spent their days in this manner (as a percent of daily time): sleep 40%; "daily living tasks" 20%; leisure time (recreation) 27%; rest 7%; and work 6% (Smith et al., 1986).

4.D.1 Time use in specified activities or locations

There is a large literature on time-averaged time use data for *specific activities or locations* that cannot be used in an event-based exposure model but could be used to evaluate their performance. Basically the idea would be to determine if the frequency, duration, and pattern of activities/locations output by the model are compatible with the extant data on them. The data would be used essentially as a "control total" to check individual activity estimates coming from APEX or SHEDS. Data on "physical activities" is provided in Section 5; this Section presents data on specific non-exercise activity/locations seen in non-sequential time use papers.

Kelly et al. (1986) discusses a survey taken in Peoria IL of "leisure activities," which include cultural, social, community participation, and home-based activities (plus travel and outdoor activities that are discussed below). Data are provided on the percentage of elderly 65-74 and 75+ by gender participating in the various activities, as well for younger age categories. The following information is provided:

Relative Participation by Age and Gender (Approximate)

	Females		Males	
	65-74	75+	65-74	75+
Cultural Events	67%	60%	41%	41%
Family Leisure	80%	55%	78%	90%
Social Activities	93%	84%	69%	90%

Community Activity	58%	61%	55%	42%
Home-Based	90%	75%	80%	56%
Exercise/Sport	15%	3%	40%	5%
Outdoor Rec.	2%	1%	16%	2%
Travel	55%	40%	66%	30%

While overall activity level in the elderly of both genders decreases, as can be seen, there are significant differences among the main activity types. Health and physical ability rather than age *per se* seems to be the most important factor in understanding age/gender differences in activity participation rates. However, there are fairly large decreases between 65-74 and 75+ in most of the activities listed (Kelly et al., 1986). The large decrease in "outdoor-" and "indoor-productive" activities, walking, and active leisure has been seen in other countries for the same two age groups, although they seem to be more active than the U.S. elderly overall (Dallosso et al., 1988).

Robinson & Caporaso (2009) published an analysis of ATUS data for people aged 65+ (as well as two other age groups). They categorize activity data into four main groups: contracted time, committed time, personal care, and free time. Contracted time focuses on working and commuting to it. The average number of hours/week for the elderly in this category is quite low: 7.1 for males and 3.8 for females (SD or SE estimates are not provided). Committed time includes housework, child care, and shopping. Mean time spent in this category is 31.0 h/wk ♀ and 20.8 ♂. Except for the "obligatory" personal care time (sleeping, eating, grooming), the free time category includes everything else. One interesting activity is "fitness activities." Elderly females spend only 1.1 h/wk, on average, in fitness tasks, while males do not spend much more: 2.2 h/wk. Total travel time is a modest 5.5 h/wk ♀ and 6.4 for males (Robinson & Caporaso, 2009).

4.D.2 Travel

Most travel information that is gathered relates to urban area commuting patterns by working-age individuals (Frusti et al., 2002). Since 2000, more information is being obtained on travel by the elderly and other "special population groups." The main sources of data available are the 1995 American Travel Survey (ATS), the 1995 Nationwide Personal Transportation Survey (NPTS), and the 2001 National Household Travel Survey (NHTS). The ATS focuses on long-distance travel (>100 miles one way) and its data are abstracted in Table 4-6 from Georggi and Pendyala (2003). Some of the demographic data in the Table are interesting. Note the rather large increase in single-person households between the ages of 65-74 and 75+, mostly widowed females. The proportion of workers drops between the two age groups, as expected. Car ownership drops, as does the use of private vehicles for long-distance travel; the number of trips almost drops in half. Mean trip length, on the other hand, increases. This increase is probably related to the relative increase in airplane usage (Georggi & Pendyala, 2003). Additional long-distance travel data appear in Mallett (1999), but its information is not as useful to us.

A very informative analysis of elderly travel pattern is Giuliano et al. (2003). The data come from the 1995 NPTS. Selected data are abstracted in Table 4-7. Gender or work/non-work breakdowns are not provided. The authors provide graphs of trips by purpose by time-of-day, but they are difficult to quantify due to their format. For most people, work trips occur in the 6:40 am to 6:20 pm time period, with many fewer work trips for the 75+ y age group than the 65-74 y age group. The vast majority of al trips occur between 6:00 am and 7:00 pm (Giuliano et al., 2003). Okola (2002) corroborates this observation and provides some data on 75+ y olds. She also provides graphical data on weekday/weekend travel splits by shopping, eating out, and socializing, but all ages are included, not just the elderly.

Hu & Reuscher (2004) analyze the 2001 NHTS information and provide limited data for the elderly. Daily mean trips/person and person-miles of travel by gender are provided for almost a 20 y period: 1983-2001 using a number of national studies. The trend in both measures approximately doubles for the total period.

Mean Daily Travel Statistics for 1983-2001 for People >65 y

	1983		1990		1995		2001	
	♀	♂	♀	♂	♀	♂	♀	♂
Trips/Person	1.5	2.2	2.2	2.8	3.0	3.9	3.1	3.8
Miles Traveled	10.2	14.8	15.3	22.5	19.2	31.7	23.5	32.9

The mean time spent in POV's was about 55 min/d for 65+ people in 2001 (Hu & Reuscher, 2004).

Frazier et al. (2009) provide descriptive statistical information on the time spent in a motor vehicle in a sample of health-compromised elderly individuals living in two very different communities: Los Angeles and Baltimore. Multiple days of data are available for each subject (see Section 4.E for a fuller description of the analysis). The mean time spent in travel in Baltimore was 20.0 ± 47.2 min d^{-1} for females (range: 0-375) and 27.8 ± 65.3 min d^{-1} for males (range: 0-450). The mean estimates for Los Angeles was 74.4 ± 72.9 min d^{-1} for females (range: 0-360) and 53.1 ± 50.4 min d^{-1} for males (range: 2-200). Note the wide range and the high coefficients of variability in both areas.

Gossen & Purvis (2006) provide travel time data for 1990 and 2000 for working and non-working 65-99 y olds, by gender. Participation rate information, however, is not provided. Surprisingly, travel time dropped between 1990 and 2000.

Time Spent in Travel, by Doers (min/d)

	Workers		Non-Workers	
Year	♂	♀	♂	♀
1990	82.5	67.9	102.2	95.0
2000	51.6	45.8	83.7	72.3

Females travel time is less than males in either working category and by year, and differences for non-workers by gender are significant (at $p<0.05$) for both of the years presented. Gender differences are not significant for the working group (Gossen & Purvis, 2006; Table 2). Ethnicity did not account for significant differences among the groups either.

With respect to travel during the day, the 2001 US National Household Travel Survey indicates that 23% of non-work related travel during peak congestion periods is by retired seniors, and only 0.2 of all travel by seniors is by public transit. Total trips per day for the elderly, however, are less than that for workers (Hildebrand, 2003; Collia et al., 2003).

Driver involvements in crashes per 1,000 licensed drivers **decrease** with age (after age 19!) even up to 85 y old, for both genders, with females having a slightly lower rate than males at any age (Ferguson & Braitman, 2006). However, crashes per million miles traveled by age **increases** after age 60 y, with males having a slightly lower rate. The obvious reason for these results is that although many elderly keep their driver's license as they get older, they drive many fewer miles (Ferguson & Braitman, 2006). Up to about age 54 y, females travel fewer miles than males (but make more daily trips); this pattern seems to continue after age 55 y (2004a). The proportion of trips made in cars (privately-owned vehicles: POVs) as a driver versus as a passenger decreases with age in both females and females:

Approximate proportion (%) of POV trips as driver/passenger

	Age Ranges									
	65-69		70-74		75-79		80-84		85+	
	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂
Driver	42	90	41	89	30	82	32	78	30	67
Passenger	58	10	59	11	70	18	68	22	70	23

Source: Rosenbloom (2004b): Figure 2.

Table 4-6. Demographic and long-distance travel (L-DT) characteristics in the elderly.

`	Age Ranges (y)	
Demographic Characteristics	**65 - 74**	**75+**
Females	55%	62%
Single-person Household	36%	55%
Married	65%	45%
Widowed	20%	45%
Employment Status		
Full-time Worker	12%	4%
Part-time Worker	7%	3%
Not Working	80%	91%
Transportation-Related		
Own 1+ Vehicles	81%	70%
Mean L-DT trips/year	3.9	2
None	40%	58%
1-4	33%	27%
5-9	15%	10%
10+	12%	4%
Mode Choice for L-DT		
Personal Vehicle	77%	70%
Airplane	15%	19%
Bus	5%	9%
Train	1%	1%
Mean Trip Length (Miles)	480 mi	510 mi

Source: Georggi & Pendyala (2003)

There are exposure and intake dose implications for the above differences, since drivers work harder than passengers (about twice as hard; METS=1.0 for being a passenger versus 2.0 for driving [Ainsworth et al., 1993]), and drivers often drive alone but passengers cannot (thus, there are more trips/person).

Rosenbloom (2004a) provides detailed information on "mobility of the elderly in an article titled "good news and bad news". Total 1995 daily trips and total VMT in the elderly are depicted in Table 4-8, by age and gender cohorts (Rosenbloom, 2004b). The vast majority of the number of trips and miles of travel undertaken are non-work related,

more so in females than males. These are not unexpected findings. There does not seem to be a trend with increasing age in either of these metrics, and statistical testing for age trend (or gender, for that matter) was not reported in Rosenbloom (2004b). However, there is an overall temporal trend in the data over the years; all metrics indicate that the trend in travel by the elderly was up for the 1983-1995 time period. Overall trips taken y^{-1} for 65+ y drivers increased 77% between 1983-1995. Vehicle miles traveled (VMT) increased even more, by 99%. Mean trip length also increased for this time span, but not significantly so. Travel time increased greatly between 1990 and 1995, but data are not available for the elderly in 1983.

Table 4-9 provides additional information on modal choice by the elderly, but specific gender data are not provided. The mode choice depends in part upon the type of trip undertaken, and there is not an obvious trend in modal choice by age in the Table. According to Rosenbloom (2004b), there is no statistical difference in the use of private vehicles (on average, at least) for total trips among the various ages depicted in Table 4-9 (and even for persons <65 y old).

Rosenbloom (2004b) also provides age and gender data on the percent of 1995 trips taken by their purpose, using the following categories: family/personal, medical, recreational/social, religious, shopping, work-related, and other. The proportion of work-related trips drops significantly after 65 y, as expected. Medical trips increase but it does not appear that there are concomitant increases in the other categories to account for the decrease in work trips. Statistical testing of these data is not provided in Rosenbloom (2004b).

An article by Pucher & Renne (2003) compares the 2001 NHTS travel data with the 1995 NPTS data analyzed in the Rosenbloom articles reviewed above. Pucher & Renne (2003) do not disaggregate their data by gender. "There are few differences between the findings of the 1995 NPTS and the 2001 NHTS regarding the impact of age on travel behavior" (Pucher & Renne, 2003: p. 70).

Table 4-7. Local travel characteristics in the elderly

	Age Ranges (y)	
Characteristic	**65-74**	**75+**
Own 1+ Vehicles	91%	72%
Mean Daily Trips Data		
All Trips		
Number	3.5	2.4
Total Distance (miles)	22.3	13.6
Time in Travel (min)	52.9	36.3
Non-work Trips		
Number	3.2	2.3
Total Distance (miles)	20.2	12.9
Time in Travel (min)	48.2	34.5
Modal Split		
POV Driver	72%	62%
POV Passenger	21%	28%
Bus or Train Passenger	1.50%	1.90%
Walking	5.40%	7.00%
Trip Length by Purpose (miles)		
Shopping	4.8	4.7
Personal Business	5.8	7.6
Social/Recreational	7.6	6.3
Time in Travel by Purpose (min)		
Shopping	12.4	13.5
Personal Business	14.1	14.5
Social/Recreational	17.2	16.4

Source: Giuliano et al. (2003)

Table 4-8. 1995 daily trip data (means) for the elderly 65+.

Daily Travel Statistics for 65+ Persons

	1983	1990	1995	% Change 1983-1995
Trips / Driver	1.7	2.3	2.9	77
VMT / Driver	9.8	14.8	19.6	99
Mean Trip Length (miles)	5.9	6.6	6.7	13
Time in Travel (minutes)		31.0	43.0	

Total Trip Rates (# / Day) by Age & Gender

	Females		**Males**	
Age Groups	Trips	Percent Non-work	Trips	Percent Non-work
65-69	3.7	94.6	4.4	86.4
70-74	3.4	94.1	4.2	90.5
75-79	2.9	96.6	3.5	94.3
80-84	2.4	95.8	3.4	100.0
85+	1.3	100.0	2.1	95.2

Total Miles of Travel/Day by Age & Gender

	Females		**Males**	
	Miles	Percent Non-work	Miles	Percent Non-work
65-69	24.9	92.8	37.4	85.6
70-74	20.6	97.1	34.5	90.1
75-79	16.4	96.3	23.8	91.6
80-84	13.0	97.7	19.0	97.4
85+	7.3	98.6	13.1	100.0

Source: Rosenbloom (2004) *Transportation in an Aging Society* (Table 3).

More recent articles on travel by the elderly could not be found. Clearly more information on this topic is needed—especially average daily travel (ADT) or vehicle miles traveled (VMT)--to ascertain what differential impacts travel activity will have on future elderly exposures. This research area seems to be under-addressed. Since NERL is focusing a lot of research on near-roadway and motor vehicle exposures, not having better information on these issues may bias exposure estimates for the elderly.

Table 4-9. Percentage of mode choice for all trips (1995), by age.

	Modal Percentage of All Trips Taken							
	Private Vehicle			Other Mode				Other
Age Range	Driver	Pass.	Total	Public Transit	Taxi	Walk	Bicycle	Misc.
65-69	71.5	18.6	90.1	1.7	0.2	4.5	0.2	3.4
70-74	67.6	21.8	89.4	1.5	0.2	5.5	0.2	3.2
75-79	63.3	25.1	88.4	2.1	0.3	5.9	<0.1	3.4
80-84	57.6	31.4	89.0	1.6	0.2	5.3	0.3	3.6
85+	49.3	32.2	81.5	2.3	0.9	11.0	0.0	4.4

Source: Rosenbloom (2004) *Transportation in an Aging Society* (Table 4).

4.D.3 Outdoors

As mentioned, most studies of the elderly (or of time use in general) do not provide information on *where* activities occur. Graham & McCurdy (2004) provide some information on the time spent outdoors by the elderly in an analysis of CHAD data. For 65+ y individuals, 57% went outdoors on the day they were surveyed, for an average of 118 min d^{-1}. The range for habitués was 1-1015 min d^{-1} and the COV was a relatively high 110%, indication a lot of inter-individual variability in time spent in that location by the elderly. Frazier et al. (2009) provide information for the mean time spent outdoors by health-compromised elderly in two communities; see Sections 4.C and 4.D for more information on the communities. There is quite a large difference in this time for the two locations, probably due to their very different climates (Frazier et al., 2009). Including those who did not go outside on any of the 4-24 days that were monitored, the subjects spent a mean of 62.7 ± 62.2 min d^{-1} outdoors in Los Angeles (range: 0-360) and 21.7 ± 51.8 min d^{-1} (range: 0-490) in Baltimore. There was a lot of day-to-day variability in both samples in the time spent outdoors.

In both areas, there are large and statistically significant differences in the time spent outdoors by gender and by season-of-the-year (Frazier et al., 2009). This study is discussed in greater detail below in the Section 4.E, as it is one of the few that addressed both intra- and inter-individual variability in time use data.

An analysis of the time spent outdoors by adults 65+ was undertaken by Nyswander et al. (2009). A figure from their report is reprinted here as Figure 4-1. A clear decrease in the time spent outdoors is seen in the CHAD database when the data are plotted by year of the study undertaken. The studies include both national probability *ex post* surveys and localized time use diary studies, so the trend line could not be statistically evaluated. The decrease is striking: an approximately 3-fold reduction over the 15+ year time period. The Baltimore study just discussed would be quite close to the trend line seen in Figure 4-1, although the Los Angeles data would be much higher than it.

