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Data Sources Available for Modeling Environmental Exposures in Older Adults

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

Office of Research and Development
National Exposure Research Laboratory

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Disclaimer

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Thomas McCurdy

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Abbreviations, Symbols, and Acronyms

♀	Female(s)
♂	Male(s)
±	Used to depict the standard deviation of the mean
μE	Microenvironment—location having a constant C_T for a time period
ACSM	American Council of Sports Medicine
ACT	Adult Changes in Thought (study)
ADL	Activities of daily living
ADT	Average daily traffic (vehicles/day)
AHEAD	Assets and Health Dynamics Study (among the oldest studies)
ANOVA	Analysis of variance
APEX	Air Pollution Exposure Model (OAQPS model)
APM	Annual Performance Measure
AT	Anaerobic threshold (L/min)
ATS	American Travel Survey
ATUS	American Time Use Survey (a yearly BLS survey)
BLS	Bureau of Labor Statistics; U.S. Department of Labor
BLSA	Baltimore Longitudinal Study of Aging
BM	Body Mass ["weight"] (kg)
BMI	Body mass index (BM/HT^2 in kg/m^2)
BMR	Basal metabolic rate (kcal/day)
BRFSS	Behavioral Risk Factor Surveillance Survey
BSA	Body surface area (m^2)
C	Calorie
C	Concentration (various units [e.g., $\mu g/m^3$, ppm])
CARB	California Air Resources Board
CDC	Centers for Disease Control and Prevention
CDS	Child Development Survey
CHAD	Consolidated Human Activity Database (www.epa.gov/chadnet1/)
CHAMPS	Community Health Activities Model Program for Seniors
CHAP	Chicago Health and Aging Project
CO	Carbon monoxide
COPD	Chronic obstructive pulmonary disease
C_{OUT}	Concentration outdoors (various units)
$C_{OUT.h}$	Hourly-specific outdoor concentration (various units)
$C_{OUT.t}$	C_{OUT} for time period [t]
C-S	Cross-sectional
C_t	Concentration for time period [t]
C_T	Concentration for a specified time period T (various units)
D	Dose (various units; moles/min is the most general)
D	Intake dose rate (moles/min)
D&A	Diversity and autocorrelation [approach]
D/E	Dose/effect relationship (individuals)
D_{IN}	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
DLW	Doubly labeled water
D/R	Dose/response relationship (cohorts)
DSM-IV	*Diagnostic and Statistical Manual of Mental Disorders*, Chapter IV. Psychological and Environmental Problems
E	Exposure (various units and averaging times
ECG	Electrocardiogram
EE	Energy expenditure (various units)
EE_a	Activity-specific energy expenditure (kcal/min)
EE_{ai}	EE_a for a particular modeled individual
EFH	EPA's *Exposure Factor's Handbook*
EI	Energy intake
EMBS	Engineering in Medicine and Biology Society
EMRB	Exposure Modeling Research Branch (EPA)
EPA	U.S. Environmental Protection Agency
EPESE	Established Populations for Epidemiological Studies of the Elderly
EPOC	Excess postoxygen consumption
EVR	Equivalent Ventilation Rate (L/BSA; L/m^2 for a specified time period)
FFM	Fat-free mass (kg); equal to LBM
FIF	Federal Interagency Forum on Aging-Related Statistics
GMHR	General Medical Health Rating
HAPEM	Hazardous Air Pollution Exposure Model
HDL	High-density lipoprotein cholesterol
HEASD	Human Exposure and Atmospheric Sciences Division
H-HEPSE	Hispanic version of EPSE
HR	Heart rate (beats/min)
HR_{MAX}	Maximal heart rate (beats/min)
HR_R	Resting heart rate (beats/min)
HR_{RES}	Heart rate reserve [$HR_{MAX} - HR_R$] (beats/min)
HRS	Hours
HT	Height (in centimeters or meters)
IADL	Independent activities of daily living [minimal ADL for independent living]
ICC	Intraclass correlation coefficient
ICF	International Classification of Functioning, Disability, and Health
IQ	Intelligence quotient

IQCODE	Informant Questionnaire for Cognitive Decline in Elderly
IEEE-MBS	International Electrical and Electronic Engineers [a society]-Engineering in Medical and Biological Engineering [a section]
LBM	Lean body mass (kg); equivalent to FFM
LPA	Light physical activity
LSOA	Longitudinal Study of Aging
MDS-COGS	Minimum Data Set-Cognition Scale
ME	Microenvironment
METS	Metabolic equivalents of work (unitless)
$METS_a$	Activity-specific METS (unitless)
$METS_{Max[I]}$	Maximum [achievable] METS
MMSE	Mini-Mental State Exam [often-used measure of cognitive impairment]
MPA	Moderate physical activity
MVPA	Moderate/vigorous physical activity
NCC	National Climatic Center
NCEA	National Center for Environmental Assessment (EPA)
NCHS	National Center for Health Statistics (National Institutes of Health)
NERL	National Exposure Research Laboratory (EPA)
NH	Nursing home
NHANES	National Health and Nutrition Examination Survey
NHEERL	National Health and Environmental Effects Laboratory (EPA)
NHIS	National Health Interview Survey
NHLBI	National Heart, Lung, and Blood Institute
NHTS	National Highway and Transportation Survey
NIA	National Institute on Aging
NICHHD	National Institute of Child Health and Human Development
NLTCS	National Long-Term Care Survey
NO_2	Nitrogen dioxide
NPTS	National Personal Travel Survey
O_2	Oxygen
O_3	Ozone
OAQPS	Office of Air Quality Planning and Standards (EPA)
OAR	Office of Air and Radiation (EPA)
ORD	Office of Research and Development (EPA)
PA	Physical activity
PAEE	Physical activity energy expenditure
PAI	Physical activity index (many alternative units; generally TDEE/BMR)
PAL	Physical activity level
PC	Personal care [activities]
PEFR	Peak expiratory flow rate (L/min)

PM	Particulate matter
$PM_{2.5}$	PM >2.5 μm in average effective diameter
POV	Personally owned vehicle
RADC	Rush Alzheimer's Disease Center
RC/AL	Residential care with assisted living
REE	Resting energy expenditure (kcal/time period)
RER	Respiratory exchange ratio
RMR	Resting metabolic rate [approximately equivalent to BMR]
ROS	Religious Orders Study
RPAHS	Regenstrief Physical Activity and Health Study
RQ	Respiratory quotient [VCO/VO_2, both as volumes] (unitless)
SD	Standard deviation
SE	Standard error
SHEDS	Stochastic Human Exposure and Dose Simulation Model
TDEE	Total daily energy expenditure (generally kcal/day)
TPA	Total physical activity
TRIM	Total Risk Integrated Method
U	Conversion factor used to relate EE to VO_2 (kcal-to-L/min)
VA	Veterans Administration
V_A	Alveolar ventilation rate (L/min or BM-adjusted mL/min-kg)
VCO_2	Carbon dioxide ventilation rate (L/min)
V_D	Dead-space volume (L)
V_E	Ventilation [breathing] rate (L/min or mL/min-kg)
$V_{E.A}$	Activity-specific V_E
$V_{E.Max}$	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)
VMT	Vehicle miles traveled
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)
$VO_{2.Peak}$	Peak (maximum) VO_2
$VO_{2.Reserve}$	Oxygen consumption reserve [$VO_{2.Max}$-$VO_{2.R}$] (L/min or mL/min-kg)
VPA	Vigorous physical activity
VQ	Ventilatory equivalent [V_E/VO_2] (unitless)
V_T	Tidal volume (L)
VT	Ventilatory threshold (L/min)
WHAS	Women's Health and Aging Study
WHO	World Health Organization

Executive Summary

This report, “Data Sources Available for Modeling Environmental Exposures in Older Adults,” focuses on information sources and data available for modeling environmental exposures in the older U.S. population, 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.

In general, this report contains the same type of information found in EPA’s *Exposure Factors Handbook* (e.g., NCEA, 1997a,b) 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 older people. In addition, the data enable scientists to check or evaluate results obtained from the modeling assessments for older adults, such as determining whether the distribution of ventilation (breathing) rates seen in a particulate matter (PM) intake dose rate assessment, for example, is realistic or not. The same is true for their time spent in motor vehicles, outdoors, or indoors. Intra- and interindividual 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 older adult exposure modeling, 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 older people on environmental loadings. The latter category focuses on pharmaceutical discharges into bodies of water. The appendix provides information on developing conditional probabilities for those individuals that have 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 older adults are becoming a larger proportion of the total U.S. population, and more and more societal resources will be directed toward their maintenance.

1. Introduction and Overview

This report focuses on information sources and data available for modeling environmental exposures in U.S. older adults, defined here to be people 60 years and older, with an emphasis on those aged 65 and greater. This subpopulation is increasing rapidly, both in relative and absolute terms (Administration on Aging, 2009), which makes it 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 and Zenick, 2005), supplemented by work directed toward improving risk estimates for older Americans. This is a review of the main topics needed to undertake and evaluate exposure and *intake dose rate* modeling in aging adults, 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 addressed more briefly.

This review reflects the current state of the science regarding exposure modeling in independent-living older adults as of the end of 2009. Thus, older adults who are confined to a nursing home or other institution are mentioned only briefly in this report.[1] This also is true for people 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 older adults 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 for which 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. Because there is a substantial cultural component associated with many of the nonphysiological 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 years. More information is available for subjects whose mean age is >55 years and having a large enough standard deviation so that a considerable portion of the sample would be 60+ years 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+-year-aged individuals; including slightly younger people does not alter the trends or findings of this report but would increase its length substantially.

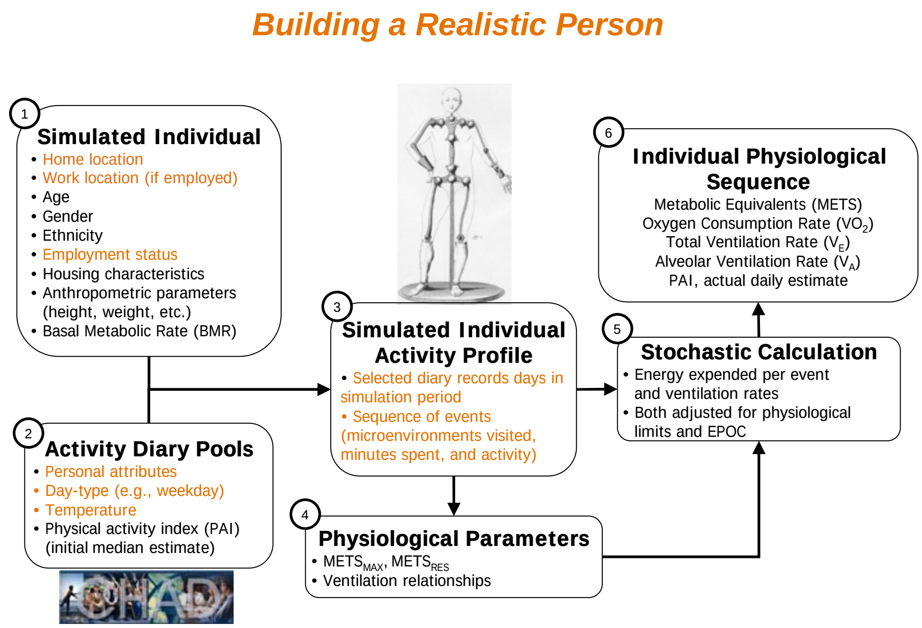
1.A Exposure Modeling Overview and Principles

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,b), along with 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 EPA's Stochastic Human Exposure and Dose Simulation model (Burke et al., 2001; Zartarian et al., 2000), of which there are a series of route-specific versions (dietary/nondietary, pesticides, etc.). It was developed by EPA staff in NERL's Human Exposure and Atmospheric Sciences 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 because 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 EPA'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 (15 in number and described

[1] For elderly residential types not discussed here, see, for example, Eckert and Murrey (1984), Marans et al. (1984), Moos and Lemke (1984), and Pruchno and Rose, 2002). The approximate proportion of the elderly not living in their home or other residence for two age groups is 65 to 74 years = 2.2% to 2.4% ♀ and 2.1% to 3.6% ♂ and 75+ years = 8.9% to 11.7% ♀ and 6.3% to 7.1% ♂ (Czaja, 1990). See the discussions of impairment, functional limitations, and disability for additional information.



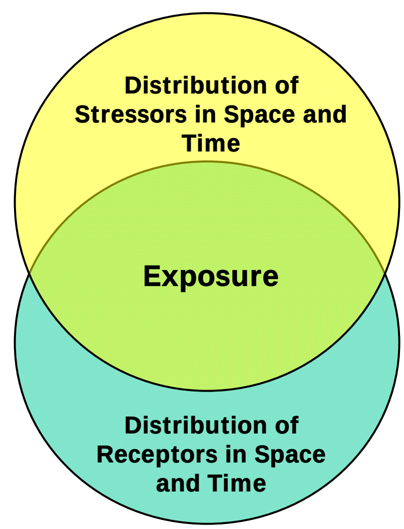
Source: Stephen Graham, OAQPS

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

just below) apply to all groups and not just to older adults.

(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 (D/E) curve to distinguish it from the population-level D/R association. D/E uniqueness results from genetic factors; preexisting disease considerations; age/gender differences in biology, physiology, and 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 older can influence greatly D/E relationships in individuals both directly and indirectly because of physiological changes, immune system challenges, neurological impairment (cognitive decline), and other physical alterations (Hertzog et al., 2008; Jette, 2006; Kiely et al., 2009).

(2) Location is critical to evaluating an exposure to an environmental pollutant (often termed a "stressor") because, by definition, exposure is the "contact between an agent [substance or 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 discussed further in principles 12 and 13.



Source: Adapted from NERL Framework for Exposure Science

Figure 1-2. A Venn diagram of exposure.

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

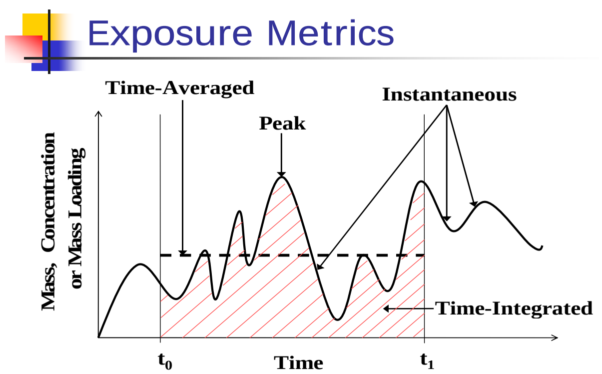
(4) A location having a constant concentration (C_T) for a specified period of time is called a "microenvironment" (μE). Microenvironmental data

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

are crucial inputs to an exposure model (locations and concentrations), and time spent in the various µEs vary greatly with age, gender, and lifestyle. In the APEX and SHEDS models, locational data come from CHAD, whereas µE concentration data are derived from ambient measurement data or route/pathway-specific model algorithms.

(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.



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

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

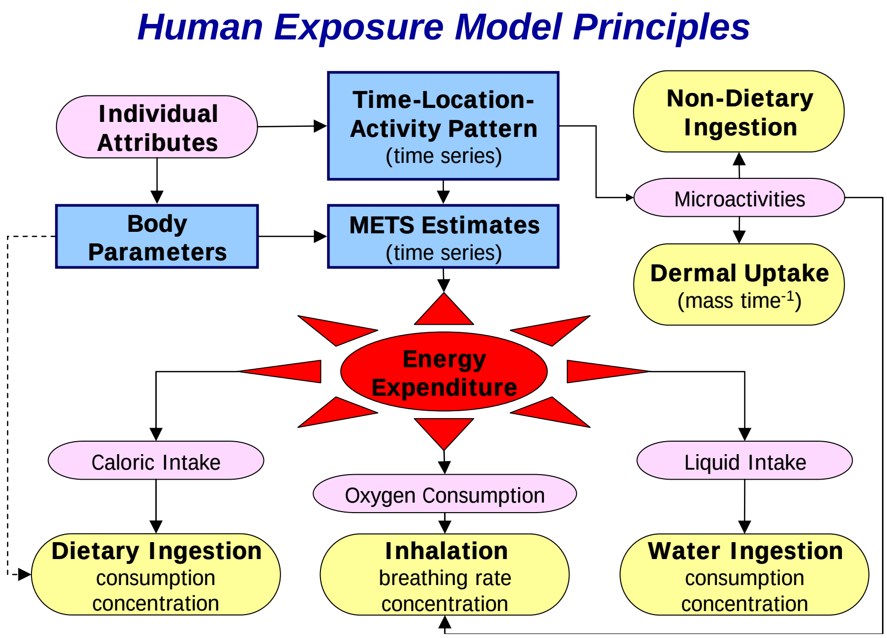
(7) Activity level is the amount of energy expended (EE) by an individual to complete the activity undertaken (expressed in kcal or kJ/min/kg). Other metrics performing the same function were used in the past in EPA's exposure models.[3] Activity level affects how much dose is received given an exposure. Activity levels are correlated over time in an individual, because prior physiological circumstances affect subsequent ones when EE reaches individually specific limits (Isaacs et al., 2008). These limits are determined, in 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 on 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 older individuals is quite different than that in 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 sometimes are used. The magnitude of intake dose rate is affected greatly 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 often is 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) enables 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 (O_3) 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 only can be modeled using an intake dose rate simulation approach that calculates the time series of

[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).