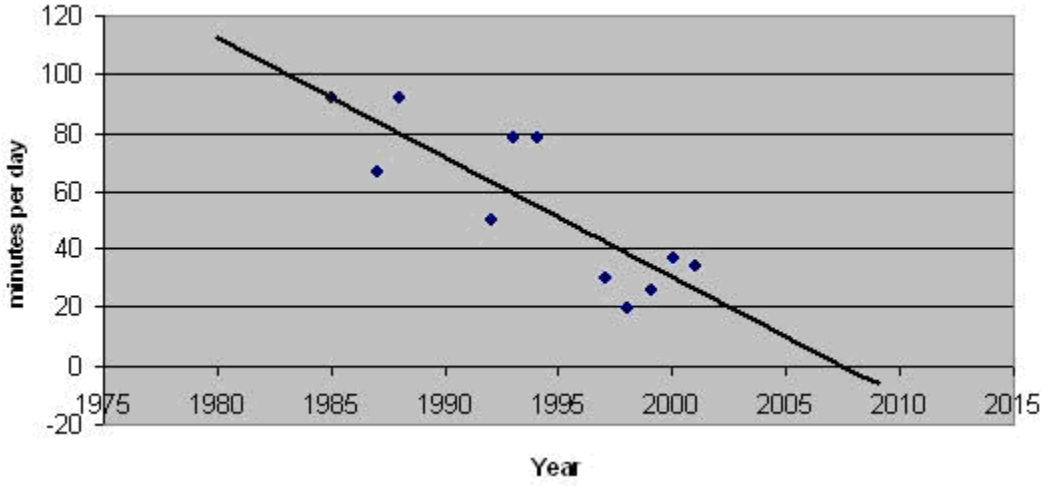


Figure 4-1. Mean time spent outdoors by study-year in adults aged 65+ y.

Source: Nyswander et al. 2009

Additional data on the time spent by the elderly outdoors could not be found; this is another under-analyzed aspect of time use/activity pattern information.

4.E Intra- and inter-individual variability in time use/activity data

As discussed in Section 1, multiple-day exposure modeling requires that some type of "decision rule" be invoked to combine time use data from different individuals to represent a single individual (Xue et al., 2004). NERL has recently developed a "D & A" approach to modeling longitudinal activity patterns from cross-sectional data (where D stands for "diversity" and A is a calculated autocorrelation coefficient: more on these metrics shortly) that is described in Glen et al. (2008). Prior to the "D & A" method, four different decision *rules* were used to obtain longitudinal time use patterns: repeat the same pattern, randomly draw from different patterns, a mixture of the two approaches, and a "conditional probability" approach that essentially followed Markov-chain sampling (Xue et al., 2004). These decision rules resulted in widely different longitudinal time use patterns in the modeled population. An abstraction of the four rules and the pattern obtained from using a D & A approach follows. See Figure 4-2.

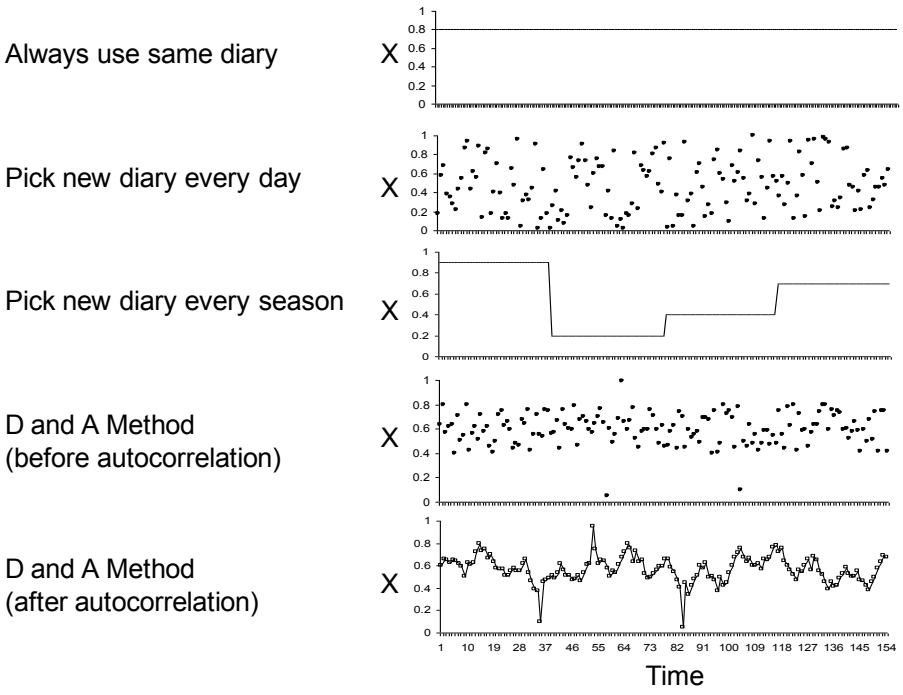


Figure 4-2. Conceptual diagram of alternative decision rules used to sample single-day diaries to develop longitudinal activity patterns.

Development of the D & A approach started with an analysis of a large longitudinal time use study which indicated that the intraclass correlation coefficient (ICC) could be used to compute the reliability of capturing the within- and between-individual variability seen in outdoor and in-home locations, two important general locations from an exposure viewpoint (Xue et al., 2004). An ICC is calculated from a repeated-measures analysis of variance (ANOVA), and is defined to be = $\sigma_B^2 / (\sigma_B^2 + \sigma_W^2)$, where the subscripted σ's present *explained* between-person (B) and within-person (W) variances, respectively. The ICC metric is often used in the exercise physiology field to determine how many days of data adequately capture population variability in time spent in exercise. Some of these studies are Baranowski & de Moor, 2000; Baranowski et al., 1999; Matthews et al., 2001; and Trost et al., 2000. While there is variety in the recommended number of days of data needed to reliability estimate intra- and inter-individual variability in the time spent in exercise, Baranowski & de Morr (2000) concluded that 28 days of data spread over four seasons of the year were needed.

NERL staff used the ICC logic with a reliability coefficient of 0.8 in its analysis of school children's locational preferences and also determined that 28 days of time use data spread over the year were needed to capture longitudinal stability in the mean observed within- and between-individual variability in the time spent outdoors (Xue et al., 2004). Less data were needed to obtain reliable estimates of the individual mean estimate of indoor

time.[15] The NERL analysis also calculated one-day "lag" autocorrelations for time spent in the same two locations. The *r* (Pearson product-moment correlations) for outdoors was about 0.36 while the *r* for indoors vas 0.45. The last statistic seems to be low, but there is surprisingly a lot of day-to-day variability in even that location.

Using the above (scanty) information and the ICC logic, the APEX/SHEDS exposure modeling team developed a "scaled rank-order "Diversity" (D) statistic, which has the same formula as the ICC. The method is fully described in Glen et al. (2008). Basically, the modeler inputs a "target" D & A for one or more important parameters into an APEX or SHEDS model simulation, and age/gender-specific cross-sectional daily activity data are ranked to replicate those values. A test of the logic indicated that the obtained D & A values were very close to those requested based on 25 simulations of 10,000 persons each. The requested and obtained D & A values are within 5% or so for simulation periods >60 days (Glen et al., 2008), which is on the low end of the time period of exposure analyses undertaken by both OAQPS and NERL.

Since early 2008, the "D & A" approach has been used to develop longitudinal activity patterns for the event-based APEX and SHEDS models. To ground the approach in reality, NERL wants to develop a "library" of ICC values that are seen in those longitudinal time use/activity studies that calculate them. To date, we have not found any "independent" (non-EPA) study focused on elderly ICC's and only a few focused on adults in general. One in-house EPA study combined data from three different longitudinal diary studies and calculated ICC's for two locations (outdoors and indoors) and two activities (travel and "hard work"). Hard work is a self-reported activity that involved "heavy breathing and/or sweating". Besides the ICC statistic, we also calculated "A" from the original data, and the D & A metrics that would be obtained from the rank-order procedure used during a modeling effort. The data have been presented in poster format at the 2009 ATUS conference in College Park, MD (Isaacs et al., 2009). Findings of this work are reproduced in Table 4-10. Only one of the individuals in the study was >65 y, so the data probably are not representative of the elderly population as a group. The Table is presented here to delineate the variability in D&A statistics due to gender, temperature classes (a surrogate for seasonal considerations), and workday/non-workday distinctions. The D&A values shown in Table 4-10 are similar to those seen in the elderly, as evaluated by Frazier et al. (2009).

[15] While the literature on applying reliability calculations to the elderly is exiguous, Jacelon & Imperio (2005) looked at the issue to determine how much longitudinal data were needed to adequately "explain" elderly activity patterns. They state that "the optimum length of time for recording diaries is between 1 and 2 weeks" (p. 995). One week of data had insufficient "depth," while subjects become noncompliant after 2 weeks (Jacelon & Imperio, 2005). Tudor-Locke et al. (2005) evaluated the number of days needed to estimate weekly steps/day in adults using a pedometer. A 3-day monitoring period achieved a reliability coefficient of 0.8+.

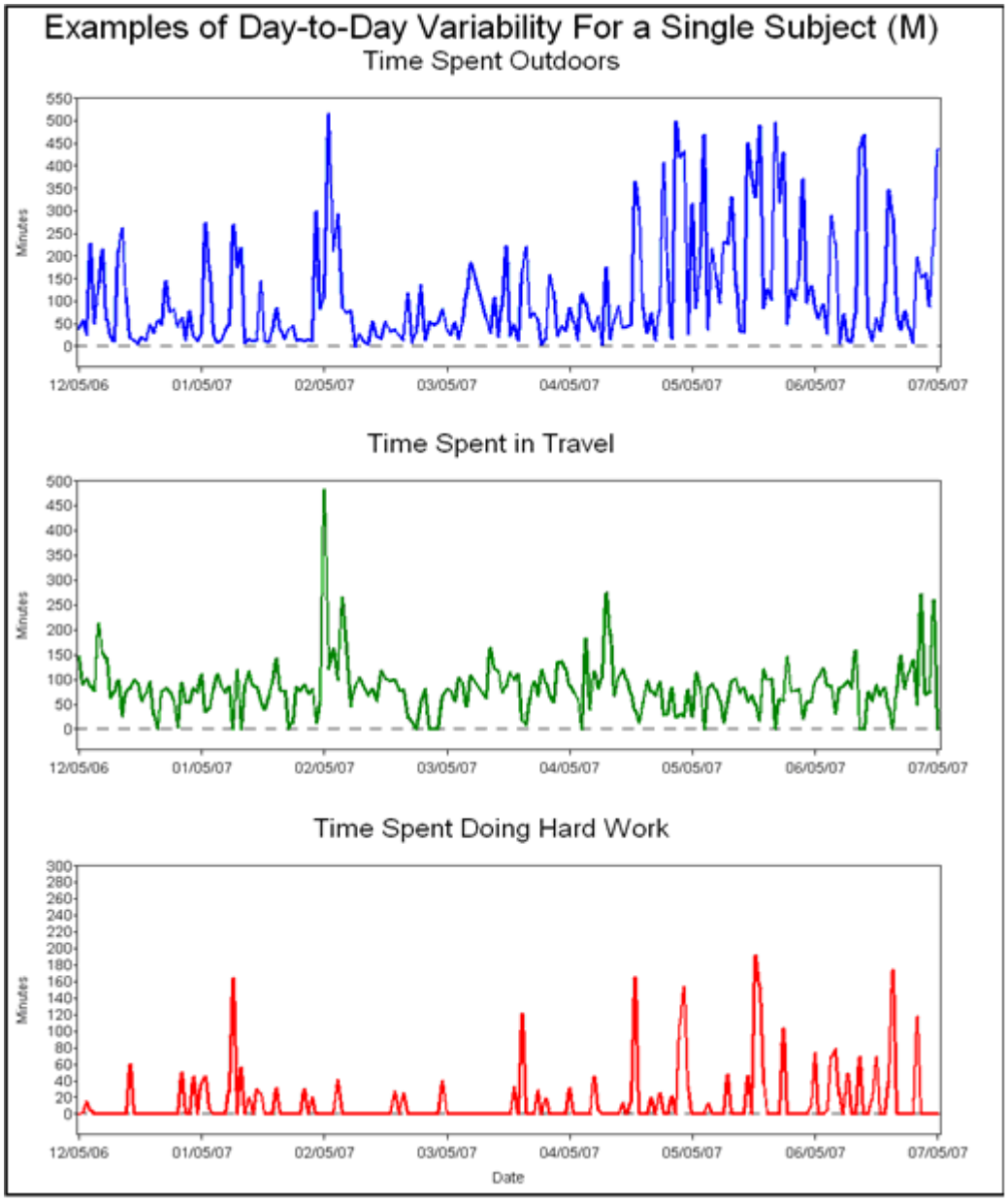


Figure 4-3. Daily variability in time use over 7 months by a single individual.

Another NERL project to delineate ICC's in the population was focused explicitly on the health-compromised elderly living in two communities: Baltimore and Los Angeles (Frazier et al., 2009). This study's findings regarding travel and outdoor time spent by the elderly have been mentioned a few times above. The Baltimore time use data came from an internal NERL project described in Williams et al., 2000a,b,c). The sample included 26 individuals aged 65-89 y and 69% of the sample had hypertension or coronary heart disease. Between 4 and 24 days of time use data were obtained for the subjects. The Los Angeles data came from a study of 30 individuals aged 56-83 with

clinically diagnosed chronic obstructive pulmonary disease (COPD) and it is described in Linn et al. (1999). Time use data were obtained for two 4-day periods in that study.

The location data from both studies were collapsed into 3 categories: time spent indoors, outdoors, and in a motor vehicle. Data for time spent outdoors and in a vehicle were provided above. Time spent indoors constitutes most of the elderly subjects daily time use, being about 1,324-1,388 min d^{-1} in the two areas and both genders. There is some variability in time spent indoors by season-of-the-year and day-of-the-week, but not much (Frazier et al., 2009). There is some time-of-day variability in the time spent indoors—with less being spent between noon and 6:00 pm, but the differences are not large.

ICC's were calculated in the Frazier et al. (2009) paper using different models. They are listed here, where the vertical symbol "|" means "given" (e.g., season given gender, a conditional variable):

Location / Model Independent Variables	Baltimore	Los Angeles
Outdoors		
Gender only	0.14	0.35
Season | Gender	0.13	0.38
Time-of-day | Gender	0.09	0.26
Day-of-the-week | Gender	0.15	0.37
In a vehicle		
Gender only	0.30	0.17
Season | Gender	0.30	0.17
Time-of-day | Gender	0.19	0.11
Day-of-the-week | Gender	0.32	0.18

As seen, the ICC's are affected somewhat in conditional form, but not greatly, and the overall pattern is not consistent. Increasing specificity through the use of conditional variables does not always provide a higher ICC. ICC values for the elderly are about the same as those seen for adults in the EPA analysis (Table 4-10).

The relationship between ICC values and the ratio of within-person to between-person variance "explained" (σ_W^2 / σ_B^2) is a non-linear one, exponentially decreasing with an increasing ICC. At ICC's on the order seen in the Frazier et al. (2009) and Isaacs et al. (2009) analyses, the within-to-between ratio is on the order of 2-5. Thus, the analyses indicate that a lot of variability in human locations and activities is explained by within-person variability. Most exposure models ignore within-person variability, which means that there is a systematic bias downward in output estimates from these models, especially at the "high end" of the exposure distribution which is of most interest to EPA. This is why we are using the "D & A" procedure in the first place.

Table 4-10. Variance & autocorrelation statistics in the internal EPA study.

	ICC's & D's for Specified Locations and Activities							
	Outdoors		Indoors		Travel		Hard Work	
Characteristic	ICC	D	ICC	D	ICC	D	ICC	D
All days and subjects	0.16	0.38	0.26	0.33	0.14	0.31	0.18	0.22
Males	0.14	0.22	0.36	0.54	0.36	0.46	-0.01	0.15
Females	0.07	0.27	0.08	0.09	0.05	0.18	0.15	0.24
"Cool" days (max. temp. <50F)	0.20	0.26	0.37	0.37	0.23	0.37	0.21	0.31
"Warm" days (max. temp. ≥50F)	0.09	0.24	0.12	0.24	0.10	0.24	0.01	0.20
Day type: workday	0.19	0.31	0.12	0.21	0.45	0.47	0.20	0.25
Day type: non-workday	0.11	0.14	0.12	0.21	0.09	0.24	0.06	0.07
	"Raw" & "Ranked" Autocorrelation (A) Estimates							
	Raw	Rank	Raw	Rank	Raw	Rank	Raw	Rank
All days and subjects	0.22	0.31	0.23	0.34	0.12	0.19	0.17	0.19
Males	0.24	0.22	0.25	0.16	0.17	0.08	0.22	0.20
Females	0.35	0.18	0.37	0.25	0.15	0.11	0.16	0.21
"Cool" days (max temp <50F)	0.33	0.18	0.23	0.19	0.20	0.09	0.14	0.14
"Warm" days (max temp ≥50F)	0.39	0.20	0.45	0.23	0.34	0.09	0.35	0.14
Day type: workday	0.78	0.07	0.56	0.05	0.30	0.01	0.53	-0.12
Day type: non-workday	0.60	0.18	0.59	0.24	0.38	0.08	0.43	0.18

Abbreviations:

A: The lag-one Pearson product-moment correlation coefficicinet

D: The rank-ordered ICC-like "diversity" coefficient

ICC: The intra-class correlation coefficient

max temp: The maximum daily temperature in degrees Fahrenheit

Source: Isaacs et al. (2009) "Statistical properties of longitudinal time-activity data" (poster).