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

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

exposures such as those produced by the APEX and SHEDS models.

(11) Multiple-route intake/uptake dose rates are correlated in an individual because of 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 nondietary ingestion associated with hand-to-mouth or hand-to-surface activity—of concern with respect to environmental exposures of children—are *not* directly associated with bioenergetics but are related instead 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. Microactivity 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 microactivity exposure modeling. For modeling air route exposures to older individuals, we assume that there is no nondietary (or dietary for that matter) ingestion resulting from hand-to-mouth activity in that population. This assumption can be evaluated if data on nondietary mouthing behavior become available for older people.

(12) There are seasonal, day-of-week (or workday/nonworkday), 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 interindividual 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 multiyear exposure modeling (Elgethun et al., 2005, 2007). Tracking is affected greatly by changing physiological and functional limitations and housing pattern changes in the aged. 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, only can be addressed by using a different model and comparing output estimates with measured data. This rarely is done because of resource limitations.

1.B Functional Structure of the APEX Model

How these principles are implemented in the APEX and SHEDS-Air models is shown in Figure 1-5. Those symbols and abbreviations not already described above are defined in the List of Abbreviations, Symbols, and Acronyms. Figure 1-5 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, as well as among different applications of either 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 measured (or modeled) ambient concentration field data, (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 with an alternative control approach, it is called a *standards impact* assessment [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 O_3 NAAQS exposure analyses (U.S. EPA, 2007a,b). Older adults with compromised cardiovascular systems (chronic obstructive pulmonary disease, angina, etc.) likely will be an important subpopulation to consider for modeling exposures in the next 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 usually are 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 for 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, a C_t may be the same as an 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 min used in the sulfur dioxide NAAQS review.

If a person is indoors or inside a motor vehicle, the concentration within that μE depends on a variety of chemical/physical factors, such as 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); and (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 home, work, school, retail establishments, motorways, retail stores, and a "residual" location ("other indoors"). Outdoor locations also are subdivided, but the concentration assigned to them may simply be the ambient concentration estimate noted above. The output of these steps is a

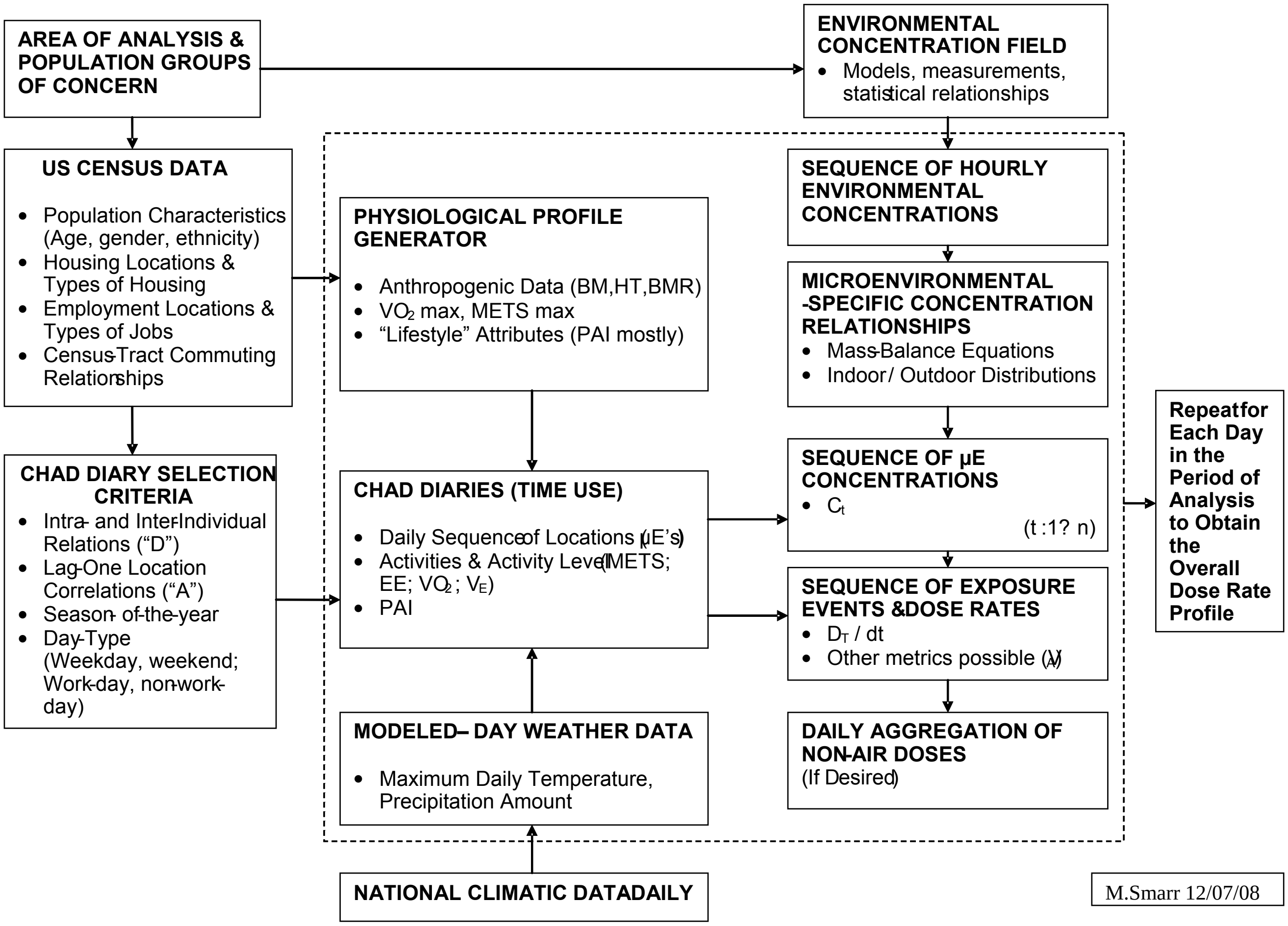


Figure 1-5. APEX/SHEDS exposure simulation process.

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 µEs than the 7 to 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, for which 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 (e.g., "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 µEs, 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 and De Ree, 1993; Harvey, 1993; Nickols and 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 are a major input to EPA's exposure models. The data are used to define how many people are within the modeling domain, along with their age, gender, employment, housing, and commuting characteristics. The proportion of people in each 1-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 United States (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, 2007a,b).

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- to 65-year-old workers of both genders. A single person within that age range is selected randomly, say, a 65-year-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 nonwork 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 locations. 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 to 69 years 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.

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.). 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. Although a number of equations are available for estimating BMR, the APEX and SHEDS models currently use the Schofield (1985) set of equations that account for variability in age, gender, and BM. Because of criticisms that the Schofield (1985)-derived equations may not reflect current population characteristics, such as the higher BM and larger BMI[4] seen in the current population (Frankenfield et al., 2005; Livingston and 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 related directly 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) all are 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 addressed quantitatively. If needed for a particular standard assessment, alveolar ventilation (V_A) can be derived from the V_E estimates; EPA staff currently are working on defining new $V_E \rightarrow V_A$ functional relationships for use in the APEX and SHEDS models.

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 and 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 on maintaining the intra- and interindividual variability in time use seen in the few repeated-measures analyses of variance that have been undertaken on multiday surveys and replicating the day-to-day correlations within individuals in the time spent in selected, important 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

[4] BMI = BM (kg)/HT^2 (m), a widely used index of relative fatness

Table 1-1. Summary of the CHAD Database

Study Name	Year*	Diaries	Number of Days of Data per Person		Sponsor
			Range	Median	
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 and Child	2008	62	31	31	EPA
Totals		34,773			

Notes and Abbreviations:

* The last year of a multiyear 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

NICHHD = National Institute of Child Health and Human Development

PSID = Population Study of Income Dynamics

RTI = Research Triangle Institute

RTP = Research Triangle Park

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 eight seasonal and meteorological categories (four temperature classes and two 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, beginning 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).

All of these steps use stochastic processes. The C_t 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 on 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.[5] This is the dose profile mentioned earlier. For O_3, 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 ≥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 three population groups in 12 Metropolitan Statistical Areas for one air quality scenario, with 2002 air quality just meeting the current O_3 8-h daily maximum standard. Five other scenarios also 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, (although not shown in the figure).[6] 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 older adults associated with exposures to xenobiotic substances. See Hattis and Russ (2003), Ginsberg et al. (2005), and Krishnan and Hattis (2005) for example risk assessment documents focused on older people. Although 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 really are 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 1995-1996 in two separate areas of San Bernardino County: (1) urban Upland, CA, and (2) two small mountain towns (Langstaff, 2007; U.S. EPA, 2007a). That was the only dataset available to the Agency for such a comparison, even though it was relatively old and based on a longer averaging time (6 to 7 days) than of interest in the assessment (1- or 8-h daily exposures). The APEX model performed reasonably well in the mid-range of the cumulative distribution of weekly exposure estimates (20th to 70th 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 of which the author is aware: Burke et al. (2001), Law et al. (1997), Ott et al. (1988), and Zartarian et al. (2000, 2006). The overestimate of low-end exposures is not of much interest, because health risks associated with low-end exposures generally are not of regulatory concern (McCurdy, 1995). The probable cause of systematically underestimating high-end exposures results from the models' inability to mimic repeated daily activity

[5] 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.

[6] 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 decisionmakers and, so, uses the two-step approach to addressing variability and uncertainty.

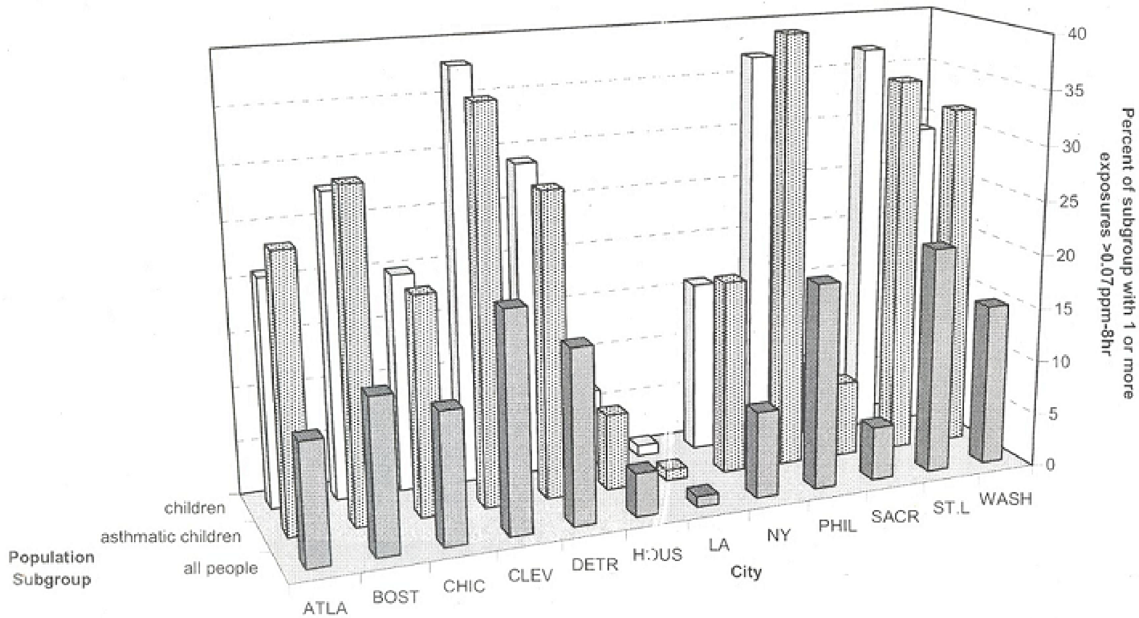


Figure 1-6. Percent of people in three groups—(1) all children, (2) asthmatic children, and (3) all persons—estimated to experience 1+ days with an 8-h daily maximum O_3 exposure >0.07 ppm while at moderate exercise when the current 8-h daily maximum NAAQS of 0.08 ppm is just met.

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 evaluated thoroughly with respect to exposure model output distributions.

The impact that time use data per se have on APEX exposure modeling results has received a limited amount of 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 12 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 1-hour maximum O_3 exposure estimates, and distributional tests. The seven variables included the following.

(1) Selection of the appropriate intra- and interindividual statistics to combine diary days into longitudinal patterns
(2) Choice of the "key location" used to sort the above statistics (e.g., in vehicles versus outdoor time)
(3) Differences in start and stop times for the diary day (All events were shifted forward and backward 1 h.)
(4) 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 1980s to 2007.)
(5) Alternative assignments of "ambiguous location codes" to either indoors or outdoors (e.g., travel by boat—indoors or outdoors?)
(6) Modifying the diary "weights" used in the National Human Activity Pattern Survey
(7) 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 among the various simulations were greater than simply selecting diaries at random, but the differences were small: ~1% to 2% versus ~0.2% to 0.5%. The one exception was age of the diary data itself (the year that the data were obtained). Using the older diaries *increased* exposure estimates by ~1.5% to 21.8% (Nysewander et al., 2009), mostly because high-end O_3 exposures were 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 µEs, rather than a function of age of the diary per se. 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 on 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 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. Because 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.

A concerted sensitivity/uncertainty evaluation of EPA’s time series exposure models following the principles advocated in Saltelli et al. (2000) would be useful and provide insights into those variables and parameters that significantly affect their performance.

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 older individuals in how and where they as groups spend time, travel, and undertake 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 interindividual variability in exposure and dose profiles in older individuals, not often addressed in exposure modeling applications for this population subgroup. There also is a surprising amount of intraindividual variability in aging individual’s time use and physiology, and this rarely is addressed in current modeling efforts. Intraindividual (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 older people, 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 older adults that are expected in the future indicate that they will be an ever-increasing percentage of the total U.S. 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.[7]

There are caveats to this report. We do not discuss certain “extra-biological” considerations that may affect how older Americans respond to exposure to xenobiotic substances. Some of these considerations might moderate disease progression given an exposure. They include religious views and practices of the aged and their psychological makeup (Olman and Reed, 1998; Sloan and Wang, 2005). Although important considerations in the etiology of disease once exposed, have no a priori data on these factors to use in our exposure models. Similarly, possible differential cognitive affects on exposure also are slighted, given the lack of information on the topic. If better data become available on these issues, we could simulate their impact on health endpoints 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 older adult population is increasing rapidly, both in the United States and worldwide (Goulding et al., 2003). They will become an important population subgroup from an exposure modeling perspective, and not just for PM. 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 older people.

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

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

ABSRACT

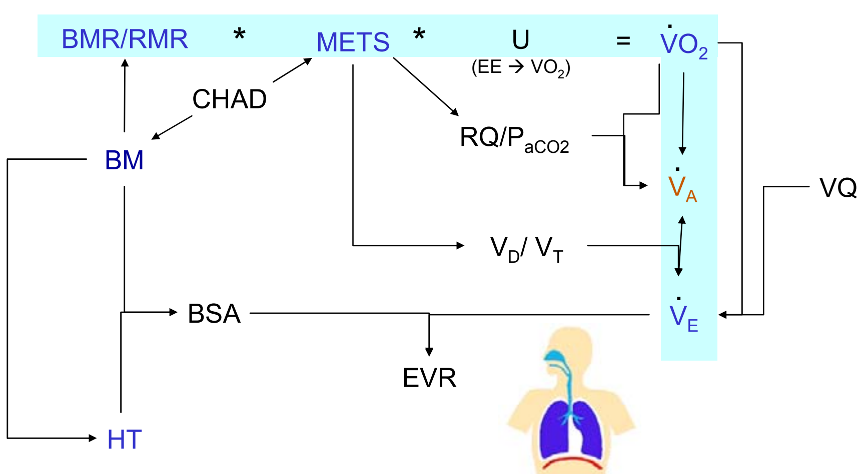
Topic: This chapter covers the the physiological input data required by EPA's human exposure models and identifies the data sources available to parameterize these variables for aging individuals.
Issue/Problem Statement: In most cases, the population distributions of these physiological characteristics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

Anthropogenic and physiological variables used in our models follow; not all of them are depicted in Figure 2-1 but are mentioned because of their widespread use in the physiological literature. Our units are all in the International System of Units (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.