It is hoped that new longitudinal human activity data will come along so that we can obtain additional ICC estimates to further test and refine the D & A approach.

5. Physical Activity, Exercise, and Aging

Abstract

Topic: This chapter discusses the impact of exercise on the health of the older person, and on estimates of physical activity in the aging population.
Issue /Problem Statement: Estimates of physical activity in older adults are required for validation and assessment of the energy-expenditure based algorithms in EPA's exposure models.
Data Available: This topic is extremely data-rich.
Research Needs: Futher assessement of EPA's current algorithms is needed, with the goal of determining how well a realistic population distribution of physical activity is being reproduced for the elderly.

5.A Overview of the literature

There are thousands of articles on the impact of physical activity (PA) and exercise on the aging process in the elderly.[16] Hundreds are being added every year. We had to cull the shear magnitude of the available information to a manageable proportion, and did so by focusing on:

1. U.S. studies (because of the cultural component of PA)
2. "free-ranging" individuals living independently at home ("institutionalized" or nursing-home residents are not discussed—with minor exceptions)
3. studies that use "objective" measurement techniques to ascertain the frequency, duration, and intensity of PA[17]

This last foci means that limited attention is given to the extensive "epidemiological" research in the elderly that rely on questionnaires for their estimates of PA. Questionnaire-derived data are by far the most extensive information available on the topic, and not using it means that a lot of elderly PA information is ignored, including some very long-term longitudinal studies. Citations for many of them are provided in Section 5.F. Examples are the Harvard Alumni Study (going on for over 50 years: see the many citations for Drs. I.-M. Lee and R.S. Paffenbarger; Sesso et al., 2000); the Physicans' Health Study (Lee et al., 1997); the Baltimore Longitudinal Study of Aging

[16] To check our literature searches for completeness, on December 2, 2009 Google Scholar was accessed using "physical activity in the elderly." 124,326 citations were provided in 0.4 seconds! The first 150 citations of U.S. studies of independently-living subjects were reviewed. 85% of them provided relevant PA data on the elderly. Of those, over 90% of the articles were on hand and were evaluated for this report. (Not all of them are listed here.) Therefore, we are confident that we have most of the relevant literature on the subject. What is more interesting is the shear number of articles on the topic. Elderly PA research is a major subject of interest that seemingly receives a lot of funding by U.S. federal agencies.

[17] Other common acronyms used in the PA field are light PA (LPA), moderate PA (MPA), vigorous—or sometimes "heavy"—PA (VPA), and the sum of moderate and vigorous PA (MVPA). In general, there is an exponential drecrease in the amount of time spent in the LPA, MPA, and VPA categories, respectively, with the elderly spending very little time in the latter category.

(Talbot et al., 2003); the Normative Aging Study (O'Connor et al., 1995); the older San Francisco Longshoremen's Study (Paffenbarger et al., 1978); the Framingham Study (Paffenbarger et al., 1984); the Nurses' Health Study (Garcia-Aymerich et al., 2009); the older University of Pennsylvania Study (Paffenbarger et al., 1966); the LIFE Study (Rejeski et al., 2005); the Cardiovascular Health Study (Geffken et al, 2001); the Iowa 65+ Rural Health Study (Cerhan et al., 1997); the Iowa Women's Health Study (Sinner et al., 2006); the Health, Aging and Body Composition Study (Colbert et al., 2004); the Rancho Bernado Study (Greendale et al., 2003; McPhillips et al., 1989); the Honolulu Heart Program (Donahue et al., 1988); the Honolulu-Asia Aging Study (Taafe et., 2008); the Minnesota Heart Study (Steffen et al., 2006); the San Antonio Longitudinal Study of Aging (Dergance et al., 2005); the Health and Retirement Study (Chung et al., 2009); the Women's' Health Initiative (Másse et al., 1998), the Women's Health and Aging Study (Simonsick et al., 2005); and the many PACE articles—those using the Physical Activity Scale for the Elderly (Allison et al., 1998; Chad et al., 2005; Martin et al., 1999; Vieira et al., 2007).

Epidemiological studies usually take questionnaire-derived estimates of PA participation in specific activities and convert them into PA energy-expenditure (PAEE), as mentioned in Section 3. Usually this is done using METS estimates from the Compendium (Ainsworth et al., 1993) or similar source. The METS estimates are then often assigned to low, medium, and vigorous PA levels, and compared to various PA normative standards developed by health professionals or government organizations (Chodzko-Zajko et al., 2009; Crespo et al. 1996,1999; Kruskall et al., 2004; Másse et al., 1998). There are a number of rater-oriented issues associated with this approach (Másse et al., 2005a,b). The questionnaire/assignment approach has been shown to over-estimate by varying amounts the amount of PA undertaken when compared to a simultaneously-monitored "objective" measurement method using an accelerometer, indirect calorimeter, or pedometer (Harris, et al., 2009a; Másse et al., 2005a). A succinct evaluation of the epidemiologic approach is contained in Shephard (2003). See also: Harada et al. (2001), Sallis & Owen (1999), especially their chapter on "Measuring Physical Activity," Tryon (1991), and Westerterp (2009). A more accessible review of self-reported PA methods is contained in Sallis & Saelens (2000), which includes mention of 8 previous reviews on the topic.

The elderly PA literature, however activity is measured, emphasizes the positive benefits of physical activity, exercise, and "fitness" in the aged (Frankel at al., 2006; President's Council on Physical Fitness and Sports, 1998; Stewart, 2005). The list of overall benefits is extensive, and includes the following attributes, many of which are related:

1. preventing or slowing of osteoporosis (decrease in bone mass and density via the enlargement of interstitial spaces), which in turn causes frailty and an increase in falling, particularly in females (Allison & Keller, 1997; Gregg et al., 1998; Hughes et al., 2004)
2. slowing the rate of decrease in maximal aerobic power ($VO_{2.Max}$), or even a reversal of this functional decrease via concerted exercise in the elderly (Ades

et al., 1996; Allison & Keller, 1997; Fleg et al., 1995; Shephard, 2009). This improves endurance and reduces heart-related issues; see #4 and #9 below.

3. reducing physical/mental unhealthy days for arthritics (Abell et al., 2005; Hamer et al., 2009).
4. preventing coronary heart disease and "cardiovascular events" (Berlin & Colditz, 1990; Geffken et al., 2001; Mason et al., 2002; Paffenbarger, 1988; Sacco et al., 1998). If the same amount of PA is undertaken (in kcal/time period), it appears that vigorous PA confers "greater cardioprotective benefits than exercise of a moderate intensity," using METS > 6 as the cut point (Swain & Franklin, 2006).
5. reducing pre-infarction angina incidents in the elderly having existing acute myocardial infarction; it also reduces stroke rates (Abbott et al., 1994; Abete et al., 2001; Sallis & Owen, 1999)
6. slowing muscle mass loss and weakness (Allison & Keller, 1997; Buchner et al., 1997; Fiatrone & Evans, 1993; Koopman & van Loom, 2009). Muscle loss is known as sarcopenia (Stewart, 2005). Improving muscle mass reduces falls and fractures and improves physical capacity (Ades et al., 2003). It makes for increased gait stability (Brach et al., 2001). It slows disability prevalence in the elderly (Berk et al., 2006). It reduces back pain by strengthening muscles that stabilize the spine and maintaining flexibility (Sallis & Owen, 1999). Overall, there is better physical functioning in older, exercising subjects (Brach et al., 2004a,b).
7. maintaining weight and decreasing obesity rates (Sallis & Owen, 1999; Van Pelt et al., 1998).
8. reducing high-density lipoprotein (HDL) cholesterol (Casperson et al., 1991; Reaven et al., 1990)
9. reducing hypertension and reducing blood pressure (Bassett Jr. et al., 2002; Reaven et al., 1991). PA also reduces "vascular stiffness (Havlik et al., 2003; Seals et al., 2006).
10. increasing joint flexibility (Birrer, 1989).
11. increasing longevity (Paffenbarger & Lee, 1996; Manini et al., 2006; Morey et al., 2002; Sallis & Owen, 1999).
12. reducing prostrate and breast cancer incidence (Cerhan et al., 1997; John, et al., 2003). This finding is not universal, and no protective effect has been found in a number of studies (Moore et al., 2000) and a credible biological mechanism for this finding cannot be derived (McTiernan et al., 1996). Probably those people who exercise more also have other lifestyle patterns that have a real effect on cancer etiology, although tobacco smoking is usually accounted for in these studies, so that "lifestyle" factor already is controlled for).
13. reducing age/gender-specific morbidity and mortality rates (Kushi et al., 1997; Sherman et al., 1994; Trolle-Lagerros et al., 2005). There is another term used for this attribute: "the compression of morbidity" (Fries, 1996). This refers to an increasing age of onset of disability and age of death; a shortening of the period when the person is disabled/frail/totally dependent before death (von Bonsdorff et al., 2009).

14. preventing or delaying the onset of diabetes (Hawkins et al., 2009).
15. reducing the risks of cognitive impairment, Alzheimer's, and dementia (Laurin, et al., 2001; Sumic et al., 2007; Weuve et al., 2004). PA also reduces the rate of cognitive decline in elderly females (Yaffe et al., 2001). The incidence of Parkinson's disease was also lower in the active elderly (Thacker et al., 2008).
16. improving general quality of life and decreasing depression (Schechtman et al., 2001; Strawbridge et al., 2002).
17. reducing the risk of lung cancer in females who are current or former smokers (Sinner et al., 2006).
18. reducing the risk of rectal cancer in both genders (Slattery et al., 2003). Stolzenberg-Solomon et al. (2008), however, find no association between PA and pancreatic cancer, although there is a positive association between adiposity and pancreatic cancer.
19. preventing early onset of ADL and IADL limitations (Stewart, 2005).
20. reducing the risk of gallstone disease (Storti et al., 2005).

Because of these perceived benefits of PA and exercise, there are a number of articles on how much PA should be undertaken by the elderly in various age/gender categories. The recommendations are quite specific, and generally involve prescriptions for the intensity, duration, and frequency of specified activities (Birrer, 1989; Chodzko et al., 2009—which is the American College of Sports Medicine's "position stand"; Haskell et al., 2007; Jordan et al., 2005; Thompson et al., 2003). Usually these recommendations take the form of a minimum number of minutes/week that should be spent in moderate and/or vigorous activity (see below), but a Canadian goal is for older adults to expend 1,000 kcal/week in moderate leisure-time PA (Sawatzky et al., 2007), a more precise objective. The epidemiological literature often compares their findings with one or more of these normative standards (e.g.: Dergance et al., 2005). A summary of many recommendations for PA is contained in Sallis & Owen (1999).

Not all researchers, however, question whether all of the attributed benefits of exercise and PA in the elderly are "real" as the following quote makes clear (Keysor & Jette, 2001:

> Late-life exercise clearly improves strength, aerobic capacity, flexibility, and physical function. Existing scientific evidence, however, does not support a strong argument for late-life exercise as an effective means of reducing disability.

Physical inactivity is, of course, the flip side of PA. Data indicate that inactivity is an independent factor for certain physical impairments in the elderly, particularly hip fracture (Coupland et al., 1993; Sallis & Owen, 1999). A sedentary lifestyle is considered to be a major contributor to the leading causes of death in adults, and about 15% of newly-diagnosed chronic health conditions are due to sedentary lifestyle *alone* (Stewart, 2005). There are some studies showing that physical inactivity is a better measure of PAEE in the elderly, and that if sedentary activities are reduced then the benefits of PA and exercise listed above can be achieved without the need for high-

intensity (vigorous) activity (Meijer et al., 2001). This approach intuitively seems to be more relevant to the elderly, since it is relatively more difficult for them to undertake vigorous activities due to all of the other changes that occur in their $VO_{2.Max}$, muscle mass and strength, etc., which are a function of aging *per se* regardless of lifestyle and fitness level.

As for national PA goals, there are national goals for reducing inactivity in the elderly population. The U.S. Public Health Service set a goal in 1991 that the proportion of adults ≥ 65 y old who engage in "no leisure-time physical activity" should be reduced to 22% by 2000 (Public Health Service, 1991).

We should probably mention that there are some risks associated with PA in the elderly, particularly musculoskeletal injury and sudden cardiac arrest (Haskell et al., 2009). The negative issues of PA are minimized in the literature, probably due to the relatively low energy expenditure levels of activities undertaken as PA by the elderly—mostly walking for exercise. Stress from walking and low-level EE activities generally is not intensive enough to invoke severe adverse health repercussions.

5.B General estimates of physical activity & inactivity in the elderly

Hawkins et al. (2009) report on an accelerometer study that was part of the 2003-2004 National Health and Nutritional Examination Survey (HNANES) cycle. This was the first time that accelerometers were used in a NHANES survey, and valid data (>4 days with at least 10 h/day of wearing time) were obtained from 2,688 adults. Only accelerometer *count* data were provided, so the estimates in Hawkins et al. (2009) are difficult to put into perspective, and no sample size (n) was provided for the number of elderly >60 y, even though count data were provided for them by age, gender, and ethnicity. That data, in activity counts in thousands are reproduced here. The counts are about 50-67% of those seen in the 40-59 y age group for all the subgroups depicted (AA=African Americans [blacks]; C=Caucasians [whites]; and H=Hispanics). The PA categories were defined above.

Accelerometer counts/day in thousands for persons > 60 y old

	Females			Males		
	AA	C	H	AA	C	H
Total PA (TPA)	145	159	156	171	182	212
LPA	125	128	130	135	132	149
MVPA	21	31	26	37	51	62

Statistical testing for significant differences among the various subgroups depicted were not uniformly provided or discussed in Hawkins et al. (2009). Female LPA is 80-86% of TPA and male LPA is 70-80% of TPA, with ethnic differences seen in the count data.

The U.S. Centers for Disease Control has data on physical inactivity in the elderly from its Behavioral Risk Factor Surveillance System (BRFSS), a random probability telephone survey of the non-institutionalized U.S. population. In 1995, it published state-specific data on elderly inactivity for the 1987-1992 time period, and overall inactivity levels decreased from 43% in 1987 to 39% in 1992 (BRFSS Coordinators, 1995). For 1992, the range in elderly inactivity among the states varied from 27.2% in Colorado to 62.5% in Mississippi (BRFSS Coordinators, 1995). Thus, in general, the Country is far from attaining the nation's reduction in elderly inactivity goal of 22%.

Macera & Pratt (2000) and Macera et al. (2005) have published BRFSS data from 1998 and 2001, respectively. Weighted, age-adjusted PA participation data for 1998 follows (Macera & Pratt, 2000):

	Females		Males	
	65 – 74	75+	65 – 74	75+
Inactive	36.1%	48.6%	31.4%	41.4%
Insufficient PA	37.7%	30.7%	37.5%	28.1%
Meets PA Recom.[18]	26.2%	20.8%	31.1%	30.5%

The 2001 data have a different format, with MPA and VPA prevalence being shown separately, and the categories are not mutually exclusive, Thus, only the Inactive and Meets-PA Recommendations data from Macera et al. (2005) are described here.

	Females		Males	
	65 – 74	75+	65 – 74	75+
Inactive	24.5%	39.6%	21.4%	29.7%
Meets PA Recom.	36.1%	26.9%	45.7%	38.4%

The most-recent national data that found on the topic is contained in CDC (2007). The Center provides the following PA estimates for citizens 65+ y old for the country as a whole and by state. The overall U.S. estimates are:

Inactive	23.7%
Insufficient PA	36.9%
Meets PA Recommendations	39.3%

[18] Meets the Surgeon General's minimum recommended levels of PA: 30+ min/day for 5 days/week at moderate intensity; **or** 20 min/day for 3 days/week at vigorous PA.

The proportion of elderly 65+ meeting the recommended PA guidelines varies from 27.7% in Kentucky to 52.3% in Alaska (CDC, 2007).

Another way that CDC presents PA data in the elderly is contained in CDC (2009a). The percentage of two elderly age/gender groups that engages in regular "leisure-time" PA (LTPA) in January-March 2009 follows (with 95% confidence intervals):

65 – 74	Females	34.0% (26.1 - 42.0)
	Males	39.1% (28.2 - 50.1)
75+	Females	13.1% (06.4 – 19.9)
	Males	20.8% (11.2 – 30.4)

These participation rate estimates are hard to reconcile with other LTPA data provided by CDC seemingly for the same year (CDC 2009b). Gender is not distinguished; numbers in parentheses are the standard errors of the estimate (SE). (Since group-specific sample sizes were not provided, SE's could not be converted into SD's.)

	65 – 74	75+
Inactive	46.0% (1.1)	56.0% (1.4)
Some activity	27.9% (2.0)	25.5% (1.2)
Regular LTPA	26.1% (1.1)	18.5% (2.0)

CDC 2009b also provides estimates for the *frequency* of vigorous LTPA bouts (defined to be at least 10 min of heavy sweating and/or a large increase in breathing or heart rate) per *week*. The percentages of elderly by number of bouts/week (with standard errors) are:

	Never	<1	1-2	3-4	≥5
65 – 74	76.5% (1.0)	0.8% (0.2)	5.5% (0.6)	8.3% (0.7)	8.8% (0.7)
75+	86.0% (1.0)	0.9% (0.3)	3.6% (0.5)	4.6% (0.6)	4.9% (0.6)

These data seem to indicate that while the LTPA exercisers are a small proportion of the two age categories' population, they undertake vigorous activity on multiple days in a week: the median number of days of LTPA for "doers" is 3-4 d w^{-1}.

It should be noted that national data on U.S. PA in the elderly, or for anyone else, have to be used with caution. In one analysis of PA prevalence contained in three different National Center for Health Statistics (affiliated with CDC) surveys with random-probability designs, there was a ten-fold difference for essentially the same time period in the national estimates for a specific cohort (Slater et al., 1987). Perhaps the U.S. data

have improved in consistency since then, but there are quite profound differences in PA estimates seen in the data reproduced above also.

As expected, a retrospective study of 127 elderly people >65 y wearing an accelerometer found that seasonal and daily weather variations in the amount of activity counts are positively correlated with daily maximum temperature, sunshine, and day length (Sumukadas et al., 2009). Other weather variables were tested (precipitation and wind speed), but those associations with PA were not statistically significant.

Washburn et al. (1990) placed an accelerometer on elderly people (23 males aged 72.9 ± 3.9 y and 22 females aged 72.9 ± 6.5 y) for 3 consecutive weekdays. The percent of time spent by the subjects in 3 general PA categories was:

	Females	Males
Lying & "sitting around"	50.5 ± 10.7	53.9 ± 14.9
Standing, performing light work	34.7 ± 12.8	26.8 ± 12.6
Walking, undertaking sports/rec. activities	9.9 ± 4.5	14.4 ± 9.1

Consistent with the time use data measured in studies reviewed by Washburn et al. (1990), elderly females were more active overall than males but not for vigorous PA. The difference between the time spent in the last category—walking etc.—was the only statistically significant gender difference (Washburn et al., 1990).

Most of the data reviewed above and in the next Section is cross-sectional. There are very few studies of PA participation in the same person over time. One longitudinal study in Germany found that sports participation and exercise drops off with age much slower than indicated in a parallel cross-sectional elderly study (Breuer & Wicker, 2009). This is caused by the mixing together doers and non-doers in cross-sectional studies, which "balance out" individual trends, especially for those elderly individuals who purposively exercise *more* in retirement than when working. The modeling of individuals in APEX and SHEDS by assigning them to "lifestyle" groups using the PAI index from CHAD, is used to minimize the mixing of physical activity doers and non-doers. If better longitudinal data on PA become available, we could do a more rigorous job of focusing on truly active individuals, who are expected to receive a larger intake dose rate than sedentary people. While their overall better fitness level might protect them better against xenobiotic "assaults" from an exposure, the underlying etiology of effects are better characterized when lifestyle factors in exposed individuals are explicitly considered, everything else being equal.

5.C Specific estimates of physical activity

Gauthier & Smeeding (2000 & 2001) provide PA data for two U.S. age groups (65-74 y and 75+y) over a 28 y time period (1965, 1975, 1985, and 1993). The sampling size,

"frame," and sampling approaches varied, so direct comparisons among the years are speculative. Sample sizes increased monotonically over the years for both genders and age categories (9→298 and 13→510 for 65-74 y old males and females, respectively). There were no 75+ people in the 1965 sample, and its sample size increased monotonically after that (29→172 for males and 65→349 for females). Even so, there is a remarkable amount of similarity among the 4 sampling periods. The only category of interest to us in this study probably is "sports & fitness." There seems to be a trend in time spent in this activity in males 65-74, from 0.1 h/d in 1975 to 0.7 h/d in 1993. For males 75+, this time varied from 0.1 h/d in 1975 to 0.3-0.4 h/d in the more recent time periods (Gauthier & Smeeding, 2001; Table 2). There did not seem to be a trend in undertaking sports & fitness for females aged 65-74, varying between 0.1-0.3 h/d for the four time points. Neither was there a trend for females aged 75+: the time in this category varied between 0.0-0.2 h/d over the years (Gauthier & Smeeding, 2001).

Iso-Ahola et al. (1994) of the University of Maryland evaluated changes that take place among the **types** of activities undertaken by the elderly aged 64 y or older. They evaluated, among other things, the numbers of people starting/ceasing/maintaining specific activities as they aged. They calculated a "replacement rate in percent for the activities: a negative rate indicates that the elderly ceased an activity faster than others in the group adopted it. The replacement rate was -4% for exercise-oriented activities, -26% for outdoor recreation, and -82% for team sports (Iso-Ahola et al., 1994). There were large increases in the replacement rate for hobbies and home-based activities: board games, TV viewing, listening to radio and/or music, reading books, etc

Katz & Morris (2007) provide selected time/participation rate data for 375 "mostly" elderly women who had rheumatoid arthritis. Their sample included women who could have been as young as 38 (mean=60 y, SD=13.2) so we do not review their information here. Over 80% of their sample spent less than 60 min/d in physical recreation—and 31% had no time in that activity—so it was a rather sedentary group.

Roberts (1995) conducted a dietary study of sedentary older males (n=18; 68.0 ± 6.4 y), and asked them to keep a diary on how many minutes/day they spent doing "strenuous" physical activity and activity requiring 5+ METS. Details were not provided on exactly how these levels were defined. The sample indicated that they spent 29.1± 35.6 min d^{-1} in strenuous activity and 4.3 ± 7.6 min d^{-1} in 5+ METS activities (Roberts, 1995). Note that the COV for both activity metrics is >1.0.

Useful quantitative information found regarding elderly PA is presented in Table 5-1. It is a scanty database, especially given the number of articles that are published every year on the subject, most of which—as mentioned above—is based on questionnaire or other subjective information.

Table 5-1. Physical activity estimates for the elderly.

Age (Mean ± SD)	G	Ethic Group	Health Status	Exercise Time by Level (h / week) MPA	MVPA	Vigor.	Citation	Comments
57.1 ± 4.3	F	Mixed	Normal	5.0 ± 6.7		0.6± 2.0	Young 1994	n=161; 7-Day recall
56.2 ± 4.1	M	Mixed	Normal	5.7 ± 6.7		0.7± 1.8	Young 1994	n=196; 7-Day recall
68.4 ± 9.4	B	Mixed	NS		2.5± 3.9		Wilcox 2006	n=538; survey
71.3 ± 8.4	B	NS	NS		9.3± 5.4		Parker 2008 JAPA	n=84; accelerometer
65-74 (1975)	F	NS	NS	0.7 ?			Gauthier & Smeeding 2000	n=134; survey: see note
65-74 (1985)	F	NS	NS	2.1 ?			Gauthier & Smeeding 2000	n=227; survey: see note
65-74 (1993)	F	NS	NS	1.4 ?			Gauthier & Smeeding 2000	n=510; survey: see note
75+	F	NS	NS	0.0 ?			Gauthier & Smeeding 2000	n=65; survey: see note
75+	F	NS	NS	1.4 ?			Gauthier & Smeeding 2000	n=114; survey: see note
75+	F	NS	NS	0.7 ?			Gauthier & Smeeding 2000	n=349; survey: see note
65-74 (1975)	M	NS	NS	0.7 ?			Gauthier & Smeeding 2000	n=81; survey: see note
65-74 (1985)	M	NS	NS	2.8 ?			Gauthier & Smeeding 2000	n=173; survey: see note
65-74 (1993)	M	NS	NS	4.9 ?			Gauthier & Smeeding 2000	n=298; survey: see note
75+	M	NS	NS	0.7 ?			Gauthier & Smeeding 2000	n=29; survey: see note
75+	M	NS	NS	2.8 ?			Gauthier & Smeeding 2000	n=87; survey: see note
75+	M	NS	NS	2.1 ?			Gauthier & Smeeding 2000	n=172; survey: see note
				Percent: Inactive	Mod Act	Very Act		
73.5 ± NS	M	Mixed	Pros	27	41	32	Cerhan 1997	n=71: recall; diagnosed prostrate cancer
73.5 ± NS	M	Mixed	NS	36	39	24	Cerhan 1997	n=979: recall; no known prostrate cancer
				Daily Time in Exercise (h / d) None	>0 - ≤ 2	> 2		

65 - 74	F	White	NS	36			Kaminoto in Shepard 2002	BRFSS: 1994-1996; "no LTPA last month"
65 - 74	F	Black	NS	53			Kaminoto in Shepard 2002	BRFSS: 1994-1996; "no LTPA last month"
60.0 ± 13.2	F	Mixed	RA	30.6	64.2	5.2	Katz & Morris 2007	n=375: recall; diagnosed RA
76.2 ± NS	B	Mixed	NS	65			Lawton 1986	n=525; recall; doers (35%) mean=13.8 h/w
				Percent Reporting Participation in "Sports, Exercise, & Recreation"				
65+	F	Mixed	NS	15			Russell 2007	n=491; ATUS recall; doer mean=69 m/d
65+	M	Mixed	NS	21.3			Russell 2007	n=479: ATUS recall; doer mean=104 m/d

Abbreviations

Act: Active
AJPH: American Journal of Public Health
B: Both genders
F: Females
IJAHD: International Journal of Aging and Human Development
JAPA: Journal of Aging & Physical Activity
LTPA: Leisure time physical activity
M: Males
MC: Medical Care
MENH: Medicine Exercise Nutrition Health
Mod.: Moderate exercise level; moderately
MVPA: Moderate and vigorous physical activity
n: Number of subjects (sample size)
NS: Not specified
Pros: Prostrate cancer cases
RA: Rheumatoid arthritis cases
Rheum.: Rheumatology
SD: Standard deviation
Vigor.: Vigorous exercise level
?: Unknown

Note:

1: Time in "sports & fitness"= "active sport" & "walking"

Pedometers are becoming an ever-increasing objective PA measure of choice because they are much cheaper than accelerometers to acquire and operate (Harris et al., 2009a; Schneider et al., 2003, 2004). Pedometer step-counts generally decrease with age, although this relationship is moderated by general health conditions, disability, BMI, and exercise "efficiency" (Harris et al., 2009b; Tudor-Locke et al., 2009a,b). While there is a *general* agreement between pedometer and accelerometer estimates of the amount of physical activity, particularly walking, undertaken by an elderly population, there is a lot of variability in pedometer outputs over a 24-h period when the same subject wears multiple units. Compared with a "criterion" pedometer (the Yamax Digi-Walker SW-200), some pedometers overestimated the number of steps by 45% while others underestimated it by 25% (Schneider et al., 2004). Accuracy can be a problem, therefore. On the other hand, intra-instrument reliability (Cronbach's $\alpha > 0.80$) of most instruments is good (Schneider et al., 2003).

Pedometers, when compared to other objective measures of PA—even the criterion pedometer--*usually* under-estimate the number of steps taken in the elderly by a considerable percent. In a study of a Yamax pedometer in nursing home (NH) and community-dwelling (CD) seniors, mostly females in their 70's (NH=79.4 ± 8.2 y; CD=70.6 ± 5.5), steps were *undercounted* by 25-74% at a slow pace, 13-38% at a moderate pace, and 7-46% at a fast pace (Cyarto et al., 2004). At all three paces for the CD cohort, the Yamax pedometer was considered to be inaccurate for quantifying *total* physical activity in the elderly (Cyarto et al., 2004), but could be used for estimating step counts in that group. Thus, step counts are not an accurate measure of total PA in the elderly, and pedometer data must be used with caution. .

A study in Oregon of five-day pedometer counts found that females aged 60-69 y took 3,888 ± 2,572 steps per day on average (n=98), and older females took only slightly fewer steps: 3,773 ± 3,051 (n=53). There was no statistically significant difference in steps taken per day over the 5 days, although there was a significant difference between weekdays and weekends (Stryker et al., 2007, but this last analysis was done using the entire sample of 270 women aged 40 y and older, so it may not be accurate for the elderly cohorts). Note that the step-count COV's for the two age groups is relatively large and it *increases* for the older group compared to the younger one (66.2% to 80.9%).

Secondary data on observed steps counts in the U.S. elderly is provided by Tudor-Locke et al. (2009a). It is reproduced here as Table 5-2. The type of pedometer used in each study is not provided in the article, so the interested reader will have to obtain the original citation for that datum. The authors indicate that there is a "clear decline" in age-stratified steps, but study-specific age groupings were broad and did not allow them to compare results qualitatively. There also was a very broad range of steps in the healthy older adults. Their range of PA behaviors was as high as 9,000 steps/day (Tudor-Locke et al., 2009a). In general, step counts in the elderly are considerably less than those in younger adults. Bassett Jr. and Strath (2002) reviewed the pedometer literature and provide data from one non-US study that indicated that the mean number of steps/day declined from 11,900 in males aged 25-35 to 6,700 in males aged 65-74. The

corresponding estimate for females of the same age brackets was 9,300 down to 7,300. The values seen in Table 5-2 for US citizens are considerably lower than those estimates.

Table 5-2. Observed steps/day pedometer counts in the U.S. elderly

Age Range (y)	Mean Age (y)	Sample Size (n)	No. of Days Obs.	Steps/Day Mean	SD	Comment	Reference
60+		29	7	5143	2459	Gender not given	Payn et al. 2008
< 65			7	5314	2316	See note	Croteau et al. 2005
50-75	60.9	93	14	6813	2955	Postmenopausal	Krumm et al. 2006
60-75	64.1	26	?	4027	2515	Females	Jensen et al. 2004
65+		45	7	3766	2805	64% Female	Tudor-Locke 2009b
	65.6	82	7	5481	3629	57% Female	Yamakawa 2004
	68.4	47	7	8088	2941	Females	Woolf et al. 2008
65-69			7	5085	4794	See note	Croteau et al 2005
	71.3	84	7	5233	2982	67% Female	Parker et al. 2008
	72.3	214	7	3536	2281	71% Female	Swartz et al. 2007
	72.4	150	7	3912	2757	Gender not given	Strath et al. 2007
70-74			7	3810	2444	See note	Croteau et al. 2005
	74.0	89	7	4728	3641	67% Female	Rowe et al. 2007
	74.2	149	7	5285		Females/median	King et al. 2003
75+		590	7	2895	2170	84% Female	Fitzpatrick et al. 2008
	77.0	46	7	3536	2281	89% Female	Sarkisian et al. 2007
75-79			7	3653	1388	See note	Croteau et al. 2005
80-84			7	2688	983	See note	Croteau et al. 2005
	83.7	28	6	9982	2925	75% Female	Cavanaugh et al. 2007
85+			7	2015	1538	See note	Croteau et al. 2005

Source: Tudor-Locke et al. (2009a). *Inter. J. Behav. Nutr. Phys. Act.*:59 doi:10.1186/1479-5868-6-59
See it for the full citations since they were not checked for this report and are not in the references.

Note The sample size per age category is not provided. The overall sample=76 (87% female).
The age range for the entire sample is 60-90. Mean step counts for everyone=4041(2824).

Step count data from other countries indicate that the U.S. elderly are less active than those in other "developed" areas. For example, a Swiss study found that females aged 65-74 took on average 7,300 ± 3,300 steps/day and males of the same age had 6,700 ± 3,000 steps/day (Sequira et al., 1995). Comparable data are available for a number of other countries, but are not reviewed here.

It should be noted that there are seasonal variations in PA for the elderly as well as for everyone else (Shephard & Aoyagi, 2009). However, there is very little quantitative information collected and published on seasonal differences in physical activities, except those that are highly "seasonally-dependent," such as skiing, ice skating, and (sometimes) outdoor sport participation, golf, etc. Exposure assessments done for specific seasons should take the differential participation rates of activities into account, but obtaining

data to do so will be difficult. The CHAD database, being calendar-day specific can help in this respect, but explicit season-of-the-year analyses of CHAD like those contained in Graham & McCurdy (2004) should be undertaken to see if additional seasonal differences for elderly PA can be discovered in CHAD.

6. Health Considerations in Older Adults

Abstract

Topic: This chapter discusses the wide variety of health issues encountered by the elderly.
Issue /Problem Statement: Both normal and pathological health changes in the aging population have the potential to impact exposure estimates.
Data Available: This topic is extremely data-rich.
Research Needs: At this point in time, very little health information has been systematically included in EPA's exposure models. This is a large potential area of research. The models should be refined to consider the changes in both physiology and time-location-activity patterns that result from health impairments.