2.A Conceptual Framework of Physiological Changes Resulting from 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 attributes affecting older individuals. 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,



Source: Stephen Graham

Figure 2-1. Activity-specific metabolic and ventilation metrics used in EPA exposure 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
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 BM 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 currently do not 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)
G	Gender; U.S. Census (female [♀], male [♂]); obtained from U.S. Census data and generally treated as a nominal variable
HR	Heart rate (beats/min) [This variable has not been 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 nonsubcutaneous 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); 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 CO_2 (torr); not currently used in our exposure models (except APEX-CO, the CO version of APEX)
PAI	Physical Activity Index (unitless); the daily time-averaged METS estimates for an individual (Σ $METS_A$ * $time_A$ [min])/1,440 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. Although 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 CO 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); 1 L O_2 ≈ 4.85 kcal, values between 4.69 and 5.01 are seen in the literature, depending on the foodstuffs being metabolized. Using the 4.85 conversion, 1 kcal = 206 mL O_2. APEX randomly samples from uniform distributions of 200 to 210 mL ♀ and 210 to 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 to 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 O_2 min^{-1}); estimated using a gender-specific U (EE to VO_2 ratio) [A “dot” should be over the “V’ because it is a rate.]
VO_{2Max}	Age/gender-specific maximal oxygen consumption rate (mL min^{-1} kg^{-1}); also known as VO_{2Peak}; considered to be “aerobic capacity” [A “dot” should be over the “V”.]

correlated relationships are depicted by curved dashed lines. Important genetic factors that directly affect an attribute are depicted by straight, lightly-dashed lines.

A plus sign on a relational line, either direct or correlated, indicates a positive impact, whereas the opposite is true for a negative sign. Looking at the diagram, and beginning with age, as age increases, a person's HT 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 complex relationships between the linked variables that probably are nonlinear and that vary 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, HT, and BM—but not LBM or BMI. Other explicit variables in the models are BMR, fitness—as estimated by maximal oxygen consumption (VO_{2Max}), and a surrogate for "fitness"—the 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 then would provide information about the impact that the altered states have on model results.

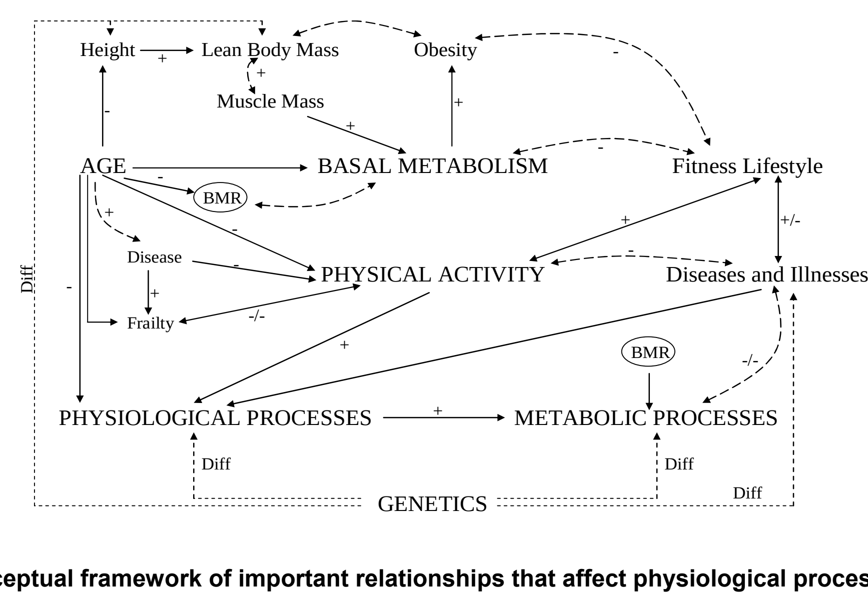
It should be noted that many of the factors depicted in Figure 2-2 have been studied and shown to be important in morbidity and mortality in older adults (Skinner, 1970). Often, these factors are known by more precise nomenclature than listed. One of the most important considerations is sarcopenia, age-associated loss of muscle (Rogers and 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 BMR

BMR is also known as resting metabolic rate (RMR) or resting energy expenditure (REE). It approximates the unavoidable loss of heat because of 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 on 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 BM-normalized units often are used (kcal kg^{-1} min^{-1} or kcal kg^{-1} day^{-1}). Alternative BMR units also

CONCEPTUAL FRAMEWORK FOR AGING



Source: Thomas McCurdy

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

are 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 aged (McArdle et al., 2001). These transformations are called BM- or LBM-normalized BMR.

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

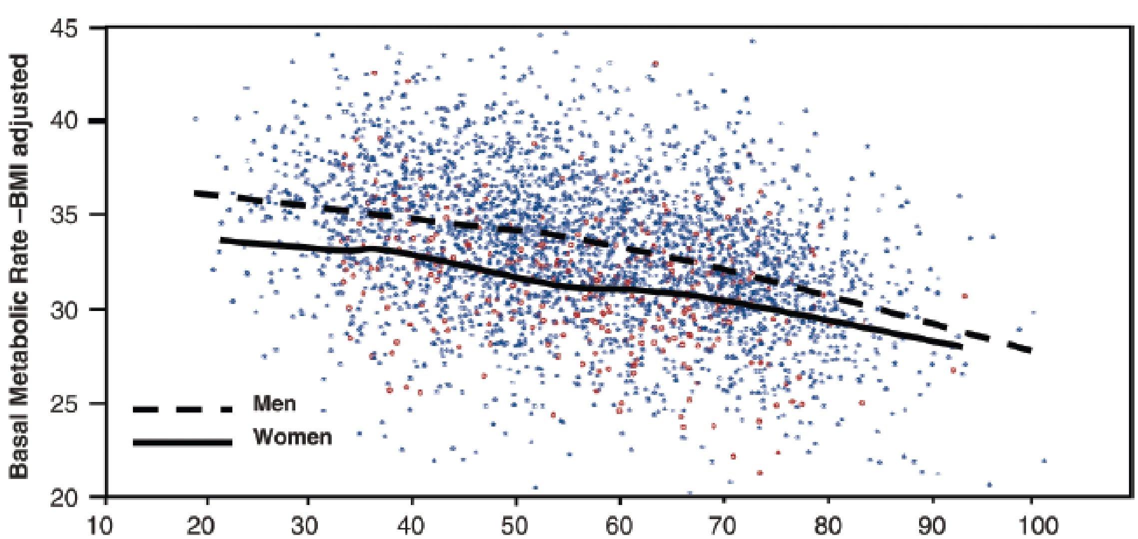
Most studies show a significant decrease in BMR over time both for individuals (longitudinally) and among older adults (cross-sectionally) (see Figure 2-3). This is true for both U.S. (Hunter et al., 2001; Obisesan et al., 2005) and non-U.S. studies (Goldberg et al., 1988; Haveman-Nies et al., 1996; 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% to 2% per decade (Keys et al, 1973). Reduction in BM in seniors by itself explains about 55% of the relative decrease in BMR (Obisesan et al., 1997). BMR is correlated positively with both activity level (fitness) and LBM (Anderson et al., 2001). However, other studies indicate that BMR is only slightly lower in older than in younger adults (Das et al., 2001). These authors state that weight gain in older individuals—a relatively recent trend—is "compensating" for the differences in body composition of older people, 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 seniors may affect future BMR predicting equations, as the LBM-to-total BM ratio changes with body composition in overweight and obese people.

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

A table of older American's BMR values seen in the literature is not presented here because EPA staff (Graham and McCurdy, in preparation) have 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. 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 turn, reproduced them from the sources noted. The equations are for adults >18 years, unless otherwise noted. BM has units kilograms, HT is in centimeters, and age (A) is in years (y). Gender-specific equations usually are presented for BMR.

From the Owens equations reproduced in Nieman (1990])

$$BMR ♂ = 879 + (10.2 * BM)$$
$$BMR ♀ = 795 + (7.2 * BM)$$



Source: Ruggiero et al. (2008)

Figure 2-3. Decrease of BMR with age.

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 World Health Organization (WHO) equations depicted in Nieman (1990) for people ≥60 years

$$BMR ♂ = 487 + (13.5 * BM)$$

$$BMR ♀ = 596 + (10.5 * BM)$$

As mentioned, in the exercise physiology literature, BMR is defined to be 1 MET (see the following section). It also often is "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 seniors and children (Kwan et al., 2004; McCurdy and 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 older individuals is complex and nonlinear. Relatively low- and high-BMR groups (compared with 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 National Institute on Aging (NIA)-funded study that began in 1958. The sample used in the Ruggiero et al. (2008) analysis consisted of 1,227 participants enrolled in the 1958-1982 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 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 seniors (Lai et al., 2009). The $METS_{MAX}$ values for people ≥ 65 years old are about 67% of those <50 years old and even lower in those people who subsequently died of cardiovascular problems (Lai et al., 2009). McArdle et al. (2001) state that $METS_{MAX}$ drops from about 10.0 in middle age to 7.0 in older people and drops again to 4.0 in the very old. Although 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 older people. Papers that do discuss them are reviewed below. It should be recognized that because of the general low fitness levels of seniors, 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 older healthy individuals (see Section 2.D).

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 year-olds (n=14) and was 3.7 ± 0.8 for 71.8 year-olds (n=5). The authors do not speculate as to 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 (with 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 to 75 years, declining to 6.5 ± 2.8 for 70 to 74 year-olds and to 5.6 ± 2.5 for ≥75 year-olds. Sergi et al. (2009) estimated that $METS_{MAX}$ for 81 females aged 70.4 ± 3.9 years was 6.1 ± 1.2, and Sagiv et al. (1989) stated that $METS_{MAX}$ for 40 males aged 67± 4 years 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 a 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) describe how the METS distributions in CHAD were developed. Activity-specific METS are discussed in Section 3.

2.D VO_{2Max}

VO_{2Max} is maximal oxygen consumption and is also known as maximal aerobic power (Jones and Lindstedt, 1993). It is highly related to the genetic makeup of an individual. McArdle et al. (2001) state that between 40% and 90% of variability in VO_{2Max} can be attributed to heredity alone. VO_{2Max} values generally are 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 seniors (Conley et al., 2000; Goodman and Thomas, 2002). An early summary of cross-sectional VO_{2Max} data on older adults is presented in Smith and Gilligan

(1989). VO_{2Max} estimates for older people seen in the literature are summarized in Tables 2-2a and 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 database 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 and Gilligan, 1989). The reduction probably is nonlinear 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 and Lakatta, 1988; Kent-Braun and Ng, 2000; Kirkendall and Garrett Jr., 1998). Thus, physical work capacity seemingly is not reduced in old people—at least into their 60s—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 and Thomas, 2002). Reduced physical activity, physiological aging (biological functioning), and increased prevalence of pathological conditions contribute to this decline. Goodman and Thomas (2002) estimate that VO_{2Max} declines 5% to 15% per decade from early adulthood.

McArdle et al. (2001) state that VO_{2Max} decreases about 0.4 to 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) provide the following equations for VO_{2Max}.

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

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

Other $VO_{2.Max}$ prediction equations for seniors exist (Blackie et al.,1989). The SE_Es of the McArdle et al. (2001) equations are about 30% of their means, so they are quite large, indicating a lot of variability in that population subgroup, as seen in Tables 2-2a and 2-2b 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 20s on a BM basis. That estimate is roughly consistent with the prediction equations presented above and with the values given in Fleg (1994). Bruce (1984) states that the decline is about 0.4 mL min^{-1} kg^{-1} $year^{-1}$, which is somewhat lower than that indicated by the above equations. In males, Jackson et al. (1995) state that the decline is 0.46 mL min^{-1} kg^{-1} $year^{-1}$. In females, the decline in $VO_{2.Max}$ has been estimated as 0.54 mL kg^{-1} min^{-1} $year^{-1}$ (Jackson et al., 1996). Larson and Bruce (1987) state that the decline is 0.4 mL kg^{-1} min^{-1} $year^{-1}$ in the healthy aged (both genders) when measured cross-sectionally but 0.9 mL kg^{-1} min^{-1} $year^{-1}$ in the same people when analyzed longitudinally. Thus, using cross-sectional data to describe $VO_{2.Max}$ change in individuals over time will underestimate systematically 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 and Wiswell (2003). They indicate that the decline in $VO_{2.Max}$ is caused by both central and peripheral physiological adaptations, especially reductions in maximal heart rate and LBM (muscle). The authors distinguish between the decline rate in inactive people (10% to 15% per decade) and athletic people (5% to 7% per decade). The decline is nonlinear with age, declining faster after 70 years (Hawkins and Wiswell, 2003). They also state that results from cross-sectional studies of $VO_{2.Max}$ in older adults give quite different results than longitudinal studies of that cohort, especially for formerly active individuals. The reader is advised to review Hawkins and Wiswell (2003) for an excellent and succinct discussion of the topic. Kenney (1997) and Stamford (1988) support the same findings. See also Pollock (1974) and Pollock et al. (1987,1997) for 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, whereas older adults (65 ± 2 years) had only 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 older people (Shephard, 2009), explaining more variance in cognitive measures than "higher order" measures of cognition (memory, speed of processing information, "executive functioning," etc.) (see: Newson and Kemps, 2006). In addition, a $VO_{2.Max}$ <30 to 35 mL kg^{-1} min^{-1} in older

Table 2-2a. Literature-Reported Estimates of VO_{2Max} for Older Adults

Age Range (Mean and 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: U.S.
	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: U.S.
	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
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 and Jackson 1999	Poor aerobic fitness
	NS	NS	28 - 30	Baumgartner and Jackson 1999	Fair aerobic fitness
	NS	NS	31 - 37	Baumgartner and Jackson 1999	Average aerobic fitness
	NS	NS	38 - 40	Baumgartner and Jackson 1999	Good aerobic fitness
	NS	NS	≥41	Baumgartner and Jackson 1999	Excellent aerobic fitness
≥60	NS	NS	≤21	Baumgartner and Jackson 1999	Poor aerobic fitness
	NS	NS	22 - 24	Baumgartner and Jackson 1999	Fair aerobic fitness
	NS	NS	25 - 30	Baumgartner and Jackson 1999	Average aerobic fitness
	NS	NS	31 - 33	Baumgartner and Jackson 1999	Good aerobic fitness
	NS	NS	≥34	Baumgartner and Jackson 1999	Excellent aerobic fitness
	Females: Normal or Healthy				
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	
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 and 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	

Age Range (Mean and SD)	Ethnic Group	Health Status	VO_{2Max} Estimate (mL/kg-min)	Citation	Comment
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 and 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
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	16.7 ± 3.3	Perini et al. 2000	n=11
80 – 89	NS	H	21.2 ± 1.3	Fleg et al. JAP 1995	n=2
	Females: Sedentary, Overweight, or Obese				
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 and Ng 2000	n=9
	Females: Fit, Active, or Athlete				
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

Age Range (Mean and SD)	Ethnic Group	Health Status	VO_{2Max} Estimate (mL/kg-min)	Citation	Comment
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
	Females: Health Problems				
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
	Males: Normal or Healthy				
60 – 67	NS	Ex-Ath.	37 ± NS	Saltin and Grimby 1968	No training in 10 years
60 – 69	NS	H	30.4 ± 8.2	Fleg et al. JAP 1996	n=26; nonobese
60 – 79	NS	N	24.2 ± NS	Buccola and 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 and 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 and 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 and 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 and 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; followup
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 and 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
	Males: Sedentary, Overweight, or Obese				
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 and Ng 2000	n=9
76 ± 9	NS	Sed	21.4 ± 6.3	Weiss et al. 2006	n=33
	Males: Fit, Active, or Athlete				
59.6 ± 8.5	NS	Ath	49.9 ± 5.4	Schulman et al. 1996	n=8
60 – 67	NS	Ath	43 ± NS	Saltin and 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
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

Age Range (Mean and SD)	Ethnic Group	Health Status	VO_{2Max} Estimate (mL/kg-min)	Citation	Comment
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
	Males: Health Problems				
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 and Shephard 1978	n=12
60 – 83	NS	Sed	30.9 ± 7.1	Sidney and Shephard 1978	n=8
60 – 83	NS	Sed	30.4 ± 4.9	Sidney and Shephard 1978	n=14
60 – 83	NS	Sed	29.8 ± 1.4	Sidney and 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. 2002	n=8
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; nonobese
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

Age Range (Mean and SD)	Ethnic Group	Health Status	VO_{2Max} Estimate (mL/kg-min)	Citation	Comment
68.1 ± 9.8	NS	N	32.6 ± 10.1	Hernandez and 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 and 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 and 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 and Franke 2005	n=10
73.9 ± 6.3	NS	N	39.0 ± 6.3	Hernandez and Franke 2004	n=10
74 ± 3	NS	N	21.1 ± 6.8	Cress and Meyer 2003	n=98
76.2 ± 6.2	NS	N	19.8 ± 6.3	Arnett et al. 2008	n=29; 70-92 years
79 ± 6	NS	N	16.8 ± 4.0	Cress and 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 and Meyer 2003	n=45

Abbreviations:

AA	African American (black)	Fit	Very active healthy exercisers
ACE	Angiotensin-converting enzyme	Frail	Mild-to-moderate frailty
	DD: deletion/deletion genotype	H	Healthy
	ID: insertion/deletion genotype	Heart	Heart "failure" patients
	II: insertion/insertion genotype	His	HISPANIC
Act	Active (but nonathletes)	HRT	Hormone replacement therapy
Ath	Athletes	Indiv	Data for individuals are provided
Cardio	Cardiovascular problems	IS	Ischemic subjects ("silent")
COPD	Chronic obstructive pulmonary disease	LF	Low functioning: a combination of five self-reported functional measure

M	Mixed ethnicity or mixed fitness level	OW	Overweight
N	Normal (mostly healthy)	Park	Parkinson's disease patients
NLF	Not low-functioning: see LF above	PD	Peripheral disease patients
NS	Not specified	Sed	Sedentary
O	Obese	W	White (Caucasian)

Notes:
a. The McArdle et al. (2001) and Baumgartner and 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 VO_{2Max} estimates for the HRT and non-HRT groups; only the non-HRT group data are shown.
d. The Hagberg et al. (1998) article provides VO_{2Max} estimates for lifestyle groups also (not presented).
e. The Sergi et al. (2009) article also provides 5th and 95th percentile values for VO_{2Max}. The 5th value is 71% of the median, and the 95th value is 136% of the median.

adults is thought to be the "threshold level" for increased mortality risk (Leaf and Reuben, 1996).