6.A Impairment, functional limitations, and disability

Depending upon the pollutant, some of the Agency's NAAQS reviews have focused on population subgroups with pre-existing diseases or activity limitations. Examples are the O3 NAAQS review that evaluated exposures to (among other subgroups), asthmatic children, the SO2 review that focused on exercising asthmatic adults, and the CO NAAQS assessment that estimated exposures to adults with cardiovascular disease (particularly angina). In all three examples, intake dose rate considerations were of paramount concern. To date, however, neither OAQPS or NERL have undertaken an exposure modeling assessment of elderly individuals with impairments, functional limitations, or disabilities that would limit their human activity patterns (and, therefore, affect their exposures to environmental contaminants). We explore these issues in this section, with emphasis on how an exposure assessment might be structured to account for health concerns that limit activity in older adults.

There are many measures of impairment, functional limitations (which include "frailty"), and disability in the literature, and it is difficult to clearly distinguish among them for our purposes (Guccione et al., 1994; Jette, 2006; Stuck et al., 1999). There "is no consensus about how to define these concepts or which are the best health or function indicators for population surveys" [of disability] (Parker & Thorslund, 2007; p. 151). The language of "disablement" (sic) is in a state of flux, and has been since the early 1990's (Jette, 2006). That is because there are both medical and social components of disability, and each discipline has its own concepts and terminology.

For exposition purposes, we make the following preliminary distinctions among chronic medical conditions, functional limitations, and disability; they follow Boult et al. (1994), but also include information from Guralnik & Simonsick (1993), Jette (2006), and the series of articles by Newman et al (2003-2006). Having two or more of these conditions is called a co-morbidity[1].

[1] See Appendix for a pilot examination of co-morbidity delineating the probability of having (1) arthritis and another medical condition or (2) arthritis and experiencing an active lifestyle.

Chronic medical conditions

Arthritis and osteoporosis
Cancer
Cerebro-vascular disease
Chronic pain (generalized and pervasive)
Coronary disease (MI, CVD, angina, stroke)
Diabetes[2]
Hypertension
Neurodegenerative disease (Alzheimer's, dementia, Parkinson's)
Obesity
Pulmonary disease/respiratory problems (COPD, asthma, emphysema)

Chronic medical conditions are also known as "active pathology" and involve the disruption of normal cellular processes and/or homeostatic efforts of the organism to regain a "normal" state. Chronic impacts can also be due to normal cellular senescence, which is defined to be an "active, genetically programmed process that responds to an inductive signal: in this case, perhaps telomere shortening" (Sedivy, 1998).

Impairment is used to describe a loss or abnormality at the tissue, organ, or whole-body system level. Active pathology usually causes an impairment, but not all impairments are associated with an active pathology (Jette, 2006).

A functional limitation is a restriction in activities undertaken by a person. A disability, on the other hand, is a physical or mental limitation in a societal context (Jette, 2006). It is "the gap between a person's intrinsic capabilities and demands created by the social and physical environment" (Jette, 2006). Two people with the same medical condition may have widely varying limitations and/or disabilities, depending upon the individuals' lifestyle behaviors, personal attitudes, and social context (Jette, 2006).

Functional limitations / disability

Activities of Daily Living (ADL)
Instrumental ADL (IADL)
Discretionary physical activity limitations (exercise)
Leisure-time and social restraints and limitations[3]
Limitations on occupational and/or other role activities

A number of these concepts have been incorporated into the World Health Organization's *International Classification of Functioning, Disability and Health* (ICF) framework. For example, it is recognized that dementia is a major cause of functional limitations and disability in the elderly (Agüero-Torres et al, 1998), and that condition will be very difficult to model in an EPA exposure assessment due to lack of *identified* time-use information for people with dementia. One limitation of the current CHAD database is that activity patterns that have been collected from older adults may include some from

[2] This probably affects physiology and metabolism rather than exposures *per se*.
[3] Verghese et al. (2003) lists a number of specific leisure and physical activities that may be considered representative of elderly interests. Most are sedentary indoor activities, but a few are outdoor activities, such as walking, bicycling, and playing team games. Others are quite (relatively) energetic but probably occur indoors: dancing, playing a musical instrument, doing housework, climbing stairs, participating in group exercise, and swimming.

individuals with dementia, but these are not identified since that condition was not included in the survey questionnaire.

There is a "feedback loop" between activity, especially physical activity, and dementia; more active people have less prevalence of dementia and Alzheimer's (Morey et al., 1998; Yaffe et al., 2001). See Section 5.A on the benefits of physical activity in the elderly.

From an exposure perspective, chronic health conditions may affect the type of activities undertaken, where they occur, and certain physiological parameters of the people so afflicted (Jones & Killian, 2000). Thus, chronic health conditions would affect both exposures and intake/uptake dose rates in an exposure modeling effort. One potential way to proceed would be to alter person-specific activity information in CHAD diaries to mimic the impact of disability on individual activity patterns. The following logic paradigm of chronic medical conditions / impairment / limitations that might be used for altering activity data in an exposure model (Figure 6-1) is based upon Boult et al. (1994). See Johnson & Wolinsky (1993) for an alternative conceptual model. The paradigm proceeds from health conditions to curtailed activities.

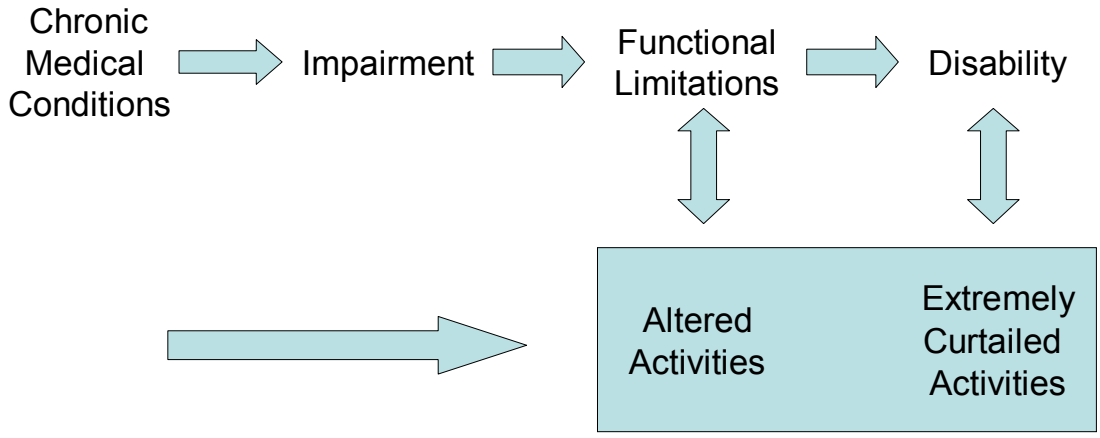


Figure 6-1. Conceptual model for modifying activity pattern data based on assessment of functional limitations and disabilities.

To more fully develop this model, it will be necessary to define and understand what is meant by "altered" and "extremely curtailed" activities. This is difficult to do because the literature often focuses solely upon very basic human activities to delineate functional limitations and disability, and these generally are considered to be "personal care" (PC) activities in CHAD and other exposure-oriented databases. PC activities are marginalized in most exposure assessments, ignoring many disparate actions subsumed under that category (e.g., sleeping, dressing, showering and bathing, putting on makeup,

and sexual activity). Thus, there is lack of specificity in the exposure modeling databases vis-à-vis the impairment and disability paradigm.

Northwestern University has undertaken a number of studies to estimate how gender and ethnicity affect disability prevalence rates (Dunlop, et al., 1997, 2002, 2007). The data come from the Longitudinal Study of Aging (LSA) and the Health and Retirement Study (HRS). An analysis of 6-year change in disability in the LSA elderly (n=1,644 ♀, whose average age at baseline = 77.3 y [range=70-99], and 1,133 ♂, whose average age was 76.9 y in the beginning [range=70-96]), found the following *increased* proportion of people who could *not* perform the following functions:

Function	Females	Males
Walking	38.2%	33.5%
Bathing	29.9%	29.7%
Transferring[4]	23.0%	18.8%
Dressing	14.1%	12.7%
Toileting	11.5%	9.1%
Feeding	8.2%	6.3%

Perhaps a better way to depict disability in older adults is to provide the median age and interquartile [IQ] range) for the *onset* of limitation in ADL activities. This is done in Dunlop et al. (1997). The onset ages are:

Functional Limitations	Median Percentage of ADL Onset & IQ Range for Females	Median Percentage of ADL Onset & IQ Range for Males
Walking	83.7 (75.6-90.0) %	85.1 (77.2-92.6) %
Bathing	86.3 (80.0-91.7) %	87.9 (81.1-93.9) %
Transferring	89.4 (81.1-96.4) %	91.9 (83.2-96.6) %
Dressing	91.7 (85.3-99.6) %	92.7 (85.7-98.3) %
Toileting	91.0 (86.8-100.1) %	96.2 (87.2-98.2) %
Feeding	99.3 (91.2-102.4) %	102.3 (92.5-104.6)%

Dunlop et al. (2002) provides data on the prevalence of functional limitations for many chronic conditions in adults aged approximately 76 y grouped by age and ethnicity (black & white). While there are some ethnic differences, in general almost all of the subjects had at least one chronic condition at the (baseline) start of the study: between 86.7-90.2% for females and 82.1-83.2% for males. The most prevalent conditions after arthritis are: cardiovascular disease (especially hypertension), about 53%; vision impairment, about 17%; hearing impairment, about 16%; followed by cancer, obesity, diabetes, incontinence, and osteoporosis, in that order (Dunlop et al., 2002). The authors state that current moderate functional limitations are the strongest predictor of future severe functional limitations, which seems logical.

[4] Getting in/out of a bed; getting up from a chair.

Dunlop et al. (2007) provide similar data from the 1998 HRS survey for 65+ y old adults. Arthritis prevalence rates are discussed in the Appendix; the second-highest chronic condition is hypertension, with a large and significant difference between blacks (61.6%) and the other ethnicities evaluated (Hispanics and whites, both in the 45-46% range). These conditions are followed by heart disease and diabetes, varying among the various ethnic groups (Dunlop et al., 2007). The authors provide prevalence rates for functional limitations, both physical functions (prevalence rates vary from 26% for whites to 44% for Hispanics who were interviewed in Spanish rather than English [31%]) and IADL disability (6% for whites to 15% for Hispanics interviewed in Spanish). Some of these disabilities likely affected time/activity patterns and thus exposures.

One of the most often used working definitions of disability in the elderly is "functional limitation": a "limitation in one or more major life activities" (Heath & Fentem, 1997). The 1992 National Health Interview Survey (NHIS-92) found that while 15% of adults are disabled, the percentage of disabled increases greatly with age. The percent of older adults with one or more activity limitation is (approximately):

Age Range	% Disabled
65 - 69	36
70 - 74	32
75 – 84	42
85+	56

In addition, the elderly >70 y old have two disabling conditions on average (Heath & Fentem, 1997). Co-morbidity is a major problem in the elderly and obtaining reliable population estimates of the numbers of persons with one or more functional limitations is difficult. An important data gap in EPA's understanding is the number and characterization of population subgroups with co-morbidities and how these affect activity patterns and/or intake dose rates. As a pilot investigation, we attempt to define the relative percentages of older adults with arthritis who also have another health or cognitive condition because arthritis is one of the most common health problems among older adults. That attempt is explained in Appendix AP; it is considered to be a preliminary investigation.

A recent estimate regarding limitations on "undertaking usual activities" for persons with one or more chronic conditions is provided in Adams et al. (2009). It contains extensive survey data from the 2008 National Health Interview Survey (NHIS). The proportion of people aged 65-74 y who have one or more limitations is 27 ± 0.8% (mean ± standard error), and for elders aged 75+, it is 43 ± 1% (Adams et al., 2009).

There is reasonable consistency over time in the type and prevalence of functional disability in a Women's Health and Aging Study (WHAS) sample of 108 females aged 65 to over 85 y old. These women completed a weekly symptom survey, and their responses were significantly and positively associated for a period up to 23 weeks. There does not seem to be an age or disability pattern in an analysis of nine [age*disability]

classes (65-74, 75-84, 85+ y times disability in 1,2,3 "domains") (Rathouz et al., 1998). The authors "found substantial evidence for internal validity and test-retest reliability of 20 self-reported measures of functioning" (Rathouz et al., 1998; p. 772). Measures made <12 weeks apart provide redundant information on chronic conditions, but measures made at intervals of 24 weeks or longer begin to show substantial within-subject variability (Rathouz et al., 1998).

It should be recognized that functional limitations can change for the better (Crimmins et al., 2009; Jette, 2006; Parker & Thorslund, 2007 Seidel et al., 2009). In the "Established Populations for Epidemiological Studies of the Elderly (EPESE) study, 18% of those who lost mobility regained it over 4 years. In the NLTCS, 18% of elders with one or more ADL disabilities had no disabilities after two years (Fried & Guralnik, 1997). The overall prevalence of disability in the elderly also is declining by about one percent per year, probably due to improvements in medical technology and healthy behavioral changes (Cutler, 2001). In longitudinal studies of the elderly, both the number of years with disability-free life and life expectancy are increasing over time (Crimmins et al., 2009). While the number of elderly living in a nursing home is increasing in absolute numbers, the relative proportion of people living in one is declining about 0.7% per year (Cutler, 2001). This decline is occurring even in the 85+ y age group.

An interesting and important consideration in understanding health changes in the elderly population is the interplay of mortality and morbidity patterns with demographic change (Parker & Thorsland, 2007). There are 3 alternative explanations with varying degrees of optimism for the future of healthy living in the elderly:

1. "expansion of morbidity": this reflects the medical paradox that as expected life span increases, morbidity increases in the "added" years.
2. "compression of morbidity": decline in morbidity rates are greater than increases in life expectancy, and overall morbidity decreases.
3. "dynamic equilibrium": longer survival results in an increase in morbidity, but medical interventions and improved lifestyle slow the progression of chronic diseases, decreasing the duration of severe disability.

Parker & Thorsland (2007) state that trend studies using disability measures related to impairment and functional limitations often present a skewed picture of the overall health status in the elderly. Thus, it is difficult to obtain a clear picture of morbidity / mortality patterns in the elderly that could serve to put an environmental exposure modeling into perspective. There are many overviews of mortality rates for the elderly in the literature (Crimmins et al., 2009). An interesting one is Rudman (1989) which provides age-specific death rates by disease and disability classes.[5] There are many articles available on the general topic; it is a subject in and of itself.

[5] He also has data on change in ADL rates and change in physiological functions referenced to age 30 by decade of life. The exposition in Rudman (1989) is very clear.

There are numerous articles on what are good predictors of future ADL and IADL limitations in elderly individuals. Current fitness level (generally $VO_{2.MAX}$), anaerobic fitness, amount of physical activity undertaken, cognitive ability (speed of response to certain tasks), and obesity, have all been investigated for their usefulness in *predicting* impairment and disability. For more information on this topic, see: Fuller et al. (1996); Jetté et al. (1990); Lee & Skerrett (2001); Meijer et al. (2001), and Sunman (1991).

A health-related issue that is only indirectly examined in this report is the increasing obesity rates in the elderly (Elia, 2001; Himes, 2000; Sharkey et al., 2006). In Section 2 we addressed some of the physiological *impacts* of obesity, such as the alterations in basal metabolism, fitness levels, maximum oxygen consumption, and maximal ventilation rate (Lee & Skerrett, 2001). In Section 3 we addressed the impact of obesity on activity-specific energy expenditure and total daily energy expenditure. In Section 5 we mentioned the impact of elderly obesity on exercise and physical activity levels. There are little or no data on how obesity affects elderly time use (Section 4) and responses to environmental exposures (Section 7).

6.B Activities of Daily Living (ADL) and Instrumental ADL (IADL)

The gerontology literature uses the ADL and IADL concepts to distinguish between basic self-care activities (ADL) and tasks considered necessary for independent living in the general community (IADL). ADL activities include bathing, dressing, moving from bed to a seat, using the toilet, and eating by one self (Guralink & Simonsick, 1993). These basic activities, and not being able to perform them are the most frequently assessed indicators of physical disability. The list was originally compiled to assess physical capability in a long-term care or rehabilitation setting, but is now widely used in surveys of community-dwelling populations (also sometimes called "free-ranging" people). For additional information, see Guralink & Simonsick (1993), Galasko et al. (2005), Katz (1983), and the series of McAuley articles listed in the References (McAuley et al., 1999, 2004, 2005a,b).

IADL activities include talking on the phone, shopping, food preparation, housekeeping, doing laundry, walking or otherwise being mobile, using transportation, taking medications, and handling finances (Guralink & Simonsick, 1993). While there is consensus in factors comprising ADLs and IADLs, how they are measured varies in the survey instruments used, wording of questions, sampling protocols, etc. Thus, estimates of non-institutionalized people "failing" one or more ADL or IADL vary widely, and it is difficult to ascertain trends in these metrics over time. In the 1980's between 5-8% of people aged 65+ living in the community could not perform all ADLs without assistance (Guralink & Simonsick, 1993). There is a marked difference among areas of the US in the percentage of older adults needing assistance on ADLs, even for the same age groups, and the proportion increases with age. The percentages approximately double between for the 75-84 y "cohort" compared to those aged 65-74 y, and double again in the 85+ y group (Guralink & Simonsick, 1993).

The doubling rate phenomenon applies to at least 3 of the IADLs: preparing meals, shopping, and doing light housework, but only for the 65-74 to 75-84 pair. From 75-84, the percent of the elderly dependent on help for one or more of the 3 IADLs mentioned more than doubles. In fact, the ratio for 85+ is about 3 times that of the 75-84 y group (Guralink & Simonsick, 1993). The number of activities for which help is needed also increases with age, as well as the percentage of people needing help. The age-adjusted mortality rate also increases with the number of ADLs affected (Guralink & Simonsick, 1993).

Adams et al. (2009), mentioned above, also provide estimates of the proportion of elderly having one or more ADL and IADL limitations. Their estimates are:

	ADLs	IADLs (mean ± standard error)
65 – 74	3.4 ± 0.3%	6.9 ± 0.5%
75+	10.0 ± 0.6%	19.2 ± 0.8%

These estimates are somewhat lower than Guralink & Simonsick's (1993) values, but the rate of increase between the two groups is about 3 times, which is somewhat larger than the "doubling time" ratio mentioned there.

There are important exposure implications of the trends in the IADL data, in that they basically alter the time-use patterns of the affected elderly. However, we have no information in CHAD or in any other time-use database that provide explicit information on IADL problems. The American Time Use Survey (ATUS) may be able to address the issue most directly by comparing the **lack** of time spent in certain activities by the elderly vis-à-vis younger cohorts. Hence, the only way to simulate exposures for the elderly with IADL restrictions would be to alter the activity patterns of diaries already collected. There is no study that explicitly provides data on how those activity patterns would change, so there would be a lot of uncertainty with doing so.

It should be noted that there is a major effort underway to develop technologies to monitor elderly movement in the residential environment, including a number of ADL activities. The rationale is that elders with disabilities could remain at home longer if they could be "watched" to see if they were still ambulatory. The 2008 IEEE-EMBS (Engineering in Medicine and Biology Society) conference has a number of articles on using "microtechnology" to monitor basic activities in the elderly, including those having falling problems. See: Bang, et al. (2008): wearable sensors to monitor ADLs, Bas et al. (2008): "fish-eye" camera to assess in-home activity: Lim et al. (2008): "pressure sensors" to recognize different activities; Min et al. (2008): wearable wireless sensors to monitor early-morning activities; Uhrikova et al. (2008): "computer vision" techniques to augment home-based activities tracked by sensors; as well as the more commonly used accelerometers to monitor movement (Guralink, 2008; Narayanan et al. 2008). The above approaches would be closer to those "objective techniques" used to monitor physical activity in the elderly, as mentioned in Section 5. They also could be used to

obtain time-use data in this population, although no proposal to do so has been published to date.

6.C Caregiver time

A relatively new theme in the time use/activity literature is the amount of time spent by the elderly and others on providing care for other older persons. In some cases, the old are taking care of the "old old" (sic). Since this activity probably does not have unique environmental exposure implications, we only mention it is passing. See the following articles for additional time use implications of elder-care: Clipp & Moore (1995), Mancini & Blieszner (1989), Moss et al. (1993), and Russell et al. (2007).

6.D Cognitive issues in the elderly

Another subject that must be only investigated briefly in this report is the decline in cognitive function seen in the elderly, except where it becomes the root cause of functional limitations and physical activity, as discussed in Section 6.B. There is an extensive literature on the origins and impacts of cognitive functioning on chronic health conditions and vice versa, "successful aging," and related subjects. Just a few of them are the series of articles that are part of the *MacArthur Studies of Successful Aging* (Seeman & Chen, 2002; Seeman et al., 1994, 2005).

Dementia, Alzheimer's, and Parkinson's are the more well-known cognitive problems, but less-severe cognitive issues also affect what the elderly can do and often results in the impairment, functional dependence, and disability issues discussed above (Aquero-Torre et al., 1998). There is a strong link between cognitive problems and the ability to function (Galasko et al., 2005).[6] Investigations into this link focus on ADLs and IADLs for the most part, but more general, exposure-related activities of interest would certainly be affected.

There is much intra-individual variability in cognitive function seen in longitudinal studies of the elderly and other age cohorts (Salthouse, 2007). In fact, intra-individual variability in cognitive "scores" are about 50% of the inter-individual variability in the same age/gender cohort (Salthouse et al., 2006). These findings are based on relatively short-term repetitions of cognitive tests, and would be even greater if the time interval between testing would increase. The implications of this variability on exposure assessment in the elderly are unknown at the present time, but if data become available to link cognitive and functional limitations, and these are shown to have an exposure impact, then we would have to devise a means of modifying activity patterns in the

[6] There also is a "feedback loop" between functional limitations and chronic health conditions that affect cognitive performance (and, importantly, depression and other psychological factors). See Samuelsson et al. (2009), Scarmeas et al. (2001) and many of the "unused" citations listed below for more information on this topic.

elderly over time in a stochastic manner (Figure 6.1). These modifications would be marked in older adults with cognitive impairments who are "confined" (voluntarily or involuntarily) to an indoor space with little or no interaction with the ambient environment.[7] If EPA can obtain data sufficient to assign these older adults to a specific location—or a series of locations—modeled exposure to older adults could focus on the temporal pattern of indoor/outdoor relationships and indoor sources. Until then, we can only be aware of the potential impact of cognitive issues on activities, locations, and exposures.

[7] New drug theraphies are being developed that can affect this state of affairs by improving cognition, changing the progression of Alzheimer's, and increasing mobility (Roundtree et al., 2009). Undoubtedly these therapies will proliferate in the future.

7. Exposure Impacts on Older Adults and Their Impact on the Environment

Abstract

Topic: This chapter discusses both environmental exposure impacts on older adults and the impacts of older adults on the environment.

Issue /Problem Statement: Older adults may be more sensitive to exposures, while the increased medical resources required by an aging population may have an environmental inpact.

Data Available: Information available on the exposure impacts on adults and vice-versa is low-to-moderate.

Research Needs: While these topics may have no bearing on research needs for exposure modeling *per se*, the increased sensitivity of the elderly to environmental pollutants is extremely significant in risk assessment. The continued investigation of this sensitivity can be used in conjunction with exposure estimates for the elderly to provide improved estimates of risk.

7.A Introduction

This Section is intended to consider both environmental exposure impacts on older adults and the impacts of older adults on the environment. These "mirror" impacts have to be understood so they can be compared to those in other age cohorts. Environmental impacts on the elderly are extensively discussed in the environmental epidemiological literature, in much more detail than is possible here. See the *sampling* of this literature contained in the bibliography attached to this Section. Much of this material is concerned with exposures to particulate air pollution in the health-compromised elderly. Those with cardiorespiratory limitations are the prime "sensitive" group[8] for both particulate matter (all size fractions) and carbon monoxide (Chen et al., 2004; Delfino et al., 1998; Liao et al, 1999; Puett et al., 2009). NERL has conducted a number of monitoring studies of elders' particulate exposure; see the partial list of papers and EPA reports by Williams et al.

The impacts of the elderly on the environment have received much less attention until recently. EPA and CDC together have provided leadership in this area. The non-physical environmental literature is almost silent on the issue of elderly impacts on non-home or non-institutional environments (except for their impact on the need for more beds, nurses, geriatric facilities, etc.).

7.B Examples of exposure impacts on older adults

Adar et al.(2007a) show that exhaled nitric oxide is increased in 44 elderly subjects aged 62-94 (of mixed ethnicity and both genders) after riding a diesel bus. Nitric oxide is a general marker for pulmonary oxidative stress and inflammation, and is probably most

[8] "Sensitive" is the term used in Section 109 of the Clean Air Act to identify susceptible people.

associated with particulate matter in the diesel exhaust. Other chemicals associated with mobile sources also likely played a role in the effect. For example, another transportation-related air pollutant, ozone, causes oxidative stress in lung cells and is associated with adverse health effects in the elderly (Alexeeff et al., 2008).

Radon is a gas that often reaches high levels inside of residences located in regions with naturally-occurring radon in soil. Since the elderly spend more time at home than most other people, they are thought to be more vulnerable to exposure to this gas than younger adults (Briggs et al., 2003).

There are a few studies on cumulative exposure to pollutants, such as lead that have a long elimination rate time constant where intake doses are sequestered in the body faster than they can be removed. Dose rate is not as important as total accumulative dose over time for these pollutants (Nie et al., 2009; Peters et al, 2009; Weuve et al., 2009). Mercury, asbestos, and some environmental carcinogens may be additional examples of this type of pollutant given the assumption made in EPA's cancer risk assessment procedures for a 70 year exposure period (Samet and Utell, 1991). It will be important to distinguish between cumulative body burden and constant exposure to when accounting for results such as the association of Parkinson's disease with dietary consumption assessment, long-term consumption of pesticides in well water (Gatto et al., 2009).

There is a growing body of literature suggestive that exposures to a wide variety of toxic chemicals in the earliest stages of life—even in the womb and infancy— may initiate neurological changes that ultimately result in Alzheimer's, Parkinson's, and other neurodegenerative diseases (Lau and Rogers, 2005).[9] This "developmental origins of health and disease" hypothesis and was originally based on heart disease and diabetes studies. Some of the toxic exposures that have been implicated include lead, mercury, pesticides, persistent organic compounds, and PCBs (Stein, et al., 2008). Many of these chemicals have cumulative effects. The exposure modeling implications for these types of chemicals probably would affect neonate and infant exposure assessments more than they would an elderly exposure assessment, however.

7.C Impact of older adults on the environment

There was very little in the peer-reviewed literature on this subject at the end of 2009, but EPA raised this as an issue in the development of its Aging Initiative (EPA, 2004). There are a number of power-point presentations about pharmaceuticals used by the elderly and other age groups getting into the environment (e.g., Krewski et al, 2009) that can be accessed on the web, and many of them are available on EPA's "Aging Initiative" website (www.epa.gov/aging/index.htm). EPA, CDC, and the California EPA seem to be the main source of information on "chemicals in the environment." See for instance, Kathy Sykes, "Prudent disposal of unused medications" why it matters to our aging

[9]Other adverse health effects mentioned in the literature are obesity, hypertension, elevated blood lipids, and the "metabolic syndrome."

population" (Sykes, 2009) and "Discarded drugs as environmental contaminants." (Ruhoy & Daughton, 2009). The Agency has studied the problem of unused pharmaceuticals in some depth (US EPA, 2009a) and has proposed effluent guidelines for them (US EPA, 2009b). It would be difficult to try to expand upon this topic since it is new and rapidly changing. The interested reader can access the EPA website provided above, and the accompanying links, for more information on (mostly) the elderly's discarded pharmaceuticals and other chemicals and their impact on the environment, particularly on water body ecosystems (see also Daughton & Ruhoy (2009)).

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Most, if not all, of the literature cited in this report is available from the author as a PDF file, a paper copy, or as a web-site citation.

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APPENDIX. An Example of Available Health and Co-Morbidity Information

AP.A Introduction and explanation of this material

This Appendix primarily is a preliminary evaluation of the literature on the health of older adults focused on two health conditions: arthritis and co-morbidity involving dementia as the "reference" illness. This Appendix is not considered to be a final product, but a first attempt at defining a complex subject. Definitions, concepts, abbreviations, and acronyms used in this Appendix appear as Section AP.5. The data come entirely from U.S. studies except for a few oriented toward physiological relationships, which are universal. There are some references on health effects on the elderly provided in Section AP.6, but they are not exhaustive on the topic.

A quantitative "summary" of how the information reviewed in this Appendix might be used in an exposure assessment follows. It takes the form of recommended joint-probability distributions for assigning "arthritis" and "co-morbidity | dementia" (the | line is to be read at "given": i.e., a conditional probability) to an individual chosen out of 65+ y old individuals included in the CHAD database. Since the data reviewed were not generally disaggregated by gender, the probabilities apply to both females and males. Since it is unlikely that EPA would estimate exposures to residents of a "group home" (of any type), nursing home, or hospital, the probability estimates apply only to the community-dwelling elderly living in a private residence.

While distribution parameters are provided, the way we would do it in practice would be to give the data to a statistician (Bayesian, preferably) and have her/him fit distributions until the best practical fit would be obtained. Therefore, the following information should be considered to be "seed values" for such an analysis. Note that the uniform distribution bounds are smaller than those seen in the literature. Where multiple values were provided in the literature, the lowest and highest estimates were removed and defined to be the range depicted. This range, of course, would be explicitly treated in a statistical distribution-fitting. For the Weibull distribution, the ς is the scale parameter and the β is the shape parameter. A "small" value suggests that its implied variance would be <10% of the mean or scale parameter. The conditional probability estimates developed from this review are:

Arthritis | Dementia (Confined):	65-79	Point estimate (40%)
	80+	Uniform (50%-60%)
Arthritis | Mild Cognitive Problems:	65-74	Uniform (50%-70%)
	75+	Uniform (50%-75%)
Arthritis | Very Active Lifestyle:	65+	Point Estimate (35%)

Arthritis | Unknown Cognitive Cond.:	65-69	Weibull (ς=57%; β=small)
	70-74	Weibull (ς =55%; β=small)
	75-79	Uniform (53%-70%)
	80+	Weibull (ς=50%; β=small)

AP.B Overview of the "population" analysis undertaken

We ultimately are interested in undertaking exposure analyses of the elderly that makes practical distinctions among important factors that result in differential exposures and intake dose rates, changes in metabolism and subsequent adverse health effects, and differential health risks. NERL's focus is on exposure and intake dose rate changes, and that will be the subject of the preliminary work that follows. To better model exposures and intake dose rates requires that we evaluate and understand differences in human activity patterns and ("whole body") physiology[10]. Our models already disaggregate people into age and gender sub-groups, but include other disaggregating factors as well, depending upon the environmental hazard of interest. Examples are exercising asthmatic adults as a susceptible subpopulation group for SO_2 exposures: the elderly with angina as the "sensitive" group of concern for CO exposures; and, exercising children and outdoor workers for O_3 exposures. With respect to the elderly as a general subpopulation group, there long has been concern about their exposures to particulate matter—either with respect to different size fractions or to chemical species absorbed on the particles and aerosols. EPA has not, however, formally evaluated PM exposures to the elderly in its NAAQS-setting process to date.

AP.C Arthritis

Three different types of disorders frequently are subsumed under the term arthritis; osteoarthritis, rheumatoid arthritis, and septic arthritis. Authors on the subject often do not distinguish among the three types, probably because many of their studies use self-reporting by their subjects and they may not know precisely what type of arthritis they have. This probably is the reason for some of the differences in prevalence rates seen below.

[10] Defined to be those physiological parameters that are needed and used (either as an input or as a "pre-input" predictor variable) in NERL's SHEDS-Air and OAQPS's APEX (TRIM-Expos) time-series exposure models. They include basal metabolic rate, oxygen consumption factors (maximum, rest, and reserve), ventilation rate (maximum, rest, and reserve), oral/nasal breathing rate distributions, and activity-specific parameters, including METS, oxygen consumption, (and decreases in same due to fatigue), ventilation, and alveolar ventilation rate. These parameters are dependent, in part, upon anthropogenic considerations that also are needed in the models, including age, gender, "fitness" level (as estimated by an individual's PAI), and BMI. To a lesser extent, predictors also could include race (ethnic group), height, lean body mass, and percent body fat.

AP.C.1 Prevalence rates for arthritis

People with chronic arthritis have problems undertaking many activities, especially those involving movement and dexterity. This is especially true for people with rheumatoid arthritis (Backman, 2006). They engage in fewer types of leisure activities (recreation and hobbies), especially among less-well educated people. Thus, people suffering from this health problem are of interest to us from a population-cohort perspective, in that their "macro-activities" may differ from the rest of the "healthy" aged population and they would be treated as a sub-population group in Agency exposure analyses.