The first part of Table 2-2a consists of $VO_{2.Max}$ estimates (in units of mL/kg-min) from textbooks 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.

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}[8]. Thus, there are issues associated with use of the metric itself and what it indicates in older people.

Training (fitness improvements), on the other hand, improves exercise performance and VO_{2Max} estimates using most metrics of maximal oxygen consumption. Saltin and Grimby (1968) state that $VO_{2.Max}$ is 40% higher in senior 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 and Grimby, 1968). The effect that lifestyle has on $VO_{2.Max}$, especially activity level, has been studied extensively by Hagberg and colleagues; they also looked at differences in $VO_{2.Max}$ in menopausal women resulting from 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 do absolute values of the same variable (McCurdy and Graham, 2004b). It is anticipated that we 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 it 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 elders. 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 V_{EMax}

The exercise physiology literature on older indivuals 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 related more directly to metabolic processes than is 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 age 80, it is 40% of what it was at age 30 (p. 877). The data that could be found on $V_{E.Max}$ in seniors appear in Table 2-3.

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

[8] The three criteria are (1) 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), (2) a respiratory exchange ratio (RER) of ≥1.10, and (3) a heart rate within 10 beats of the subject's age-predicted HR_{MAX} (White et al., 1998). RER approximates the "true" nonprotein respiratory quotient of metabolism under a steady-state condition (Astrand and 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.

Table 2-2b. Estimates of VO_{2Max} for Older Adults Seen in the Literature

Age Range (Mean and 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 years
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 and 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 years
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 years
	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
75.3 ± 4.6	NS	Sed	1.47 ± 0.89	Kent-Braun and 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

Age Range (Mean and SD)	Ethnic Group	Health Status	VO_{2Max} Estimate (L/min)	Citation	Comment
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 and Grimby 1968	n=5
60 – 69	NS	N	1.87 ± 0.44	Tlusty 1969	n=25; 65 years
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 and 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 and 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 years
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 years
		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
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

Age Range (Mean and SD)	Ethnic Group	Health Status	VO_{2Max} Estimate (L/min)	Citation	Comment
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 and Ng 2000	n=9
		Males: Active, Fit, or Athlete			
60 – 67	NS	Ath	2.68 ± NS	Saltin and 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 Oca et al. 1996	n=25; severe
68 ± 6	NS	Heart	1.96 ± 0.22	Sheldahl et al. 1996	n=8
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 and Shephard 1978	n=12
60 – 83	NS	Sed	2.09 ± 0.53	Sidney and Shephard 1978	n=8
60 – 83	NS	Sed	1.96 ± 0.64	Sidney and Shephard 1978	n=14
60 – 83	NS	Sed	1.96 ± 0.32	Sidney and 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

Age Range (Mean and SD)	Ethnic Group	Health Status	VO_{2Max} Estimate (L/min)	Citation	Comment
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-Martiń 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- Martiń 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)	M	Mixed ethnicity or mixed fitness level
Act	Active (but nonathletes)	N	Normal (mostly healthy)
Ath	Athletes	NS	Not specified
COPD	Chronic obstructive pulmonary disease	O	Obese
Fit	Very active healthy exercisers	OW	Overweight
Frail	Mild-to-moderate frailty	Park	Parkinson's disease patients
H	Healthy	PD	Peripheral disease patients
Heart	Heart "failure" patients	Sed	Sedentary
HRT	Hormone replacement therapy	W	White (Caucasian)

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

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+ years in Graham and McCurdy (2005) is

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

where

e_B is the between-individual variability (interindividual) residual, and e_W is the within-individual variability (intraindividual) residual.

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

$$V_{E.Max}\ ♀ = 120.6 – (1.103 * Age) \qquad R^2 = 0.42$$
$$V_{E.Max}\ ♂ = 130.6 – (1.007 * Age) \qquad R^2 = 0.25$$

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 COV among the subgroups, even when they are defined by a single gender and lifestyle or health grouping. These COVs are in the 15% to 28% range. When the genders are combined (in the “Both” group), the COVs increase to 30% to 40% or so, with a few at the 20% and 50% levels. Undoubtedly there are large intraindividual differences in daily $V_{E.Max}$ estimates also, but there are no data on this point.

2.F VQ

Although ventilatory equivalent (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 older adults is discussed here. Hagberg et al. (1989) present VQ at maximum exertion (VQ_{MAX}) data on three 70 to 79-year-old groups of mixed (both) genders. Assignment of an individual to one of the three groups was done on a random basis, without regard to the VQ

Table 2-3. Estimates of $V_{E.Max}$ for Older Adults

Age Range (Mean ± SD)	Health Status	$V_{E.Max}$ 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 and 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 and 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 and Grimby 1968	n=5;10 years 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 and 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
75.7 ± 4.7	Sed	98.3 ± 21.9	Kent-Braun and 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

Age Range (Mean ± SD)	Health Status	$V_{E.Max}$ Estimate (L/min)	Citation	Comment
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	n	Sample size
COPD	Chronic Obstructive Pulmonary Disease	NS	Not specified (unknown)
Heart	Heart disease or coronary artery disease	Sed	Sedentary
N	Normal health		

of the subsets. VQ_{MAX} at $VO_{2.Max}$ for the three groups was 32.2 ± 4.4, 34.6 ± 4.2, and 35.5 ± 6.6. Large COVs for the groups indicate that there is substantial variability in VQ data, 13.7%, 12.1%, and 18.5%, respectively. Statistical testing of the means or the SDs was not presented. The high variability in VQ is but one of the reasons this parameter no longer is used in APEX and SHEDS exposure/intake dose models.[9]

Panton et al. (1996) provide VQ_{MAX} estimates for 68.6 ± 5.7 year-old females and 68.7 ± 5.1 year-old males. The VQ_{MAX} estimates are 41.3 ± 7.7 and 39.8 ± 8.7, respectively. Besides the absolute values being relatively high, the COVs 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 older males are provided in Hagberg et al. (1988). The VQ_{MAX} for sedentary 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 seniors is about 50% to 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 older males in another study was between 56% and 61% of $VO_{2.Max}$, regardless of the subject's fitness level (Takeshima et al., 1996).

2.G HR and HR_{MAX}

Heart rate in an individual associated with a particular work load and HR_{MAX} itself are other physiological traits that largely are inherited from a person's parents (McArdle et al., 2001).[10] 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

[9] 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 nonlinearly with VO_2, and the increasing slope of V_E with VO_2 was not acknowledged explicitly 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. subjects aged 66 ± 5 years was 36 ± 4, and the VQ_{MAX} for athletes aged 65 ± 3 years was 33 ± 4 (n=10 for both groups). These differences were not significantly different using analysis of variance (ANOVA) and author-identified "appropriate contrasts."

[10] 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.

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 older 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. Because 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 (years). However, this approximation does not apply to fit individuals, who show a smaller HR_{Max} reduction with age than predicted by this formula (McArdle et al., 2001). The decrease in HR_{Max} in the older adults can be reversed to some extent by training.

Because the absolute HR-to-VO_2 relationship for given workloads is highly individualistic and is 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 aged, and PM concentrations often seen in the epidemiological literature (e.g., Pope and Dockery, 2006; Zanobetti and 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 because of the highly individualistic nature of its relationship to other important physiological parameters.

2.H HT

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 seniors, HT decreases at an accelerating rate after about 45 years, especially in females (Sorkin et al.,1999). In one longitudinal study of 1,068 males and 390 females, the following decreases were measured in centimeters per year.

Age Group (years)	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 to 94-years group is only three individuals with a short "follow-up" longitudinal period also. Gender difference in the slopes is statistically significant for all age groups <90 years (and >50 years [not shown]).

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

2.I Section 2 Concluding Comments

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 seniors 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 older Americans. 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 because they affect the ability to participate in exercise or travel outside the home. These include muscle mass, heart rate, strength, mobility, and the like.[11] Heart rate change is one physiological component that has been shown to be associated with environmental exposures, especially to small-sized PM (Stein et al., 2009; Schlesinger et al., 2006). For instance, Adar et al. (2007b) state that HR variability is associated negatively with fine particulate exposure in 44 older people wearing an electrocardiogram (ECG) recorder, both for short-term and daily exposures. Exposure to fine particulates reduces parasympathetic tone. Although HR change because of age is not a factor in APEX or SHEDS yet, it could be added. As discussed, exercise scientists treat HR rather superficially, normally using the very broad HR_{Max} = 220 – Age [years] 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 modeled explicitly.

Physiologic variables of secondary interest do affect some of the major parameters discussed above, but often the relationships among them are tenuous and

[11] 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.

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, although 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 older population. The proportion of seniors who are overweight hovers around 35% to 42% for all 5-year age groups between 65 and 85, while those categorized as obese decrease from 38% to 17% for the same age classes (Marriott et al., 2008; p. 6). An overweight older population is a relatively new phenomenon. Because being overweight or obese (especially) affects intake dose rates, these conditions probably also affect heath effects associated with airborne exposures.

A review of seniors' BMI data was conducted in 2009 by the Centers for Disease Control and Prevention (CDC, 2009b). CDC provided the following age-adjusted percentage estimates by body weight categories based on four BMI cutoffs (in kg m^{-2}): (1) underweight (BMI < 18.5); (2) healthy weight (18.5 ≤ BMI < 25.0); (3) overweight (25.0 ≤ BMI < 30.0); and (4) obese (BMI ≥ 30.0).

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

	Under-weight	Healthy	Over-weight	Obese
65-74 years	1.1 (0.2)	30.2 (1.1)	38.3 (1.2)	30.4 (1.1)
≥75 years	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 be used only descriptively and not as an operative variable in EPA's older Americans' exposure modeling efforts.

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

ABSTRACT

Topic: This chapter discusses physical activity in older adults 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 seniors is relatively data-rich, and these data are mostly useful in validating EPA's physical activity algorithms. Activity-specific energy expenditure data in older individuals, 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 and Total Daily Energy Expenditure

Because of the commonly identified systematic biases associated with estimates of energy intake (EI, in kilocalories), energy expenditure metrics are used in the APEX and SHEDS-Air models. Discussions of problems in estimating EI in older adults are contained in Johnson et al. (1994), Tooze et al. (2007), and Young et al. (1992). Basically, EI has been shown to be underreported by approximately 40% of the respondents, particularly in low-income seniors (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 the condition that a person is neither losing nor gaining weight. For some persons, this assumption generally is valid from a practical perspective (i.e., there may be minimal changes in body weight within a relatively short timeframe, 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 multiday period, but they are averaged over the number of elapsed days since drinking the isotope-labeled water to obtain a daily average estimate.[12] In the APEX and SHEDS models, TDEE is calculated as the sum of activity-specific EEs obtained by multiplying activity-specific METS by the time spent in each activity (McCurdy, 2000). See Section 2 for more information on these parameters.

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

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 older individuals. See Section 3.B.

$TDEE_i$ also can be obtained from multiplying the simulated person's PAI_i by BMR_i. Basically, PAI is the subject's daily averaged METS for all activities undertaken during the day. This approach essentially follows the "factorial method" used by exercise physiologists and clinical nutritionists to estimate TDEE in individuals (Roberts and Rosenberg, 2006). There are scores of prediction equations relating TDEE in the aged to both BMR and BM; see Carpenter et al. (1995) for a survey of more than 20 such equations. The "pooled mean" COV for PAI for older males is 22.5% (versus 12.3% for all age groups). Thus, there is considerable relative variability within the older population, probably resulting from variability in health

[12] 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 CO 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 and 14 days in different studies.

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 seniors, 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 problems. Roberts (1996) is a comprehensive article of that type. Probably the single most relevant review of TDEE in older people is Roberts and Rosenberg (2006). They state that TDEE usually is divided into three major categories: (1) basal metabolism (see Section 2), (2) physical activity, and (3) the thermic effect of feeding. The thermic effect of feeding generally is about 10% of TDEE and is never directly measured (Rogers and 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).

Section 5 focuses entirely on PA in seniors. 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 PAEE in older adults that is 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, which 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 likely would be biased. Calculating TDEE in the model simulations and comparing them with distributions found in literature values provide 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 older individuals appear in Table 3-1.

We note that the intraindividual variation in TDEE is quite large. Based on 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 and Cole (2000) report that the "pooled mean" COV for TDEE is 11.8% for all age groups and 16.3% for male subjects 65 to 74 years old. A longitudinal study that only presents cross-sectional data by age groups is Sunman et al. (1991). In this study, which began in 1952, TDEE was assessed after 24 years, when the male college graduates were in their late 60s, and again when they were in their mid-70s. 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 seven 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 ± 27	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 (1) a much larger TDEE decline in controls (19%) than in former athletes (6%); (2) relatively large TDEE COVs exist in both groups, ranging from 36% to 47%; (3) very large COVs in PAEE occurs in both groups, being 95% to 120% of the mean; and (4) the relatively narrow proportion of PAEE-to-TDEE in both groups, 9.5% to 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 1970s and early 1980s, 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, because BMR (about 50% to 70% of TDEE in most adults) and PAEE both decrease with age (Roberts and Dallal, 2005). This trend holds for TDEE adjusted by BM or by LBM. Roberts and Dallal (2005) provide an extensive table of TDEE and PAI for seniors by decade of age, which is included in Table 3-1. Their information comes from a National Academy of Sciences database of doubly labeled water studies, but it is not otherwise identified. One important age-related phenomenon is that seniors have greater fluctuations in total body and fat mass following under- and overeating events relative to that of younger adults. This results in a greater imbalance between daily EI and EE because of reduced compensation from adaptive changes in EE (Roberts and 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 contraindicatory effects in postprandial EE that minimize this problem in older adults (Roberts and 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 intraindividual variability in modeled TDEE approximates the values seen in the literature. Too narrow or overly wide modeled COVs would provide insight into the sampling procedures used in the exposure models. That has not been done to date in

Table 3-1. Estimates of TDEE, PAEE, and/or PAI for Older Adults

Age Range (years)	Mean Age (years)	Sample Size (number)	Gender	TDEE (kcal/day)	PAI (-)	Reference	Comment
	Normal Weight Individuals						
60 - 69		48	♀	2042 ± 343	1.69	Roberts and Dallal 2005	SD for PAI: 0.31
		14	♂	2397 ± 437	1.61	Roberts and Dallal 2005	SD for PAI: 0.18
70 - 79		14	♀	1888 ± 295	1.55	Roberts and Dallal 2005	SD for PAI: 0.26
		30	♂	2407 ± 374	1.62	Roberts and Dallal 2005	SD for PAI: 0.25
80 - 89		6	♀	1382 ± 152	1.21	Roberts and Dallal 2005	SD for PAI: 0.09
		4	♂	1700 ± 239	1.17	Roberts and Dallal 2005	SD for PAI: 0.15
90 - 97		9	♀	1356 ± 166	1.17	Roberts and Dallal 2005	SD for PAI: 0.13
		6	♂	1935 ± 156	1.38	Roberts and Dallal 2005	SD for PAI: 0.17
	Overweight Individuals						
60 - 69		46	♀	2061 ± 294	1.52	Roberts and Dallal 2005	SD for PAI: 0.23
		30	♂	2851 ± 420	1.71	Roberts and Dallal 2005	SD for PAI: 0.29
70 - 79		19	♀	1868 ± 402	1.51	Roberts and Dallal 2005	SD for PAI: 0.28
		34	♂	2624 ± 461	1.55	Roberts and Dallal 2005	SD for PAI: 0.27
80 - 89		6	♀	1748 ± 464	1.41	Roberts and Dallal 2005	SD for PAI: 0.37
		6	♂	2294 ± 357	1.47	Roberts and Dallal 2005	SD for PAI: 0.16
90 - 97		7	♀	1766 ± 292	1.33	Roberts and Dallal 2005	SD for PAI: 0.22
		2	♂	1863 ± 46	1.29	Roberts and 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 and 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 and 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	Noncathectic 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 and 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

Age Range (years)	Mean Age (years)	Sample Size (number)	Gender	TDEE (kcal/day)	PAI (-)	Reference	Comment
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)	HP	Heart patients
B	Both genders	♂	Males
CHD	Coronary heart disease	NS	Not specified
♀	Females	SD	Standard deviation
H	Healthy	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 aged. One of them is Roberts et al. 1992 in the references. P&W is Pannemans & Westerterp, 1995 *Brit. J. Nutr.* 73: 571-581, which is 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 also is supplied in units of kcal/day-kg.