There are numerous estimates of the percentage of the population 65 y old with arthritis. Probably the most definitive is the Center for Disease Control and Prevention (CDC), National Center for Health Statistics (NCHS) presentation of data from the biannual National Health Interview Survey (NHIS). Hereafter these data are just cited as NHIS with the years included denoted by the **last** year of the survey; thus, NHIS 2002 covers the 2001-2002 time period and NHIS 2004 is for the 2003-2004 time period. NHIS 2002 indicates that 31% of elderly males have arthritic symptoms as do 39% of females. NHIS 2004 increases these estimates to 43% and 55%, respectively.
Another source of information on arthritis is the Federal Interagency Forum on Aging-Related Statistics, hereafter cited as FIF. There is no discussion in FIF (2006) of why the estimates increase so dramatically between the two time periods. A number of reasons could be proposed: a slightly older population; different populations sampled; different questions; different criteria, or varying definitions of the chronic condition. The two FIF reports do use different labels for arthritis: "arthritic symptoms" in FIF 2004 versus "arthritis" in FIF 2006.

Other estimates of chronic arthritis found in the literature are listed here in an abbreviated format:

Bean (2004)	CDC: National	70 y: 60%
Dunlop (2002)	LSA	76±6 y black ♀: 71% 76±5 y white ♀: 58% 76±5 y black ♂: 54% 76±5 y white ♂: 42%
Dunlop (2007)	HRS	65 y black: 60% 65 y white: 53% 65 y Hispanic: 45%[11]
Lyketsos (2005)	Cache County	65 y: 54%

[11] These are for Hispanics who were interviewed in Spanish, their native language. The prevalence rate was higher, 53%, for Hispanics who were interviewed in English.

Schmader (1998)	Durham EPESE	>65 y: 69%
Song (2006)	HRS 1998-2000	65y: 57%

Bruce et al. (2005) compare arthritis rates for runners and "healthy" controls in a 14-year longitudinal study of the benefits of aerobic exercise to diminish musculoskeletal pain. The runners were members of the "Fifty-Plus Runners' Association" from across the US (all 50 states; n=492, 83% ; mean age=61.6) and the community controls were from a random sample of subjects enrolled in Stanford University's Lipid Research Clinics Study (n=374, 56% ; mean age=65.1); thus, makeup of the two samples is quite different. The proportion of subjects suffering from arthritis in the runner's group is 35% versus 41% for the community controls. This difference is not statistically significant (using a t-test at α=0.05.

Baseline data from a clinical exercise intervention study provides some comparative arthritis data for relatively low income community-dwelling people who attend two outpatient health clinics for medical care operated by an urban hospital (Clark et al., 2003). The centers are linked to the Regenstrief Medical Records System (RMRS), and this was used as the sampling frame to randomly select older patients at the centers. The researchers used the RMRS data and an interviewer-administered survey to determine each subject's chronic disease state. The people selected who decided to participate were actually less healthy at the baseline than those who did not participate. Participants were aged 63.7 y on average, were 67.5% black, and 22.8% had arthritis (among other chronic diseases). Non-participants were aged 63.1 y on average, were 55.9% black, and 18% had arthritis. These relative arthritis estimates are much lower than the others provided above.

In a paper describing an unusual approach to gathering health and activity data, Clark (1999) describes a focus-group study (8-10 people at a time) that eventually included 771 individuals who were randomly selected from the RMRS system, as was used above. The RMRS data came from seven primary care centers in and around Indianapolis. The study itself used the Regenstrief Physical Activity and Health Survey (RPAHS) as the instrument for gathering data. Gender and ethnic group breakdowns of the Survey-takers are not provided. The percentage of RPAHS respondents > 70 y old with arthritis was 44.1%. Clark compared this estimate to the 1984 National Health Interview Survey, which showed a 55.0% incidence of arthritis in the 70+ population.

Dunlop et al. (2002) report data on changes in functional limitations in the elderly over a six year period using data from the Longitudinal Study of Aging (LSOA). The LSOA is a prospective survey of community-dwelling people 70 y when first interviewed in the 1984 National Health Interview Survey. The proportion of people with arthritis in 1990 who did not have a functional limitation in 1984 is 53.1% (n=4,206; mean age = 76.4 ± 5.3). The age/race breakdown is:

Black, 70.7% (n= 308)
Black, 53.6% (n= 168)
White, 57.9% (n=1,303)

In a review of HRS findings, Feinglass et al. (2005) indicates that 44.1% of elders have arthritis, defined as answering "yes" to questions involving (1) diagnoses of arthritis, rheumatism, bursitis, and tendonitis; and, (2) having pain, stiffness, or swelling *sometimes* in the joints. In those people—whose average age is only 56 y—68% were overweight or obese, and they had about 2 chronic medical conditions total ($\tilde{x}$ = 2.1 ± 1.2).

Another longer-term study of the elderly is reported by Gill & Gahbauer (2005). This paper describes a sample 552 people, 70 y that had no baseline disability in four essential activities of daily living (bathing, dressing, walking inside the house, and getting out of a chair). They were members of the "Participating Events Project," but details as to their location and other project details are not provided. A monthly telephone interview of study participants provided information on new and chronic disability rates, and the paper reports data for those who completed interviews at 54 months after the study began. The median age of the sample by this time was 81.5 y (range: 75-101); 67.2% were female and 89.7% were white. About 46.2% of them had arthritis.

Another under-explained study of community-dwelling people in an unnamed location is reported in Ho et al. (2002). Since the researchers are from the University of South Carolina in Columbia, study subjects probably are located nearby. An interviewer-administrator questionnaire was used to ascertain the participant's physical, vision, cognitive, nutritive, and hearing functioning. Multiple specific health items were included within each category. If a subject had difficulty on half of the items included within any one of these functional categories, they were identified at being "at risk for frailty". The Strawbridge protocol was used in this regard (Strawbridge et al., 1998). Of the 78 participants, 47.4% (37) were identified as being at "high risk" (mean age=74.1 ± 6.1; 100% white), with the remainder (42, 52.6%; mean age=69.8 ±,7.8; 95% white) being labeled as "low risk." About 68.8% of the high risk group had arthritis, as did 73.7% of the low risk group. Analyses of statistically significant differences were not reported for any data presented.

Another prospective cohort study representative of the community-dwelling U.S. population, 70 y is reported in Holroyd Leduc (2004). The study is the "Asset and Health Dynamics Among the Oldest Old" (AHEAD), and it is a supplement to the HRS study. The proportion of 6,506 subjects with self-reported arthritis is a surprisingly low 25%, given ages of the respondents: 40% between 70 and 74 y, 29% aged 75-79 y, and 31%, 80 y. About 63% of the respondents were female and 86% were white.

A study proving both cross-sectional and longitudinal data on arthritis is discussed in Janssen (2006), but few details regarding it are reported; the reader is referred to other papers. The data come from the Cardiovascular Health Study (CDS) sponsored by the National Heart, Lung, and Blood Institute (NHLBI). The cross-sectional (C-S) part of the study included 5,036 people of varying ages, while 3,694 people contributed data to the

longitudinal (L) part (see below). Almost all of the participants were white: 94.7% and 95.1% for the two parts, respectively. "Prevalent arthritis" was self-reported by 50.9% C-S participants and by 44.6% of the L subjects. The age distributions of the two parts are similar:

Ages	C-S Percentages	L Percentages
65-70	42.7%	46.2%
71-76	32.7%	33.0%
83-89	18.2%	16.1%
≥ 90	6.4%	4.7%

Apparently there were no participants between the ages of 77-82. No statistical analyses of the data are provided in Janssen (2006).

A study of residents of a particular continuing-care retirement community, called Air Force Villages, is discussed in Royall et al. (2005). The sample consists of 547 randomly-selected retirees 60 y living in the community (non-institutionalized). The mean age is 77.9 ± 4.9,, with a range of 60-100. About 58% were female. The proportion of residents with arthritis was 61.2%.

An important study of arthritis prevalence from the national perspective is described in Shih et al. (2005). It uses data on people "free of ADL limitations" from the 1998 and 2000 HRS interviews who have self-reported arthritis using this question: "Have you ever had, or has a doctor ever told you, that you have arthritis or rheumatism?," a fairly broad question. The number of HRS respondents who responded "yes" was 3,451, which is 45.6% of the 7,758 HRS participants provided in Song et al. (2006). (The total was not provided in Shih et al., 2005!) A majority of them have one or more physical limitations and do not participate in regular vigorous physical activity. A high proportion has other chronic conditions; see Table AP-1. See the discussion of this study below.

There was a study undertaken somewhere in California (otherwise undefined) entitled "Community Health Activities Model Program for Seniors" (CHAMPS) that ascertained arthritis status information from 249 community-dwelling residents that subsequently participated in an exercise program (Stewart et al., 2001). The mean age of the sample was 74.1 y ± 5.6), with a range of 65-90 y; about 64% of them were female and 92% were white. Almost 59% of the sample had self-reported "arthritis or joint problems."

In a random-digit telephone survey of residents 60 y in two counties in southern New Mexico as part of a 3-year study of the health needs of southwestern US residents, the University of Texas-El Paso asked a number of health-related questions (Tomaka et al., 2006). The total sample size was 755: 72% were white or "Anglo," and 23% were Hispanic. The average age of the sample is 71.1 y, with a range of 60-92 y. Fifty-seven percent of the Hispanic and Caucasian respondents (separately) stated that they had arthritis.

A study of multiple chronic conditions in Seattle elderly provides lower arthritis prevalence rates than most of the studies reviewed here. The data are from the "Adult Changes in Thought" (ACT) study, which is a population-based prospective cohort evaluation conducted by the University of Washington's Alzheimer's Disease Patient Registry. The study population was sampled from Group Health Cooperative members aged 65+ y in the Seattle area from 1994 to 1996 (L. Wang et al., 2002). A total of 2,578 people at baseline did not have dementia; their age breakdown is: 65-69 y: 23%; 70-74 y: 30%; 75-80 y: 24%; 81-84 y: 15%; and 85 y: 8%. Most of the respondents were white: 91%, and 4% were black. The proportion of the sample with arthritis was 26%. and 46%

Wilcox et al. (2006) describe an evaluation of community programs designed to increase physical activity in older adults. Participants in this program could be as young as 50 y, and 35% of the sample was between 50-64 y of age. The average age was 68.4 y ± 9.4) and 80.6% were female. There were two different programs evaluated, but their proportion of participants with self-diagnosed arthritis was not statistically different, so their data are combined. About 61% of the sample had arthritis.

In an intervention study of improving balance among 72 reclusive independent- living center residents, the analysts found that 69.4% of them had arthritis at baseline in the three groups studied (Wolf et al., 1997). (There was not a statistically significant difference among the 3 groups experiencing different intervention approaches, with the range being 62.5-75.0%). The mean age of the sample was 76.9 y (SD: 5.7) and 83.3% were female.

Table AP-1. Comorbidity associated with arthritis without ADL limitations

Source: Shih et al. (2005). "Racial differences in Activities of Daily Living limitation in older adults: a national cohort study." Arch. Phys. Med. Rehab. 86: 1521-1526.

	African-American	Hispanic	White
Percent of sample	10.7	5.1	84.2
Mean age	73.3	73.3	73.8
Percent female	68.3	64.0	61.5
Percentage of people with arthritis having other medical conditions			
Diabetes	23.0	18.8	12.9
Heart disease	70.3	57.9	62.4
Lung disease	7.3	5.9	10.9
Serious illness	74.5	65.0	62.7

A study that provides estimates for **rheumatoid arthritis** (RA), a more severe type of arthritis having a more complex etiology, is Corrada et al. (2006). They report on a longitudinal large-scale population-based study of the elderly in Leisure World, Laguna

Hills California. This is a retirement community and 13,451 people participated in the study for 13 y on average. The age of study participants varied between 44-101 y at entry, with a mean of 73.5 y. Overall, 5.9% of them had rheumatoid arthritis, and this percentage changed only marginally with Body Mass Index (BMI). The prevalence of RA by BMI category was:

Underweight (BMI <18.5):	5.8%
Normal (BMI 18.5-14.9):	5.7%
Overweight (BMI 25-29.9):	6.3%
Obese (BMI>30):	6.4%

AP.C.2 Physical activity difficulties for people with arthritis

A quote from Shih et al. (2005) succinctly places the issue of activity limitations due to arthritis into perspective.

The prevalence of arthritis increases with age, affecting approximately 60% of people 65 years and older [cites MMWR 51: 948-950 (2002)]. Arthritis is also among the principal sources of restricted activity and bed disability days every year [cites Collins Vital Health Stat 10 194: 1-89 (1997)], and a major reason for limitations in activities of daily living (ADL) …..Numerous national population-based studies indicated substantially more activity or functional limitations among minorities compared with white Americans, disproportionate to differences in arthritis prevalence. African and Hispanic minorities with arthritis consistently have higher rates of activity limitations. (p. 1521).

Data from Shih et al. (2005) on limitations follow for people 65 y with arthritis but no ADL limitations at baseline:

Characteristic	African-American	Hispanic	White
Sample size	380	179	2,982
Mean age	73.3	73.3	73.8
Percentage	68.3%	64.0%	61.5%
One+ physical limits	74.5%	65.0%	62.7%
Lack of VPA	64.7%	63.4%	54.4%

VPA is vigorous physical activity; the term “vigorous” is age-adjusted and includes participating in sports, heavy housework, or having a physical laboring job for at least three times a week over the past 12 months.

Additional information, if any, should be evaluated on this issue. We did not have time to undertake any more work on the subject.

AP.D Co-morbidity

AP.D.1 Dementia as the reference health problem

There are a number of studies that provide data on co-morbidity, defined to be multiple health and/or mental conditions, adverse health problems, or disabilities in a single individual. However, their frame of reference or population groups covered are very different. Some studies focus on people with dementia, and provide data on the proportion of people in differing dementia classifications that have one or more chronic health conditions. Two studies of this type are Lyketsos et al. (2005) and Schmader et al. (1998). See Table AP-2.

Their population groups are quite different with respect to ethnic makeup, location of the study, methods of classifying dementia, and residential living arrangements of the subjects. Lyketsos et al. (2005) reports on data from the Cache County, Utah, Study, and its subjects are almost entirely white people, some of whom live in nursing homes. Cognitive classification was done using the Modified Mini-Mental State Exam (MMSE) or the Informant Questionnaire for Cognitive Decline in Elderly (IQCODE). Medical conditions were ascertained using self-reports and the Johns Hopkins' General Medical Health Rating (GMHR) procedure assigned by a geriatric psychiatrist based on direct and nurse (proxy) interviews. Schmader et al. (1998) presents data from community-dwelling individuals in Durham NC that are part of a long-term epidemiological study conducted by Duke University. Dementia status was ascertained using a neuro-psychological battery of tests that included the MMSE. The health data came from information in that paper; the reader is referred to other papers for details. Selected information from the two papers is reproduced in Table AP-2.

In the two studies, dementia classification significantly affected co-morbidity for stroke in both studies, for arthritis in the Durham study (but not in Cache County), and for "serious physical illness" in the Cache County (not reported in Durham). The authors do not specifically define what is included in that term, but it was based on the GMHR procedure.

A study listed on Table AP-2 focuses on elderly Mexican-Americans that are participating in a longitudinal study entitled "Hispanic Established Population for Epidemiological Study of the Elderly" (H-HEPSE) funded by the National Institute on Aging (Raji et al., 2005). The study population comes from five southwestern states and data have been collected over an eight year period (1993-2001). The data depicted come from the baseline: 1993-1994. Cognitive capability is defined using MMSE scale, and disabilities are based on responses to seven items on a modified version of the Katz ADL

scale. Medical conditions were assessed by self-report based upon a doctor's diagnoses of a condition. There are no statistically significant differences in medical conditions (that were evaluated) experienced by the two cognitive-functioning groups except for stroke.

S. Wang et al. (1997) provide dementia-referenced co-morbidity estimates for residents of a large long-term care institution in Massachusetts. The average age of the residents is 86.7 ± 7.1 y. The proportion of residents having heart disease, both the "non-demented independently functioning" and those with dementia, are much greater than the previously mentioned studies. Otherwise the relative co-morbidity estimates are in line with those cited above. The Katz ADL Scale and the MMSE tests were used to classify the residents into the two classes. The residents were evaluated for 3-6 years, as a distinction was made in the paper between people who were admitted with dementia and those who required total care during the period of evaluation, but these two groups were combined into one group for our Table AP-2.

Another study depicted in the Table is Fillenbaum et al. (2005)--like the Schmader et al. (1998) study part of Duke University's long-term community-based study residents in five North Carolina counties. See the above discussion of how dementia was defined. Of the co-morbidity health status indicators, only the percentage of prescription drugs taken was statistically significantly different, with subjects having "incident dementia" taking fewer drugs on average than subjects with no dementia. That observation is consistent with Wang et al. (2006) data, but is inconsistent with the Lyketsos et al. (2005) data.

Estimates of co-morbidity with respect to dementia class are found in Wang et al. (2006). For dementia-free people 65 y, 16% had coronary heart disease and 6% had cerebrovascular disease, compared to 26% and 14%, respectively, for elderly with dementia (both statistically significant at $p<0.001$ using a Wilcoxon rank sum test at $\alpha=0.05$.

Table AP-2. Comorbidity associated with different degrees of dementia (in percentages)

Study citation	Lyketsos et al. 2005			Schmader et al. 1998			Fillenbaum et al. 2005		Raji et al. 2005		Wang et al. 1997	
Cognitive Condition	Normal	CIND	Dementia	Intact	Impaired	Demented	None	Incident Dementia	High	Low	None	Demented
Percent of sample	46.2	32.4	21.4	58.3	22.5	19.2	77.1	22.9	62.9	37.1	24.8	75.2
Mean age	79.3	82.4	83.9	77.3	80.1	83.1	72.3	74.9	71.7	75.0	86.7	86.0
Age SD	6.3	7.5	6.3	5.2	6.7	6.3	6.2	6.4	5.8	7.1	7.1	5.5
Percent female	54.8	53.8	64.4	63.0	67.0	72.0	62.1	62.4	57.1	56.5	69.2	86.0
Percent white	99.4	100.0	99.3	47.0	74.0	61.0	38.3	36.2	0.0	0.0		
People in the dementia categories having other medical conditions												
Mean # of conditions	3.7	4.1	4.1	2.3	2.4	2.1						
# Conditions SD	2.3	2.4	2.5	1.3	1.5	1.3						
Mean # of prescribed meds.	4.5	5.2	6.2				Note1	Note2			4.5	3.0
Pres. Medications SD	3.4	4.4	4.7								2.6	2.1
Percentage of people in the various categories having other medical conditions (if specified)												
Arthritis	56.1	52.4	50.3	70.0	74.0	58.0			37.1	38.8		
Diabetes	13.4	18.2	19.6	19.0	25.0	20.0	20.6	23.4	20.4	21.7		
Hypertension	40.9	41.7	37.1	58.0	55.0	44.0	59.9	52.9				
Heart disease				33.0	38.0	33.0	12.8	10.6	7.2	6.6	MI=84.6	MI=70.9
Stroke				10.0	19.0	26.0	7.2	7.8	3.6	6.1	26.8	39.1
Thyroid disease	21.5	22.8	21.8	13.0	9.0	7.0					26.9	16.5
Lung disease				16.0	9.0	16.0						
Serious physical illness	22.1	28.9	34.5									
Chronic Pain	19.6	23.2	15.9									
High cholesterol	17.3	14.0	12.4									

Notes & abbreviations: CIND = Cognitive impairment but no dementia MI = Myocardial infarction

SD = Standard deviation

Note1: Percentage of sample taking: **0** prescription drugs-24.6; **1-4** drugs-61.3; **5+** drugs-27.2%
Note2: Percentage of sample taking: **0** prescription drugs-38.3; **1-4** drugs-56.0; **5+** drugs-5.7%.

Dementia obviously affects what people do, especially their leisurely activities. We could only uncover one study that looked explicitly at leisure activities in people who eventually developed dementia: Verghese et al. (2003). They classified people as having probable, possible, or mixed vascular dementia using two schemes developed by the Alzheimer's Disease and Related Disorders Association and the Alzheimer's Disease Research Centers of California. The frequency of participation by subjects with dementia was classified as being "frequent" if the person undertook the activity at least several times per week and "rare" otherwise. There was no information presented on the intensity, duration, or actual frequency of the participation rate. The percentage of people with dementia who frequently participated in selected activities[1] that might affect environmental exposures follows.

Playing a musical instrument	3.2%
Dancing	20.2%
Housework	68.5%
Walking	84.7%
Climbing stairs	64.5%
Bicycling	5.6%
Swimming	12.9%
Team games	3.2%
Group exercises	29.0%

I could not found any other paper on this topic.

AP.D.2 Arthritis as the reference health problem

The elderly with arthritis have other chronic conditions that may affect their exposures, physiology, or metabolism, usually at statistically significant higher rates than people without arthritis. Song et al. (2006) provides such data from the HRS; the data that follow comes from the subset of 7,758 people aged 65 who did not have any ADL disability at baseline. In terms of the percent of elderly with arthritis, 15.4% also have diabetes, 26.2% have heart disease, 11.3 % have pulmonary disease, 20.2% are obese, and 7.1% had a stroke. All of these conditions were statistically significant higher than elderly without arthritis using a χ^2 test at an α=0.05 except for stroke (6.5% for elderly without arthritis).

AP.D.3 Alzheimer's disease and dementia

This section relates to AP.4.A, but the focus there was dementia and other health problems. We focus here on Alzheimer's as a type of dementia.

Bennett et al. (1999) provide estimates of the proportion of elderly individuals having Alzheimer's (AZ) in three different longitudinal panel studies, called "cohorts" in the

[1] With respect to having a METS value substantially different than a "sitting" METS score; i.e., a METS of 2.0 or higher.

paper. All three studies used the MMSE test to define Alzheimer's. The proportion of cohorts diagnosed with AZ varies widely among the studies. One cohort is from the Chicago Health and Aging Project (CHAP), a population-based study in a bi-racial community; the average age of its participants is 79.6 ± 7.4), 52% were female, and 51% were African-American. One-third of this cohort had AZ. The second cohort is from the Religious Orders Study (ROS), a longitudinal study of people over 65 who served as clergy (priests, nuns, and brothers) in nine US states. The mean age of this cohort was 76.6 ± 7.0, 60.3% were female, and <1% were African-American; 10.8% had dementia. The final study evaluated was the Chicago-based Rush Alzheimer's Disease Center (RADC) tertiary diagnostic and treatment clinic. The mean age of this cohort was 77.1 ± 6.0, 65.2% were female, 17.5% were African-American; 89.0% of this cohort had AZ. The high percentage for the RADC population is to be expected, since the facility treats AZ patients.

Many elderly patients with Alzheimer's need full-time care that must be provided by some type of institution. (To avoid "double-counting" in our exposure models, these people should be "removed" quantitatively from the US Census data on residences and "placed" into the institutionalized category.) Sloane et al. (2005) undertook a study of people with varying degrees of dementia who already were in two types of institutions for their malady. It was a longitudinal cohort study of 1,252 residents with dementia in 106 "residential care/assisted living" facilities (RC/AL), often known to the public as "group homes," and 40 nursing homes (NH) in four states. Dementia classifications were accomplished using the "Minimum Data Set Cognition Scale" (MDS-COGS) roughly equivalent to the MMSE. Other instruments were used to classification depression, behavioral problems, and social withdrawal. RC/AL units had statistically significant more cases of mild dementia (70.6%) than NH (50.7%; $p<0.001$, but the type of test used is not provided). Conversely, NH had more cases of moderate or severe dementia.

Hospitalization rates for patients staying in either type of facility were not significantly different: 12.6% for RC/AL v. 10.1% for NH, but for those residents of an RC/AL who then transferred from the facility, the hospitalization rate was 29.2%. It is clear that worsening dementia was partially responsible for the hospitalization and subsequent relocation to a higher-level-of-care facility. Between 22-25% of residents of an RC/AL unit will be transferred to a NH per year. In a repeated measures Poisson regression model, the per-year rate in worsening morbidity of residents of either facility who stay within it is 21-24%; for increasing ADL dependency it is 4-6% for people with mild dementia and about 1% for moderate or severe dementia.

AP.E Definitions and concepts used in this Appendix

3MS: Modified MMSE.

ACT: Adult Changes in Thought study: a long-term longitudinal study of aging and dementia in Seattle.

AD: Alzheimer's Disease. Criteria listed in the joint National Institute Of Neurological and Communicative Diseases and the Stroke-Alzheimer's Disease and Relation Disorders Association are used to define it. Other dementias are defined using DSM-IV criteria.

ADL: Activities of Daily Living. There are many versions of this scale, with different items included and different ways of scoring each dimension. Most include the following factors, that often are scored from 0-4, with 0=complete dependency, cannot perform to 4=can perform independently. The scores usually are summed across all the dimensions to obtain the overall rating.

Daily Activity Dimensions
- Engage in social activities
- Household responsibilities
- Personal care
- Meals / feeding
- Incontinence
- Mobility
- Mental Acuity
- Memory
- Cognitive symptoms

AHEAD: Assets and Health Dynamics Among the Oldest Old: a random-probability interview survey of adults in the US (see Wray et al., 2005a,b).

AI/AN: American Indian / Alaska native.

APOE: Apoli-proprotein-E allele (genotype).

Arthritis: Inflammation of the joints and its effects. In its acute form, arthritis is marked by pain, inflammation, redness, and swelling, mostly in the joints. The impact of arthritis is to limit movement. If often involves the breakdown of cartilage surrounding bones of a joint. The rubbing of bone against itself, gives rise to arthritis, generally a chronic condition. There are three principal forms: osteoarthritis, rheumatoid arthritis, and septic arthritis. The most common joint disorder is osteoarthritis, having the symptoms listed above, but sometimes involves a bone spur. The cartilage becomes rough due to wear over the years, leading to the pain, etc. Rheumatoid arthritis affects females more than males, and it is a auto-immune disorder. The connective tissue adjacent to a joint become inflamed, and the immune defense system works to reduce it, but functions improperly so as to thicken joint membranes and eroding cartilage, and if it continues, bones, associated tendons, and ligaments. Bursitis and/or tendonitis is often included as a subset of arthritis or rheumatism (or both). HRS asked two questions related to arthritis: (1) Has a doctor ever told you, or have you ever had, arthritis or rheumatism (bursitis/tendonitis included)?, (2) Do you sometimes have pain, stiffness, or swelling in your joints?

BLSA: Baltimore Long-term Study on Aging (JH).

BMI: Body Mass Index (weight in kg / Height in m**2)

Bronx Aging Study: (See: Verghese et al, 2003) The study uses the following tests to define dementia: Blessed Test (Blessed Information-Memory-Concentration Test); Wechsler Adult Intelligence Scale (verbal and performance IQ); Fuld Object-Memory Evaluation test; Zung depression Scale

Cache County Study (Utah): Described in Lyketsos et al. (2005)

CAD: Coronary Artery Disease.

California Verbal Learning Test (CVLT): A test of verbal-free cued recall: a sensitive test for cognitive deficits associated with abnormal aging (Swan et al, 1998).

CASI: Cognitive Ability Screening Instrument: a screening test for cognitive function using a structured interview.

CC: Cardiac Conditions: Myocardial infarction; congestive heart failure; stroke; HBP; diabetes.

Center for Epidemiological Studies Depression Scales (CES-D). Described in Song et al. (2006).

CHAP: Chicago Health and Aging Project.

CHD: Coronary heart disease

CHF: Congestive heart failure

CHS: Cardiovascular Health Study (Newman et al., 2005).

Chronic bronchitis: Chronic inflammation of bronchi resulting in cough, sputum production, and progressive dyspnea.

Chronic disability: A disability lasting or expected to last at least 90 days according to a protocol that was established by the National Long-Term Care Survey (Gill & Gahbauer, 2006).

CIND: Cognitive Impairment, Non-Dementia

Color Trails Making Test: A test of visual attention and scanning, and graphomotor skills (Swan et al., 1998).

Comorbidity: Multiple health and/or mental conditions, adverse health problems, or disabilities.

COPD: Chronic obstructive pulmonary disease.

CVD: Cerebrovascular disease.

Dementia: A general term that includes Alzheimer's disease, vascular dementia, and "mixed dementia" (see: *Older Adults, 1986*).

Disability: Limitation in performance of socially defined roles and tasks within a sociocultural and physical environment (Vette, 2006).

DSRS: Dementia Severity Rating Scale: An 11 item scale of signs and symptoms associated with dementia (Lyketsos et al., 2005).

Emphysema: A chronic pulmonary disease characterized by loss of lung function due to destruction of alveolar or terminal bronchiole walls with resultant enlargement of air spaces in the lung. The total epithelial surface for gas exchange is reduced.

EPESE: Established Populations for Epidemiological Studies of the Elderly; see Fried & Guralnik, 1997.

ERT: Estrogen Replacement Therapy.

Functional limitation: Limitation in performance at the level of the whole organism or person (Vette, 2006).

General Medical Health Rating (GMHR): used by the Johns Hopkins hospital (Lyketsos et al., 1999).

GMHR: See above.

HABCS: Health, Aging and Body Composition Study (Newman et al. 2003, 2005, 2006)

HBP: High blood pressure.

Health and Retirement Study (HRS): A national probability study of non-institutionalized elderly undertaken by the University of Michigan and sponsored by the National Institute of Aging.

Heart problems: A general term usually including heart attacks, coronary hearth disease (CHD), angina, and congestive heart failure (CHF).

IADL: Instrumental ADL's (Song et al, 2006). IADL's include **physical limitations** (4 tasks using lower and upper extremities: walking several blocks, climbing several flights

of stairs w/o resting, pushing / pulling large objects, and lifting / carrying > 10 lbs); **task limitations** (5 specific tasks: preparing hot meals, going grocery shopping, using a telephone, taking medications, and managing money).

ICD-9: *International Classification of Diseases; version 9*.

ICF: The *International Classification of Functioning, Disability, and Health*; World Health Organization, Switzerland (2001). This supersedes the ICIDH.

ICIDH: The *International Classification of Impairments, Disabilities, and Handicaps;* World Health Organization, Switzerland (1980).

ICL: Institute for Continued Learning.

IFG: Impaired fasting glucose.

IGT: Impaired glucose tolerance.

Impairment: Anatomical, physiological, mental, or emotional abnormalities (ICF definitions: Jette, 2006)

Informant Questionnaire for Cognitive Decline in Elderly (IQCODE): cited in Jorm et al. (2007).

Iowa Screening Battery for Mental Disease: 3 tests assessing time orientation, visuospatial skills, visual memory, and associative word fluency.

IQCODE: See the above.

LOSA: Longitudinal Study on Aging. Part of the National Health Interview Study sponsored by NIH, and evaluated by the National Center for Health Statistics. It basically is a subset of people aged 70 or older in the 1984 baseline period who were re-interviewed at two-year intervals.

LTC: Long Term Care (Facility).

MCI: Mild cognitive impairment.

Metabolic Syndrome: A complex of health conditions having the following symptoms: abdominal adiposity, elevated triglycerides; low HDL-C; HBP; and high fasting blood glucose.

MI: Myocardial infarction.

Mild cognitive impairment: a non-demented elderly person with isolated cognitive and minimal functional impairment (Royall et al., 2005).

MMSE: Mini-Mental State Exam. See also 3MS. A 30-oiunt test including questions on time and place orientation; registration, attention, calculations, recall, language, and visual construction. A score <23 signifies significant cognitive impairment (Swan et al., 1998).

Modified Mini-Mental State Exam (3MS): a MMSE having itself two versions; one for sensory impaired and not impaired individuals.

MVPA: Moderate or vigorous physical activity.

NGT: Normal glucose tolerance (tolerant).

NH: Nursing home.

NHLBI: National Heart, Lung, and Blood Institute.

NHIS: National Health Interview Survey.

NLTCS: National Long Term Care Survey.

NMAPS: New Mexico Aging Process Study.

NMF: No More Falls Program.

Obesity: BMI ≥ 30 kg / m**2.

Overweight: ≥25 but <30 BMI.

PA: Physical activity.

Physical disability: In the HRS/AHEAD study, it is measured by the sum of any difficulty (Y/N; 1/0) on 10 PA /ADL tasks. These include: ADL (transferring, dressing, bathing, toileting, eating), mobility (lower body) activities (walking across a room, walking several blocks, climbing stairs), and strength (upper body) activities (pushing furniture, lifting 10 lbs). It seems very similar to the IADL above.

Pulmonary diseases: Considered to be chronic bronchitis and emphysema.

RADC: Rush Alzheimer's Disease Center.

RC/AL: Residential care with assisted living.

ROS: Religious Orders Study.

RPAHS: Regenstrief Physical Activity and Health Survey.

RVPA: Regular vigorous physical activity, including sports, heavy housework, and physical labor job > 3 times per week (Song et al, 2006).

SPB: Systolic blood pressure.

SPPARCS: Study of the Physical Performance and Related Changes in Sonoman's project (JH).

TIA: Transient ischemic attack.

Underweight: <18.5 BMI.

Wechsler Adult Intelligence Scale: A digit / symbol substitution test (Swan et al., 1998).

Western Collaborative Group Study: longitudinal study of SBP over 30 y. It began in the early 1960's as a prospective cardiovascular epidemiology study at 10 California corporations (Swan et al., 1998).

WHAS II: Women's Health and Aging Study.

AP.F References for this Appendix

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