APEX or SHEDS modeling applications. We are not addressing full variability within and among individuals if the resultant TDEE COVs are too narrow.

3.B Activity-Specific EE_A and Oxygen Consumption

As just mentioned, the APEX and SHEDS models use activity-specific estimates of EE (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 oxygen consumption ($VO_{2.A}$) and $V_{E.A}$ could result, because 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 that 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.

EPA's modeling group 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 the $METS_A$ value on which it is based) is not adjusted directly; the effective change in EE_A is accounted for by an oxygen debt correction to $VO_{2.A}$ and breathing rate.

There are a number of articles presenting EE_A data for older population 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_As 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 older American's EE_A data (as VO_2) is Leaf and MacRae (1995). They tested 20 subjects (15 ♀ and 5 ♂) having a mean age of 71.2 ± 4.5 years (range: 65 to 81 years). Although 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 EEs 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 and 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 to 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 three small, mixed-gender samples (n=10 in each case). Their "G80" group was 81.6 ± 3.3 years 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 years 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 youngest group (age = 24.6 ± 2.6 years, 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 and MacRea (1995) study.

There is one article that apportions EEs 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 years participated in a study that estimated TDEE three different ways: (1) DLW, (2) the factorial method, and (3) 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.

	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

Table 3-2. Estimates of Activity-Specific Energy Expenditure for Older Adults

Activity Descriptor	Mean Age	n	Gender	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		
	Mean			**EE**		
Activity Descriptor	**Age**	**n**	**Gen**	**(kcal/min)**	**Reference**	**Comment**
Lying	68 ± 5	6	♂	1.37 ± 0.15	Calloway and 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 and 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 and Zanni 1980	Healthy
				Oxygen Consumption Units		
	Mean			**VO2/BM**		
Activity Descriptor	**Age**	**n**	**Gen**	(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		
	Mean			**VO2**		
Activity Descriptor	**Age**	**n**	**Gen**	(mL/Min)	**Reference**	**Comment**
Walking	72.0±4.0	29	♀	16	(Misplaced)	

average, but there was wide variability among the individual factorial/DLW comparisons (Morio et al., 1997).

3.C METS$_A$

There is little direct data on METS for older individuals. 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 are (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 seniors, although that group is not explicitly identified in the article. To accomplish a fixed workload, METS$_A$ should be adjusted upward for elders to indicate the increase in energy expenditure needed to accomplish that workload. In addition, METS$_{MAX}$ values are lower in older people. This is because older adults have muscle atrophy, diminished balance, and less LBM, making them less efficient in accomplishing work than the younger people on which most METS estimates are based. These factors increase EE$_A$ and VO$_{2A}$ for selected relatively-high VO$_{2.Max}$ activities for seniors, or at least many of them. Further, when considering the fact that seniors have a relatively lower BMR, the $METS_A$ needed to accomplish the same amount of work as younger people has to be higher in the aged (or the time needed to complete a fixed task has to increase). Data on healthy seniors being able to accomplish a specific task at lower $METS_A$ than health-compromised older people (postmyocardial infarction patients) indicates that the hypothesized needed adjustment to "standard" $METS_A$ estimates is logical for older adults (Woolf-May and Ferrett, 2008).

Regardless of the precise applicability of $METS_A$ in seniors, it has been found that older people who cannot exercise at a METS of 5 "generally indicates a higher mortality group," compared with 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 seniors suffering from coronary disease (Franklin, 2007; Franklin et al., 2003; Shaw and Mieres, 2008). Thus, $METS_A$ capability can be used as a marker of fitness in the aged. The reason for an increased $VO_{2.A}$ in older individuals for a particular workload seems to be that VO_2 kinetics are reduced because of slow adaptation of muscle blood flow and oxygen delivery (DeLorey and Babb, 1999; DeLorey et al., 2004, 2005, 2007).

3.D PAI or PAL

PAI in the "free-living" population (all ages) ranges from 1.2 to 2.2 (Black et al., 1996), but estimates over 2.5 are not uncommon in active people (Goldberg, 1997), including seniors. A United Nations report recommends that the PAI for people >65 years should be at least 1.5 to "prevent accelerated changes in muscle and bone" (Dupont et al., 1996). Estimates of PAI for seniors seen 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 seniors are close to being labeled "moderately active" (a PAI between 1.75 and 1.99) in our exposure modeling scheme (McCurdy, 2000). That also holds true for selected ethnic groups in the 70 to 79-year age range (Blanc et al., 2004).

Roberts et al. (1996) performed a meta-analysis of 574 DLW studies and provide the following summary data for PAI values in seniors.

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

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

4. Time Use and Human Activity

ABSTRACT

Topic: This section discusses human activity patterns in older individuals.
Issue /Problem Statement: The pattern and distribution of time spent in different microenvironments and activities is markedly different in seniors than in younger adults. In EPA's exposure models, microenvironment determines encountered concentration, whereas 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 where older Americans' spend their time, on average, but distributional data for their time is scanty. There also is a moderate amount of cross-sectional event- or diary-based information available on seniors from a number of time-use surveys. However, longitudinal time-use information is scant.
Research Needs: More data should be collected and 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 on seniors' locational and activity data from the time use literature. Specific data on these items that are used in our exposure models come from CHAD and other diary data. However, that information needs to be put into perspective to check model performance and the diaries used to estimate exposure. We attempt to do that here. Most of the available older adult time use data in the general literature are not sequentially event based. The data generally are time-averaged, indicating the number of minutes or the proportion of time spent per day in selected activities. There is very little published location information provided for older adults.

EPA uses time use data in its event-based (sequential) exposure models, although it generally calls it human activity or activity-pattern data.[13] 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?")[14] and (2) the contemporaneous time budget diary approach, where the subjects record activities as they undertake them (Ås, 1978; Gershuny and Sullivan, 1998; Niemi, 1993; Stafford, 2009). There are advantages and shortcomings associated with either approach, but the diary approach usually provides more information on more events than the recall approach (McCurdy and 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 seniors has been studied extensively by sociologists, economists, and epidemiologists because the use of time reflects, among other things, functional capabilities, including working potential, interactions with others, and health impacts, of that subpopulation (Lawton, 1999; Singleton, 1999). In fact, the congruence between actual and desired time use is an important concept in the psychology of aging (Calderon, 2001; Seleen, 1982). Life satisfaction is increased when older people 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 older people. It is called the congruence theory of life satisfaction (Seleen, 1982). Part of the congruence theory is "transport mobility" by seniors, 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 older adult 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 nonwork categories, in the second. Both sociology and economics usually disaggregate time use into obligatory and discretionary activities without regard to locations (Gauthier and 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 (NHAPS; Klepeis et al., 1996, 2001; Robinson, 1989; Robinson and Blair, 1995; Robinson and Silvers, 2000; Robinson et al., 1996; Robinson and Thomas, 1991; and Robinson et al.,

[13] 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.
[14] 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 television, and they rarely left their houses. The same findings have been obtained for elderly stroke victims in Australia (McKenna et al., 2008). We could not find a similar U.S. study, but the observations probably apply in this country as well.

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 because of physical 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 frequently is obtained (Lawton, 1999). A sequential structured interview of "yesterday's events" seems to be the preferred method used to obtain activity data from older people (Klumb and 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 and Baltes, 1999).

There are many dimensions of the use of time by people that are important for exposure modeling. They are outlined 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/nonworkday) arrangement of life, captured by the sequence (S) and cycle (C) dimensions. To date, seasonal or yearly estimates of exposure (related to the T and T_{TOT} metrics) have been utilized, but additional time dimensions can be accommodated easily.

4.B Factors Affecting Time Use in Older Individuals

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

Time use changes over the life cycle (biological lifestage) because of age (per se), disability, and health status. But it also changes because of "social" (family role) lifestage factors (Vadarevu and Stopher, 1996). The latter include marriage, parenthood,

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, $\mathbf{e_t}$ 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 $\mathbf{T_{TOT}}$, 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., $\mathbf{e_{x=1}}$ always proceeds $\mathbf{e_{x=2}}$). 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 $\mathbf{e_x}$'s per **T**
Duration (D_x)	Total duration of $\mathbf{e_x}$'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 { $\mathbf{e_{x=1/i}, e_{x=1/i+1} \ldots e_{x=1/n}}$}
Proportional Duration (%D_x)	$\mathbf{D_x / T * 100}$
Rhythm (R.e_x)	A regular pattern of $\mathbf{e_{x=i}}$ 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 $\mathbf{e_{x=i}}$'s that are approximately equal in duration.
Sequence (S)	The order of events in a class ($\mathbf{e_{x=1/1}, e_{x=1/2}, \ldots e_{x=1/n}}$) or for all events ($\mathbf{e_1, e_2, \ldots e_n}$)
Trend	A temporal pattern of events of a given class $\mathbf{e_{x=i}}$ that shows a systematic directionality over time

employment/retirement status, household income, children living nearby, and other considerations (e.g., the “empty nest” syndrome) (McGrath and Tschan, 2004). The largest impact on time use by the aged 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 begin spending a large proportion of time in passive activities (Lawton, 1991).

Most older adult single-person households consist of a female living alone. Females 65+ years are four 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 years, 50% of females live alone versus 23% of males. By 85 years, the proportion is 86% for females and 41% for males (Rosenbloom, 2004b). These factors certainly affect time use by older persons.

Retirement obviously affects elders’ time use (Kim and Hong, 1998; Mancini and Orthner, 1982); Piekkola and 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 older people, leisure usually means discretionary or nonobligatory activities (Lawton, 1999). One type of leisure is voluntary work. In recent years, “unpaid productive activities” (voluntary work) have increased greatly,[15] which results in seniors being “socially productive” for years beyond their (paid/housework) working life (Altergott and McCreedy, 1993). In general, retired males spend more time in active leisure and in the traveling associated with it than do 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 day^{-1} for individuals in the 65 to 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 resulting from differences in time spent outdoors, in motor vehicles, or indoors if pollutant sources are present.

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

Hospitalization obviously affects locational aspects of daily living for older people (Boyd, 2005). Because EPA does not estimate exposures to environmental contaminants inside hospitals 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 older females (>65 years) in a given 18-mo 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 affect 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 U.S. time use information into perspective; see European Commission (2003), Horgas et al. (1998), the series of articles by Leech and co-workers (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, 1990, 1993]).

Literature on the aged, 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 require more social engagement. 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 older persons 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 and 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 and Thomas (1991) directly state that most activity information cannot be used to estimate where people spend time.[16] Some locational data on where

[16] An extended quote from Robinson and 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 older Americans spend time are contained in EPA's *Exposure Factors Handbook* (NCEA, 1997a) and are reproduced here in Table 4-2. Gender-specific data are not available.

Aggregate data on time use distributions by seniors abstracted from various tables in the *Exposure Factors 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 and Klepeis (1996, 1997). The information is arranged under four main categories:
(1) bathing/showering, useful for estimating dermal and inhalation to water contaminants; (2) motor-vehicle oriented locations, useful for estimating inhalation exposures to air toxics and other gaseous pollutants; (3) outdoors, for estimating exposures to any ambient pollutant; and (4) 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 per week, hours per month, and minutes per month and do not fit easily into the minute per day units used in Table 4-3 without making the assumption that daily time is simply the monthly value divided by 29 to 31 days/mo. As already noted, there is a wide variety of time use by seniors 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 and Klepeis (1996) used a number of recodes for both locations (called NEWLOC) and activities (NEWACT). It is not clear from either Tsang and 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 and 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 older adults 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 senior "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+ years in California, but for our purposes the data are insufficient for checking on outputs from the APEX/SHEDS exposure models.

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, because he was funded by EPA to investigate the relationships between time use and potential exposures to smoking and environmental contaminants (Robinson, 1988; Robinson and Thomas, 1991; Thomas and Behar, 1989). This published work, however, is very general with respect to older adults, who rarely are discussed as a separate subgroup. This is also true of Robinson (1977) and Robinson and 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 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 and 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 dataset to represent the wide range of activities in older Americans. Approximately 3,400 of those days were added as part the Aging Initiative program, a tangible result of the Agency's Aging Initiative work. Additional diary days of data are being pursued.

As EPA researchers have shown analytically, there are contextual factors that affect time use by seniors and others, such as day of the week, seasons of the year, special times of the year, social class, educational levels, etc. (Graham and McCurdy, 2004; McCurdy and Graham, 2003). Overall, in the CHAD database, people >64 years old spend about 65 min/day outdoors, but variability in this population group is large; the COV is

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(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).

Table 4-2. Selected Activity-Location Data for Seniors in EPA's *Exposure Factors Handbook*

	Mean "Doer" Time for People Aged 65+ (rounded)*			
	CARB Data		NHAPS Data	
Location/Activity Combination**	**% Doers**	**(min/day)**	**% Doers**	**(min/day)**
"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
Nonresidential 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 and 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.

120% for "habitués" (those people who actually go outdoors). Only 57% of older Americans went outside on the days they were surveyed. Both the time spent outdoors and the "participation rate" by seniors are lower than that for adults <65 years old and children, on average, but the differences are not large, even though they are statistically significant at p=0.05. When gender differences in the time spent outdoors are investigated, older females are outside less than males (60 versus 118 min/day on average), and this difference is significant (p<0.001) (Graham and McCurdy, 2004). Older adults spend less time in motor vehicles (86 min/day on average) than other adults, about 105 min/day, and also have a lower participation rate for that location (Graham and McCurdy, 2004).

4.C.2 The American Time Use Survey

A potentially good source of older adult diary data is the Bureau of Labor Statistics' (BLS) American Time Use Survey (ATUS). There is 1 day of data per person in the survey. See Abraham et al. (2006), Hamermesh et al. (2005), Herz and Devens (2001), Krantz-Kent and Stewart (2007), Russell et al. (2007), and Schwartz (2002) for information on this database. This survey is large and ongoing, with between 12,250 and 14,000 person-days of information being obtained each year since 2004[17]. Approximately 17% of the diary-days in ATUS are for people aged 65+ years. There are some structural problems with the ATUS data from an exposure modeling perspective, but we have conditional plans to address them and attempt to use the database for our work (George and McCurdy, 2011). 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 in 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. Although the

[17] 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 as follows: 13,973 in 2004, 13,038 in 2005, 12,943 in 2006, 12,248 in 2007, and 12,723 in 2008. Thus, there are 85,645 days of diary days available for the 2003 to 2008 time period, the largest and most recent source of U.S. time use data available for analysis from any source.

Table 4-3. Selected Time Use Data for People Aged 65+ Years 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)							Source*
			5%	25%	50%	75%	90%	95%	99%	
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
Playing on grass	3	0.2	30	30	121	121	121	121	1231	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	1205	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 people aged 65+ (1,349) given in Tsang and Klepeis, 1996

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Table 4-4. Activity Diaries in CHAD for Older Adults

Age Range	Total Number of Diary Days	Number of Diary Days Available per Individual					Percent with Only 1 day
		1 Day	2 Days	3 or 4 Days	5 to 9 Days	10+ Days	
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					

United States is included in this essentially historic time use database, the published papers describing it do not focus on seniors 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 and Stolze, 2008; Tudor-Locke et al., 2007), which contains data only on time use patterns of U.S. 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 multiday 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 noncompliant. 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 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 overestimate exposures to pollutants particular to that region, of course. (And exposures experienced in another region are completely ignored.) Although this is a problem with all exposure modeling efforts, it may be a particularly important one for retired seniors because 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 and House (2006). Their focus is on seniors in Florida. From a random-probability telephone survey of people 55+ years old in Florida over a 3-year period, they identified those who spent 1 mo or more per year out of state. They were called "temporary residents" if they were nonpermanent Florida residents. Nonresidents who spent <1 mo in Florida were excluded. They classified the residents as "stayers" if they spent <1 mo 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 >65 years old (Smith and 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 seniors include different emphases, age/gender combinations, and formats. Therefore, it is difficult to summarize the information succinctly. Selected data from U.S. 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 and Lawton (1982), so the data are not very current. The estimates probably are similar to those cited below under Lawton et al. (1986) because the mean age of the sample is the same (76.2 years). 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 time use by U.S. seniors, but combines 31 activity types into six 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. Because of 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+ aged females participate more frequently than 75+ aged males.

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 and 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 and hobbies	44	32
Rest and relaxation	128	200
Sleep	456	452
3. "Gap" and 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 and Lawton, 1982).
The means are "statistically adjusted" to account for age, gender, education, ethnicity, income, and household consumption (Moss and Lawton, 1982).

Knipscheer et al. (1988) provide information on time use (hours per day) in older adults, disaggregated into two age groups of interest to us: (1) 65 to 74 years and (2) 75+ years. 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 houseork, helping others, volunteering, and “going out.” Nonproductive activities are leisure, mass media, television news watching, and newspaper reading (Knipscheer et al., 1988).

The most promising-sounding article on elders' time use is entitled "How do older Americans spend their time?" (Krantz-Kent and 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: (1) 65 to 69 years and (2) 70+ years (other age groupings are included also). We cannot get very much useful exposure information from the article, however, because 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 because 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.

For the "leisure and sports" category, the following mean hours/"average" day information is provided for older females and males (Krantz-Kent and Stewart, 2007). The category is broad, including socializing, communicating, watching television, sports, exercise, recreation, relaxing and thinking, and reading. Most of these activities are quite passive and have low Table 4-5. Time Spent per Day in energy expenditures, usually resulting in a low dose rate even if an exposure occurs.

	Females (h/day)			Males (h/day)		
Age	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 years 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 and 5). The travel time estimates are lower than those provided by Gossen and Purvis (2006); see Section 4.D.1 for more information on that activity.

Activity	Participation Rate (%)	Time Spent (min/day)
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 years; 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/day. 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/day. 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/day 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 seniors do so on any 1 day for a median of 110 min/day.

Linn et al. (1999) provide time use data on 30 COPD subjects aged 56 to 83 years 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 min. 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 and 5).

Group Mean Time Spent in the Categories Shown

	Midnight-6 a.m.	6 a.m.-Noon	Noon-6 p.m.	6 p.m.-Midnight
Percent clock hours 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 hours away from home in Linn et al. (1999) includes those diary hours with one or more 20-min periods that were 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/partial blocks relate to exactly. The authors also provide the following locational data in their Table 5 (p. PM-113). The monitored week is a 4-day time period with concomitant personal particulate and home monitoring data. Coded time use information is available for it and a "reference" week, which 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 nonsignificant 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/day outdoors	62.4	86.4
Min/day in vehicles	36.0	55.2

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

Ott (1989) provides an early description of time use data in modeling exposures, but older individuals are not a prominent subgroup of concern in this article.

Pruchno and Rose (2002) provide selected summary information on time use by a group of frail elders in Cleveland, OH. Some of the 123 people included lived in a nursing home (n=45), whereas 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 and Rose (2002) follow.

Mean Minutes/Day Spent by Frail Elders and Participation Rate by Housing Type

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

As can be seen, time use by frail individuals 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 seniors contained 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." Although 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. Older families socialize almost twice as much (not significant based on an ANOVA analysis) as the other life stage groups and about four times as much for recreation (significant at $p=0.01$). Time (hours per day) spent in recreation also is significantly different (against the population mean, using a z statistic from multiple pair-wise comparisons [Vadarevu and Stopher, 1996]). Some of the differences found in the older family life stage group undoubtedly result from most of them not working compared with the other groups (except for nonworking 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 older adults 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 in Section 4.E.

There are a few articles on the time use of nursing home residents, but because 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 years on average (range: 65 to 99 years) living in a nursing home to keep an activity diary for 2 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 its 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 nonexercise activity/locations seen in nonsequential time use papers.

Kelly et al. (1986) discuss a survey taken in Peoria, IL, of "leisure activities," which include cultural, social, community participation, and home-based activities (plus travel and outdoor activities, which are discussed below). Data are provided on the percentage of older people aged 65 to 74 and 75+ by gender participating in the various activities, as well as for younger age categories (see just below).

Relative Participation by Age and Gender (approximate)

	Females		Males	
Age	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 Recreation	2%	1%	16%	2%
Travel	55%	40%	66%	30%

Although overall activity level in older adults 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 seem to be the most important factors in understanding age/gender differences in activity participation rates. However, there are fairly large decreases in most of the activities listed between the 65 to 74 age groups and those aged 75+ (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 U.S. seniors overall (Dallosso et al., 1988).

Robinson and Caporaso (2009) published an analysis of ATUS data for people aged 65+ (as well as for two other age groups). The authors categorize activity data into four main groups: (1) contracted time, (2) committed time, (3) personal care, and (4) free time. Contracted time focuses on working and commuting to it. The average number of hours per week for seniors 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/week ♀ and 20.8 h/week ♂. Except for the "obligatory" personal care time (sleeping, eating, and grooming), the free time category includes everything else. One interesting category is "fitness activities." Older females spend only 1.1 h/week, on average, in fitness tasks, whereas older males do not spend much more: 2.2 h/week. Total travel time is a modest 5.5 h/week ♀ and 6.4 h/week for males (Robinson and 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 aged 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 ages 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 drops almost in half. Mean trip length, on the other hand, increases. This increase is probably related to the relative increase in airplane usage (Georggi and 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 older Americans' travel patterns is Giuliano et al. (2003). The data come from the 1995 NPTS. Selected data are abstracted in Table 4-7. Gender or work/nonwork breakdowns are not provided. The authors provide graphs of trips by purpose by time-of-day, but these are difficult to quantify because of their format. For most people, work trips occur in the 6:40 a.m. to 6:20 p.m. time period, with many fewer work trips for the 75+ years age group than for the 65 to 74 years age group. The vast majority of all trips occur between 6:00 a.m. and 7:00 p.m. (Giuliano et al., 2003). Okola (2002) corroborates this observation and provides some data on 75+ year olds.

Table 4-6. Demographic and Long-Distance Travel (L-DT) Characteristics in Seniors

Demographic Characteristics	Age Ranges (years)	
	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 (mi)	480	510

Source: Georggi and Pendyala (2003)

She also provides graphical data on weekday/weekend travel splits by shopping, eating out, and socializing, but all ages are included, not just older cohorts.

Hu and Reuscher (2004) analyze the 2001 NHTS information and provide limited data for older individuals. Daily mean trips per person and person-miles of travel by gender are provided for almost a 20-year 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 Years Old

	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 POVs was about 55 min/day for people aged 65+ in 2001 (Hu and Reuscher, 2004).

Frazier et al. (2009) provide descriptive statistical information on the time spent in a motor vehicle in a sample of health-compromised older 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 day^{-1} for females (range: 0 to 375) and 27.8 ± 65.3 min day^{-1} for males (range: 0 to 450). The mean estimates for Los Angeles were 74.4 ± 72.9 min day^{-1} for females (range: 0 to 360) and 53.1 ± 50.4 min day^{-1} for males (range: 2 to 200). Note the wide range and the high coefficients of variability in both areas.

Table 4-7. Local Travel Characteristics in Seniors

Characteristic	Age Ranges (years)	
	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
Nonwork 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)

Gossen and Purvis (2006) provide travel time data for 1990 and 2000 for working and nonworking 65 to 99 year 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/day)

Year	Workers		Nonworkers	
	♂	♀	♂	♀
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 both working categories and years, and differences for nonworkers by gender are significant (at $p<0.05$) for both of the years presented. Gender differences are not significant for the working group (Gossen and Purvis, 2006; Table 2). Ethnicity did not account for significant differences among the groups either.

With respect to travel during the day, the 2001 NHTS indicates that 23% of nonwork-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 seniors, 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—beginning after age 19!—even up to 85 years old, for both genders, with females having a slightly lower rate than males at any age (Ferguson and Braitman, 2006). However, crashes per million miles traveled by age increases after age 60 years, with males having a slightly lower rate. The obvious reason for these results is that, although many seniors keep their driver's licenses as they get older, they drive many fewer miles (Ferguson and Braitman, 2006). Up to about age 54 years, females travel fewer miles than males (but make more daily trips); this pattern seems to continue after age 55 years. The proportion of trips made in cars (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

There are exposure and intake dose implications for the above differences, because 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 per person).

Rosenbloom (2004a) provides detailed information on mobility of seniors in an article titled "good news and bad news." Total 1995 daily trips and total vehicle miles traveled (VMT) by older Americans 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 nonwork related, more so in females than males. These are not unexpected findings. There does not seem to be a trend with

Table 4-8. 1995 Daily Trip Data (Means) for People Aged 65+

Daily Travel Statistics for 65+ Year-Old 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 (Number per Day) by Age and Gender				
	Females		Males	
Age Groups	Trips	Percent Nonwork	Trips	Percent Nonwork
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 per Day by Age and Gender				
	Females		Males	
	Miles	Percent Nonwork	Miles	Percent Nonwork
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) 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 aged was up for the 1983-1995 time period. Overall trips taken per year for 65+ year old drivers increased 77% between 1983 and 1995. 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 older people in 1983.

Table 4-9 provides additional information on modal choice by seniors, but specific gender data are not provided. The mode choice depends, in part, on 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 (even for persons <65 years 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 years of 55 age, 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 Purcher and Renne (2003) compares the 2001 NHTS travel data with the 1995 NPTS data analyzed in the Rosenbloom articles reviewed above. Purcher and 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” (Purcher and Renne, 2003; p. 70).

More recent articles on travel by seniors could not be found. Clearly more information on this topic is needed, especially regarding average daily travel (ADT) and VMT, to ascertain what differential impacts travel activity will have on future exposure profiles in the aged. This research area seems to be underaddressed. Because EPA 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 older individuals.

4.D.3 Outdoors

As mentioned, most studies of seniors (or even younger people) do not provide information on where activities occur. Graham and McCurdy (2004) provide some information on the time spent outdoors by older Americans in an analysis of CHAD data. For 65+ year-old individuals, 57% went outdoors on the day they were surveyed, for an average of 118 min day^{-1}. The range for habitués was 1 to 1,015 min day^{-1}, and the COV was a relatively high 110%, indicating a lot of interindividual variability in time spent in that location by seniors. Frazier et al. (2009) provide information for the mean time spent outdoors by health-compromised older people in two communities (see Sections 4.C and 4.D for more information on this study). There is quite a large difference in this time for the two locations, probably because of their very different climates (Frazier et al., 2009). Including those who did not go outside on any of the 4 to 24 days that were monitored, the subjects spent a mean of 62.7 ± 62.2 min day^{-1} outdoors in Los Angeles (range: 0 to 360 min day^{-1}) and 21.7 ± 51.8 min day^{-1} (range: 0 to 490 min day^{-1}) in Baltimore. There was a lot of day-to-day variability in both samples in the time spent outdoors.

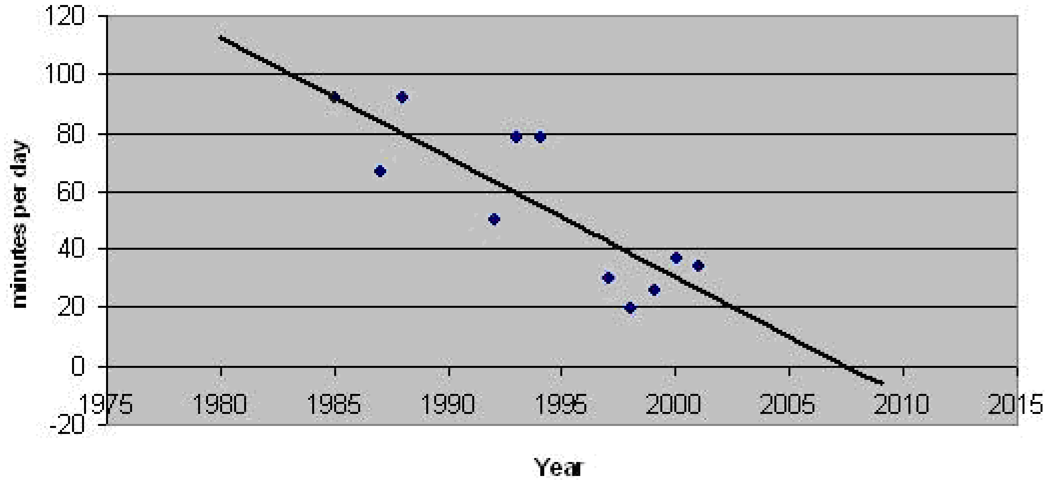
In both areas, there are large and statistically significant differences in the time spent outdoors by gender and by season of the year (Frazier et al., 2009). This study is discussed in greater detail in Section 4.E, as it is one of the few that addressed both intra- and interindividual variability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

Table 4-9. Percentage of Mode Choice for All Trips (1995), by Age

Modal Percentage of All Trips Taken								
	Private Vehicle			Other Mode				
Age Range	Driver	Passenger	Total	Public Transit	Taxi	Walk	Bicycle	Other 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).



Source: Nyswander et al. 2009

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

use diary studies, so the trend line could not be evaluated statistically. The decrease is striking, an approximately threefold 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.

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

4.E Intra- and Interindividual 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). EPA recently has 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: (1) repeat the same pattern, (2) randomly draw from different patterns, (3) a mixture of the two approaches, and (4) 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).

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 equal to $\sigma_B^2/(\sigma_B^2 + \sigma_W^2)$, where the subscripted σs present explained between-person (B) and within-person (W) variances, respectively. The ICC metric often is 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 and de Moor (2000); Baranowski et al. (1999); Matthews et al. (2001); and Trost et al. (2000). Although there is variety in the recommended number of days of data needed to reliability estimate intra- and interindividual variability in the time spent in exercise, Baranowski and de Morr (2000) concluded that 28 days of data spread over four seasons of the year were needed.

Xue et al. (2004) used the ICC logic with a reliability coefficient of 0.8 in their 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. Less data were needed to obtain reliable estimates of the individual mean estimate of indoor time.[18] The analysis also calculated 1-day "lag" autocorrelations for time spent in the same two locations. The *r* (Pearson product-moment

[18] Although the literature on applying reliability calculations to the elderly is exiguous, Jacelon and 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," whereas subjects become noncompliant after 2 weeks (Jacelon and Imperio, 2005). Tudor-Locke et al. (2005) evaluated the number of days needed to estimate weekly steps per day in adults using a pedometer. A 3-day monitoring period achieved a reliability coefficient of 0.8+.

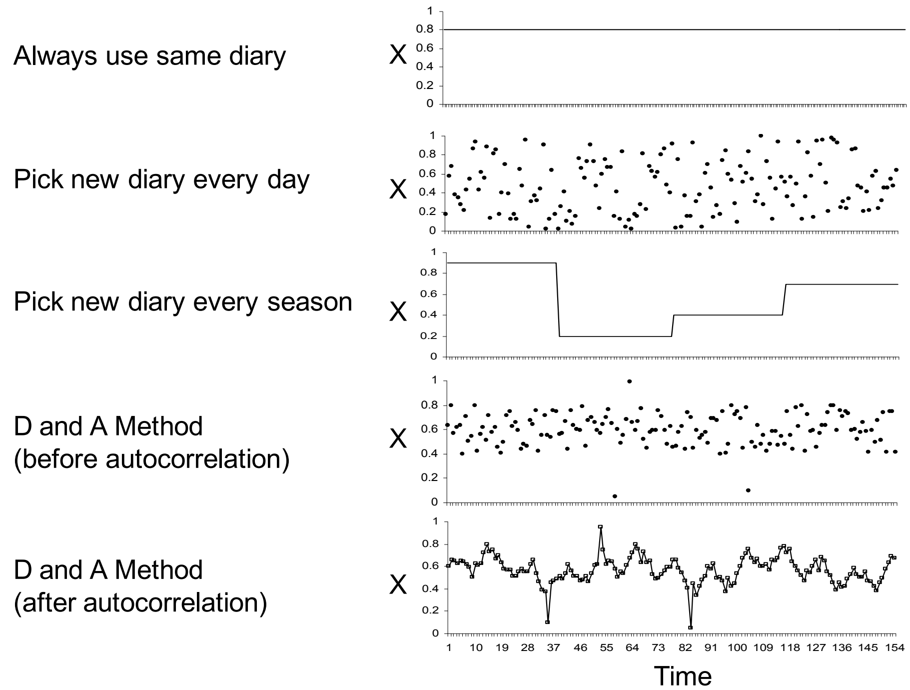

Figure 4-2. Conceptual diagram of alternative decision rules used to sample single-day diaries to develop longitudinal activity patterns.

correlations) for outdoors was about 0.36, whereas the *r* for indoors was 0.45. The last statistic seems to be
57 low, but, surprisingly, there is a lot of day-to-day variability in even that location (Xue et al., 2004).

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 described fully 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 analysis used in EPA's time series exposure models.

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, EPA is developing 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 older adult ICCs and only a few focused on adults in general. One in-house EPA study combined data from three different longitudinal diary studies and calculated ICCs 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 years, so the data probably are not representative of older populations. The table is presented here to delineate the variability in D&A statistics caused by gender, temperature classes (a surrogate for seasonal considerations), and workday/nonworkday distinctions. The D&A values shown in Table 4-10 are similar to those seen in seniors, as evaluated by Frazier et al. (2009).

Another EPA project to delineate ICCs in the population was focused explicitly on health-compromised seniors living in two communities, Baltimore and Los Angeles (Frazier et al., 2009). This study's findings regarding travel and outdoor time spent by seniors have been mentioned a few times above. The Baltimore time use data came from an EPA project described in Williams et al., 2000a,b,c). The sample included 26 individuals aged 65 to 89 years, 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 to 83 years with clinically diagnosed COPD, and it is described in Linn et al. (1999). Time use data were obtained for two 4-day periods in that study.

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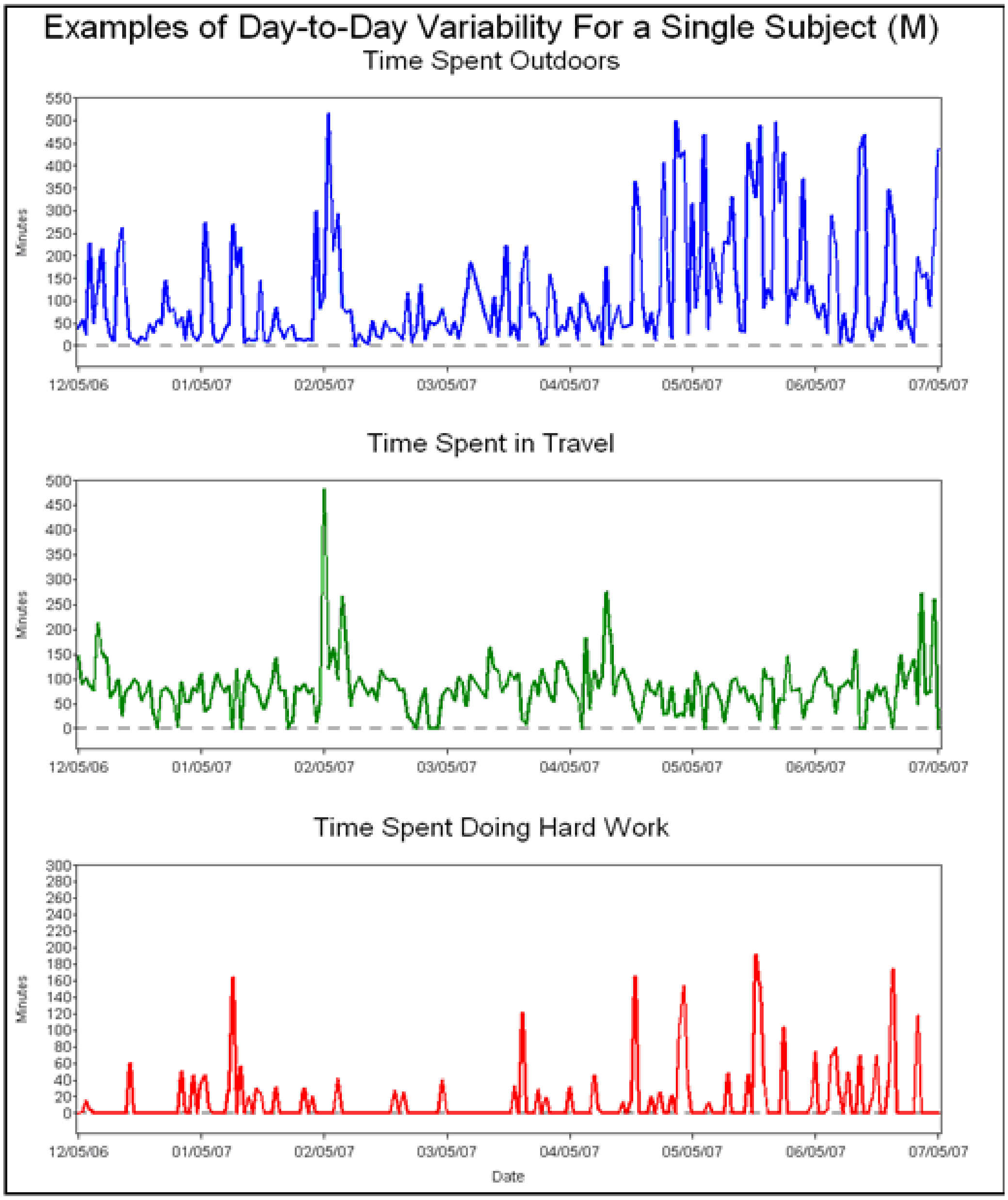

Figure 4-3. Daily variability in time use over 7 mo by a single individual.

The location data from both studies were collapsed into three categories: (1) time spent indoors and (2) outdoors and (3) in a motor vehicle. Data for time spent outdoors and in a vehicle were provided above. Time spent indoors constitutes most of seniors' daily time use, being about 1,324 to 1,388 min day^{-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 p.m., but the differences are not large.

ICCs were calculated in the Frazier et al. (2009) paper using different models. They are listed below, where the vertical symbol (|) means "given" (e.g., season|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 ICCs 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

Table 4-10. Variance and Autocorrelation Statistics in the Internal EPA Study

Characteristic	ICCs and Ds for Specified Locations and Activities							
	Outdoors		Indoors		Travel		Hard Work	
	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: nonworkday	0.11	0.14	0.12	0.21	0.09	0.24	0.06	0.07
	"Raw" and "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: nonworkday	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 coefficient
D: The rank-ordered ICC-like "diversity" coefficient
ICC: The intraclass correlation coefficient
max temp: The maximum daily temperature in degrees Fahrenheit

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

higher ICC. ICC values for seniors are about the same as those seen for younger 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 nonlinear one, exponentially decreasing with an increasing ICC. At ICCs 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.

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 EE-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 older adults.

5.A Overview of the Literature

There are thousands of articles on the impact of PA and exercise on the aging process in seniors.[19] Hundreds are being added every year. We have had to cull the shear magnitude of the available information to a manageable amount by focusing on the following.

- U.S. studies (because of the cultural component of PA)
- "Free-ranging" individuals living independently at home (Institutionalized or nursing-home residents are not discussed, with minor exceptions.)
- Studies that use objective measurement techniques 60 to ascertain the frequency, duration, and intensity of PA[20]

This last focus means that limited attention is given to the extensive "epidemiological" research in the seniors 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 older adult 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 (ongoing for more than 50 years; see the many citations for I.-M. Lee and R.S. Paffenbarger (1991-2001) and Sesso et al., 1999, 2000, 2003); the Physicans' Health Study (Lee et al., 1997); the Baltimore Longitudinal Study of Aging (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 al., 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 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 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 then often are assigned to low, medium, and vigorous PA levels and compared with 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 overestimate by varying amounts the amount of PA undertaken when compared with 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 and 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 and Saelens (2000), which includes mention of eight previous reviews on the topic.

The older adult PA literature 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,

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[19] 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.

[20] 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 decrease in the amount of time spent in the LPA, MPA, and VPA categories, respectively, with the elderly spending very little time in the last category.

2005). The list of overall benefits is extensive, and includes the following attributes, many of which are related.

- 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 and Keller, 1997; Gregg et al., 1998; Hughes et al., 2004)
- Slowing the rate of decrease in $VO_{2.Max}$ or even reversal of this functional decrease via concerted exercise in older people (Ades et al., 1996; Allison and Keller, 1997; Fleg et al., 1995; Shephard, 2009) [This improves endurance and reduces heart-related issues (see items 4 and 9 below).]
- Reducing physical/mental unhealthy days for arthritics (Abell et al., 2005; Hamer et al., 2009)
- Preventing coronary heart disease and "cardiovascular events" (Berlin and 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 per 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 and Franklin, 2006).]
- Reducing preinfarction angina incidents in older people having existing acute myocardial infarction; also reducing stroke rates (Abbott et al., 1994; Abete et al., 2001; Sallis and Owen, 1999)
- Slowing muscle mass loss and weakness (Allison and Keller, 1997; Buchner et al., 1997; Fiatrone and Evans, 1993; Koopman and 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 seniors (Berk et al., 2006). It reduces back pain by strengthening muscles that stabilize the spine and maintaining flexibility (Sallis and Owen, 1999). Overall, there is better physical functioning in older, exercising subjects (Brach et al., 2004a,b).]
- Maintaining weight and decreasing obesity rates (Sallis and Owen, 1999; Van Pelt et al., 1998)
- Reducing high-density lipoprotein (HDL) cholesterol (Casperson et al., 1991; Reaven et al., 1990)
- Reducing hypertension and reducing blood pressure (Bassett et al., 2002; Reaven et al., 1991) [PA also reduces "vascular stiffness (Havlik et al., 2003; Seals et al., 2006).]
- Increasing joint flexibility (Birrer, 1989)
- Increasing longevity (Paffenbarger and Lee, 1996; Manini et al., 2006; Morey et al., 2002; Sallis and Owen, 1999)
- 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.]
- 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).]
- Preventing or delaying the onset of diabetes (Hawkins et al., 2009)
- 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 older females (Yaffe et al., 2001). The incidence of Parkinson's disease was also lower in active older individuals (Thacker et al., 2008).]
- Improving general quality of life and decreasing depression (Schechtman et al., 2001; Strawbridge et al., 2002)
- Reducing the risk of lung cancer in females who are current or former smokers (Sinner et al., 2006)
- 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.]
- Preventing early onset of ADL and IADL limitations (Stewart, 2005)
- 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 older individuals 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 [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 per 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 its 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 and Owen (1999).

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

Physical inactivity is, of course, the flip side of PA. Data indicate that inactivity is an independent factor for certain physical impairments in older people, particularly hip fracture (Coupland et al., 1993; Sallis and 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 result from sedentary lifestyle alone (Stewart, 2005). There are some studies showing that physical inactivity is a better measure of PAEE in seniors, and that, if sedentary activities are reduced, 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 older people because it is relatively more difficult for them to undertake vigorous activities because of all 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.

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

We probably should mention that there are some risks associated with PA in seniors, particularly musculoskeletal injury and sudden cardiac arrest (Haskell et al., 2009). The negative issues of PA are minimized in the literature, probably because of the relatively low energy expenditure levels of activities undertaken as PA by older adults, 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 and Inactivity in Older Adults

Hawkins et al. (2009) report on an accelerometer study that was part of the 2003-2004 NHANES cycle. This was the first time that accelerometers were used in an 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 people aged >60 years, 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% to 67% of those seen in the 40 to 59-year age group for all the subgroups depicted (AA = African Americans; C = Caucasians; and H=Hispanics). The PA categories were defined above.

Accelerometer Counts per Day in Thousands for Persons >60 Years 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 provided uniformly or discussed in Hawkins et al. (2009). Female LPA is 80% to 86% of TPA and male LPA is 70% to 80% of TPA, with ethnic differences seen in the count data.

CDC has data on physical inactivity in seniors from its Behavioral Risk Factor Surveillance System (BRFSS), a random probability telephone survey of the noninstitutionalized U.S. population. In 1995, CDC published state-specific data on older adults' inactivity for the 1987 to 1992 time period; overall inactivity levels decreased from 43% in 1987 to 39% in 1992 (BRFSS Coordinators, 1995). For 1992, the range in inactivity among the states' older people varied from 27.2% in Colorado to 62.5% in Mississippi (BRFSS Coordinators, 1995). Thus, in general, the United States is far from attaining its goal of having a senior inactivity goal of 22%.

Macera and 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 and 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.[21]	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 was found on the topic is contained in CDC (2007). They provide the

[21] 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.

following PA estimates for citizens 65+ years old for the country as a whole and by state. The overall U.S. estimates are as follows.

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

The proportion of people aged 65+ that meet recommended PA guidelines varies from 27.7% in Kentucky to 52.3% in Alaska (CDC, 2007).

Another way that CDC presents PA data on seniors is contained in CDC (2009a). The percentage of two older age/gender groups that engage in regular LTPA in January through 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%	(6.4 - 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). (Because group-specific sample sizes were not provided, SEs could not be converted into SDs.)

	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 seniors attaining different numbers of vigorous bouts per week (with standard errors) are shown below.

	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, although 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 to 4 days w^{-1}.

It should be noted that national data on U.S. PA in seniors, 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 (NCHS; affiliated with CDC) surveys with random-probability designs, there was a 10-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 older people aged >65 years wearing an accelerometer found that seasonal and daily weather variations in the amount of activity counts are correlated positively 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. (1990b) placed an accelerometer on older people (23 males aged 72.9 ± 3.9 years and 22 females aged 72.9 ± 6.5 years) for 3 consecutive weekdays. The percent of time spent by the subjects in three general PA categories is shown just below.

	Females	Males
Lying and "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. (1990a,c), older females were more active overall than older 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., 1990c).

Most of the data reviewed above and in the next section are 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 study (Breuer and Wicker, 2009). This is caused by the mixing together doers and nondoers in cross-sectional studies, which "balance out" individual trends, especially for those older 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 nondoers. 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. Although their overall better fitness level might protect them better against xenobiotic "assaults" from an exposure, the underlying etiology of effects are characterized better when lifestyle factors in exposed individuals are considered explicitly, everything else being equal.

5.C Specific Estimates of Physical Activity in Older Adults

Gauthier and Smeeding (2000, 2001) provide PA data for two U.S. age groups (65 to 74 years and 75+ years) at four points over a 28-year 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 to 74 year-old males and females, respectively). There were no 75+ year-old 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 four 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 to 74 years old, from 0.1 h/day in 1975 to 0.7 h/day in 1993. For males aged 75+, this time varied from 0.1 h/day in 1975 to 0.3 to 0.4 h/day in the more recent time periods (Gauthier and Smeeding, 2001; Table 2). There did not seem to be a trend in undertaking sports and fitness for females aged 65 to 74, varying between 0.1 and 0.3 h/day for the four time points. Neither was there a trend for females aged 75+; the time in this category varied between 0.0 and 0.2 h/day over the years (Gauthier and Smeeding, 2001).

Iso-Ahola et al. (1994) of the University of Maryland evaluated changes that take place among the types of activities undertaken by seniors aged 64 years or older. The authors evaluated, among other things, the numbers of people beginning, ceasing, or maintaining specific activities as they aged. They calculated a "replacement rate" in percent for the activities (a negative rate indicates that seniors ceased participating in 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, such as board games, television viewing, listening to radio and/or music, reading books, etc.

Katz and Morris (2007) provide selected time/participation rate data for 375 older women who had rheumatoid arthritis. Their sample included women who could have been as young as 38 (mean=60 years, SD=13.2), so we do not review their information here. More than 80% of their sample spent less than 60 min/day 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 years) and asked them to keep a diary on how many minutes per 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 day^{-1} in strenuous activity and 4.3 ± 7.6 min day^{-1} in 5+ METS activities (Roberts, 1995). Note that the COV for both activity metrics is >1.0.

Useful quantitative information found regarding PA data for seniors 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, are based on questionnaires or other subjective information.

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). Although there is a general agreement between pedometer and accelerometer estimates on the amount of physical activity, particularly walking, undertaken by seniors, 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%, whereas others underestimated it by 25% (Schneider et al., 2004). Accuracy can be a problem, therefore. On the other hand, intrainstrument reliability (Cronbach's α >0.80) of most instruments is good (Schneider et al., 2003).

Pedometers, when compared with other objective measures of PA, even the criterion pedometer, usually underestimate the number of steps taken by seniors by a considerable percent. In a study of a Yamax pedometer in seniors dwelling in a nursing home (NH) and a community (CD), mostly females in their 70s (NH=79.4 ± 8.2 years; CD=70.6 ± 5.5), steps were undercounted by 25% to 74% at a slow pace, 13% to 38% at a moderate pace, and 7% to 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 older adults (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 seniors, and pedometer data must be used with caution.

A study in Oregon of 5-day pedometer counts found that females aged 60 to 69 years 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 years and older, so it may not be accurate for older cohorts). Note that the step-count COVs for the two age groups are relatively large and increases for the older group compared with the younger one (66.2% to 80.9%).

Secondary data on observed step counts in U.S. seniors is provided by Tudor-Locke et al. (2009a). They are reproduced here in 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

Table 5-1. Physical Activity Estimates for U.S. Older Adults

Age (Mean ± SD)	G	Ethnic 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 et al. 1994	n=161; 7-day recall
56.2 ± 4.1	M	Mixed	Normal	5.7 ± 6.7		0.7± 1.8	Young et al. 1994	n=196; 7-day recall
68.4 ± 9.4	B	Mixed	NS		2.5± 3.9		Wilcox et al. 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 and Smeeding 2000	n=134; survey: see note
65-74 (1985)	F	NS	NS	2.1 ?			Gauthier and Smeeding 2000	n=227; survey: see note
65-74 (1993)	F	NS	NS	1.4 ?			Gauthier and Smeeding 2000	n=510; survey: see note
75+	F	NS	NS	0.0 ?			Gauthier and Smeeding 2000	n=65; survey: see note
75+	F	NS	NS	1.4 ?			Gauthier and Smeeding 2000	n=114; survey: see note
75+	F	NS	NS	0.7 ?			Gauthier and Smeeding 2000	n=349; survey: see note
65-74 (1975)	M	NS	NS	0.7 ?			Gauthier and Smeeding 2000	n=81; survey: see note
65-74 (1985)	M	NS	NS	2.8 ?			Gauthier and Smeeding 2000	n=173; survey: see note
65-74 (1993)	M	NS	NS	4.9 ?			Gauthier and Smeeding 2000	n=298; survey: see note
75+	M	NS	NS	0.7 ?			Gauthier and Smeeding 2000	n=29; survey: see note
75+	M	NS	NS	2.8 ?			Gauthier and Smeeding 2000	n=87; survey: see note
75+	M	NS	NS	2.1 ?			Gauthier and 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 and 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/week
				Percent Reporting Participation in "Sports, Exercise, and Recreation"				
65+	F	Mixed	NS	15			Russell 2007	n=491; ATUS recall; doer mean=69 min/day
65+	M	Mixed	NS	21.3			Russell 2007	n=479: ATUS recall; doer mean=104 min/day

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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 and fitness"= "active sport" and "walking"

Table 5-2. Observed Steps per Day Pedometer Counts in U.S. Seniors

Age Range (years)	Mean Age (years)	Sample Size (number)	No. of Days Obs.	Steps/Day Mean	Steps/Day 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).

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 older adults are considerably less than those in younger adults. Bassett and Strath (2002) reviewed the pedometer literature and provide data from one non-U.S. study that indicated that the mean number of steps per day declined from 11,900 in males aged 25 to 35 to 6,700 in males aged 65 to 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 U.S. citizens are considerably lower than those estimates.

Step count data from other countries indicate that U.S. seniors are less active than those in other "developed" areas. For example, a Swiss study found that females aged 65 to 74 took on average 7,300 ± 3,300 steps/day and males of the same age had 6,700 ± 3,000 steps/day (Sequeira 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 older people, as there are for others (Shephard and 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 and McCurdy (2004) should be undertaken to see if additional seasonal differences for PA in seniors can be discovered in CHAD.

6. Health Considerations in Older Adults

ABSTRACT

Topic: This chapter discusses the wide variety of health issues encountered by seniors.
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 on the pollutant, some of the Agency's NAAQS reviews have focused on population subgroups with preexisting diseases or activity limitations. Examples are the O_3 NAAQS review that evaluated exposures to (among other subgroups) asthmatic children, the SO_2 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 EPA's OAQPS nor NERL have undertaken an exposure modeling assessment of older individuals having 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 and Thorslund, 2007; p. 151). The language of "disablement" [sic] is in a state of flux and has been since the early 1990s (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 and Simonsick (1993), Jette (2006), and the series of articles by Newman et al. (2003, 2005, 2006). Having two or more of these conditions is called a co-morbidity[1].

Chronic medical conditions

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

Chronic medical conditions also are 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 also can be the result of 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 on the individuals' lifestyle behaviors, personal attitudes, and social context (Jette, 2006).

Functional limitations/disability

- ADL
- IADL
- Discretionary physical activity limitations (exercise)
- Leisure-time and social restraints and limitations[3]

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[1] See the 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.

[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

- Limitations on occupational and/or other role activities

A number of these concepts have been incorporated into WHO's *International Classification of Functioning, Disability and Health* (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 aged (Agüero-Torres et al, 1998), and that condition will be very difficult to model in an EPA exposure assessment because of the 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 individuals with dementia, but these are not identified because 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 older individuals.

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 and 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 on Boult et al. (1994). See Johnson and Wolinsky (1993) for an alternative conceptual model. The paradigm proceeds from health conditions to curtailed activities.

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 on 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, 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 (LSOA) and the Health and Retirement Study (HRS). An analysis of 6-year change in disability in LSOA seniors (n=1,644 ♀, whose average age at baseline = 77.3 years [range = 70 to 99], and 1,133 ♂, whose average age was 76.9 years in the beginning [range = 70 to 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 shown below.

Functional Limitations	Median Percentage of ADL Onset and IQ Range for Females	Median Percentage of ADL Onset and 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) provide data on the prevalence of functional limitations for many chronic conditions in adults aged approximately 76 years grouped by age and ethnicity (black and white). Although there are some ethnic differences, in general, almost all of the subjects had at least one chronic condition at the beginning (baseline) of the study, between 86.7% and 90.2% for females and 82.1% and 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.

Dunlop et al. (2007) provide similar data from the 1998 HRS survey for 65+ year-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

but probably occur indoors: dancing, playing a musical instrument, doing housework, climbing stairs, participating in group exercise, and swimming.

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

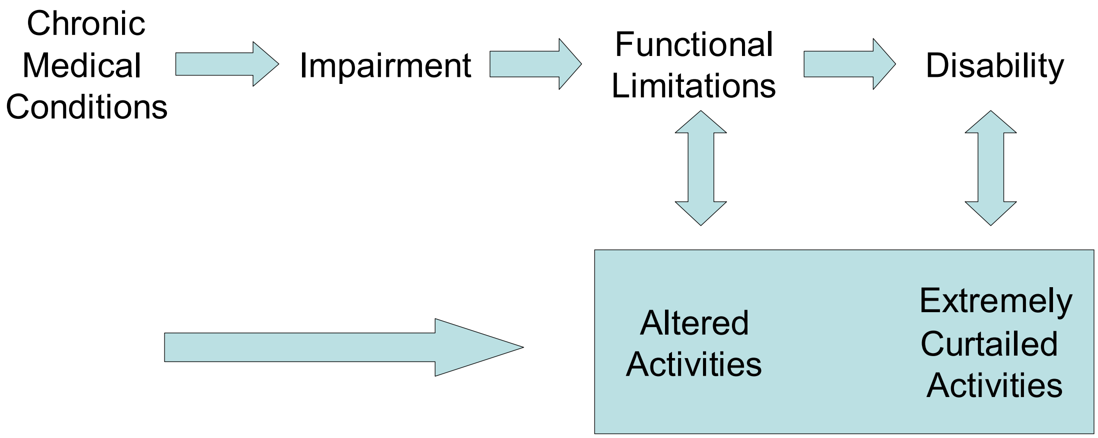

Figure 6-1. Conceptual model for modifying activity pattern data based on assessment of functional limitations and disabilities.

whites, both in the 45% to 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 70 these disabilities likely affected time/activity patterns and, thus, exposures.

One of the most often used working definitions of disability in the aged is “functional limitation,” a “limitation in one or more major life activities” (Heath and Fentem, 1997). The 1992 National Health Interview Survey (NHIS-92) found that, although 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 approximated below.

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

In addition, people older than 70 years have two disabling conditions on average (Heath and Fentem, 1997). Co-morbidity is a major problem in the aged, 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, which is considered to be a preliminary investigation, is explained in the appendix.

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 NHIS. The proportion of people aged 65 to 74 years who have one or more limitations is 27% ± 0.8% (mean ± standard error), and, for elders aged 75+ years, 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 more than 85 years old. These women completed a weekly symptom survey, and their responses were significantly and positively associated for up to 23 weeks. There does not seem to be an age or disability pattern in an analysis of nine [age * disability] classes (65 to 74, 75 to 84, and 85+ years 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 and 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 National Long-Term Care Survey (NLTCS), 18% of elders with one or more ADL disabilities had no disabilities after 2 years (Fried and Guralnik, 1997). The overall prevalence of disability in older adults also is declining by about 1% per year, probably because of improvements in medical technology and healthy behavioral changes (Cutler, 2001). In longitudinal studies of the aged, both the number of years with disability-free life and life expectancy are increasing over time (Crimmins et al., 2009). Although the number of elders 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+ year old age group.

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

(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 and 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 older adults. Thus, it is difficult to obtain a clear picture of morbidity/mortality patterns in seniors that could serve to put an environmental exposure modeling into perspective. There are many overviews of mortality rates for older people in the literature (Crimmins et al., 2009). An interesting one is Rudman (1989), which provides age-specific death rates by disease and disability classes.[1] There are many articles available on the general topic; it is a subject in and of itself.

There are numerous articles on what are good predictors of future ADL and IADL limitations in older 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, all have 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 and Skerrett (2001), Meijer et al. (2001), and Sunman et al. (1991).

A health-related issue that is examined only indirectly in this report is the increasing obesity rates in older people (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 and 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 senior obesity on exercise and physical activity levels. There are little or no data on how obesity affects older individuals' time use (Section 4) and responses to environmental exposures (Section 7).

6.B ADL and 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's self (Guralink and Simonsick, 1993). These are 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 it now is used widely in surveys of community-dwelling populations (also sometimes called "free-ranging" people). For additional information, see Guralink and 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 and Simonsick, 1993). Although 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 noninstitutionalized people "failing" one or more ADL or IADL vary widely, and it is difficult to ascertain trends in these metrics over time. In the 1980s between 5% and 8% of people aged 65+ living in the community could not perform all ADLs without assistance (Guralink and Simonsick, 1993). There is a marked difference among areas of the United States in the percentage of older adults needing assistance with ADLs, even for the same age groups, and the proportion increases with age. The percentages approximately double or the 75 to 84 year-old "cohort" compared with those aged 65 to 74 years, and double again in the 85+ year-oldgroup (Guralink and Simonsick, 1993).

The doubling rate phenomenon applies to at least three of the IADLs, (1) preparing meals, (2) shopping, and (3) doing light housework, but only for the age 65 to 74 to age 75 to 84 pairs. From age 75 to 84, the percent of older people dependent on help for one or more of the three IADLs mentioned more than doubles. In fact, the ratio for 85+ is about three times that of the 75 to 84 years group (Guralink and 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

[1] 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.

increases with the number of ADLs affected (Guralink and Simonsick, 1993).

Adams et al. (2009), mentioned above, also provide estimates of the proportion of older individuals having one or more ADL and IADL limitations. Their estimates (mean and standard error) are as follows.

Age	ADLs	IADLs
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 and Simonsick's (1993) values, but the rate of increase between the two groups is about three 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 affected seniors. However, we have no information in CHAD or in any other time use database that provides explicit information on IADL problems. ATUS may be able to address the issue most directly by comparing the lack of time spent in certain activities by seniors vis-à-vis younger cohorts. Hence, the only way to simulate exposures for older people 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 seniors' movement in the residential environment, including a number of ADL activities. The rationale is that seniors with disabilities could remain at home longer if they could be "watched" to see if they were still ambulatory. The 2008 Institute of Electrical and Electronics Engineers-Engineering in Medicine and Biology Society (IEEE-EMBS) conference has a number of articles on using "microtechnology" to monitor basic activities in older people, 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 and Nugent (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 older individuals, 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 seniors and others on providing care for other older persons. In some cases, the old are taking care of the "old old" [sic]. Because 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 and Moore (1995), Mancini and Blieszner (1989), Moss et al. (1993), and Russell et al. (2007).

6.D Cognitive Issues in Older Individuals

Another subject that must be investigated only briefly in this report is the decline in cognitive function seen in seniors, except where it becomes the root cause of functional limitations and physical activity, as discussed in Section 6.B. There is 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 and 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 aged can do and often result 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).[2] 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 intraindividual variability in cognitive function seen in longitudinal studies of seniors and other age cohorts (Salthouse, 2007). In fact, intraindividual variability in cognitive "scores" are about 50% of the interindividual 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 older adults 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 older individuals 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

[2] 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.

involuntarily) to an indoor space with little or no interaction with the ambient environment.[3] 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 be aware only of the potential impact of cognitive issues on activities, locations, and exposures.

[3] 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: Although these topics may have no bearing on research needs for exposure modeling per se, the increased sensitivity of seniors 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 aged 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 seniors are discussed extensively—in much more detail than is possible here—in the environmental epidemiological literature. 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 health-compromised older people. Those with cardiorespiratory limitations are the prime “sensitive” group[1] for both PM (all size fractions) and CO (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 and colleagues.

The impacts of older people on the environment have received not much attention until recently. EPA and CDC together have provided leadership in this area. The nonphysical environmental literature is almost silent on the issue of impacts by seniors on nonhome or noninstitutional 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 seniors subjects aged 62 to 94 (of mixed ethnicity and both genders) after riding in a diesel bus. Nitric oxide is a general marker for pulmonary oxidative stress and inflammation and is probably most associated with PM in diesel exhaust. Other chemicals associated with mobile sources also likely played a role in the effect. For example, another transportation-related air pollutant, O_3, causes oxidative stress in lung cells and is associated with adverse health effects in seniors (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. Because older people spend more time at home than younger 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 such that 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 when accounting for results, such as the association of Parkinson’s disease with dietary consumption assessment and 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, 2004?).[2] This “developmental origins of health and disease” hypothesis was based originally on heart disease and diabetes studies. Some of the toxic exposures that have been implicated include lead, mercury, pesticides, persistent organic compounds, and polychlorinated biphenyls (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 older population 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

[1] “Sensitive” is the term used in Section 109 of the Clean Air Act to identify susceptible people.

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

(U.S. EPA, 2004). There are a number of PowerPoint presentations about pharmaceuticals used by seniors 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 Web site (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, Sykes (2009), "Prudent disposal of unused medications: why it matters to our aging population" and "Discarded drugs as environmental contaminants" (Ruhoy and Daughton, 2009). The Agency has studied the problem of unused pharmaceuticals in some depth (U.S. EPA, 2009a) and has proposed effluent guidelines for them (U.S. EPA, 2009b). It would be difficult to try to expand on this topic because it is new and rapidly changing. The interested reader can access the EPA Web site provided above and the accompanying links for more information on the impact of discarded pharmaceuticals and other chemicals (mostly by seniors) on the environment, particularly on water body ecosystems. See Daughton and Ruhoy (2009) also.

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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: (1) arthritis and (2) co-morbidity involving dementia as the "reference" illness. This appendix is not considered to be a final product but, rather, 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+ year-old individuals included in the CHAD database. Because the data reviewed generally were not disaggregated by gender, the probabilities apply to both females and males. Because 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 community-dwelling seniors living in a private residence.

Although 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 treated explicitly 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 as follows.

Arthritis | Dementia (Confined)	65-79 80+	Point estimate (40%) Uniform (50%-60%)
Arthritis | Mild Cognitive Problems	65-74 75+	Uniform (50%-70%) Uniform (50%-75%)
Arthritis | Very Active Lifestyle	65+	Point estimate (35%)
Arthritis | Unknown Cognitive Condition	65-69 70-74 75-79 80+	Weibull (ς=57%; β=small) Weibull (ς=55%; β=small) Uniform (53%-70%) Weibull (ς=50%; β=small)

AP.B Overview of the "Population" Analysis Undertaken

We ultimately are interested in undertaking exposure analyses of older adults 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. EPA's modeling 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[31]. Our models already disaggregate people into age and gender subgroups but include other disaggregating factors as well, depending on the environmental hazard of interest. Examples are exercising asthmatic adults as a susceptible subpopulation group for sulfur dioxide exposures; older people with angina as the "sensitive" group of concern for CO exposures; and, exercising children and outdoor workers for O_3 exposures. With respect to seniors as a general subpopulation group, there long has been concern about their exposures to PM—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 that cohort in its NAAQS-setting process to date.

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[31] 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 because of fatigue), ventilation, and alveolar ventilation rate. These parameters are dependent, in part, on 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 Arthritis

Three different types of disorders frequently are subsumed under the term arthritis; (1) osteoarthritis, (2) rheumatoid arthritis, and (3) 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, who may not know precisely what type of arthritis they have. This probably is the reason for some of the differences in the prevalence rates seen below.

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 subpopulation group in Agency exposure analyses.

There are numerous estimates of the percentage of the population 65 years old with arthritis. Probably the most definitive is the CDC, National Center for Health Statistics (NCHS) presentation of data from the biennial NHIS. Hereafter, these data are cited just as NHIS with the year 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 older males have arthritic symptoms as do 39% of older 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 below in an abbreviated format.

Bean et al. (2004)	CDC: National	70 years: 60%
Dunlop et al. (2002)	LSOA	76±6 years black ♀: 71% 76±5 years white ♀: 58% 76±5 years black ♂: 54% 76±5 years white ♂: 42%
Dunlop et al. (2007)	HRS	65 years black: 60% 65 years white: 53% 65 years Hispanic: 45%[32]
Lyketsos et al. (2005)	Cache County	65 years: 54%
Schmader et al. (1998)	Durham EPESE	>65 years: 69%
Song et al. (2006)	HRS 1998-2000	65 years: 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 United States (all 50 states; n=492, 83%; mean age = 61.6 years), 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 $\alpha=0.05$).

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 years on average, were 67.5% black, and 22.8% had arthritis (among other chronic diseases). Nonparticipants were aged 63.1 years on average, were 55.9% black, and 18% had arthritis. These relative arthritis estimates are much lower than those provided above.

In a paper describing an unusual approach to gathering health and activity data, Clark (1999) describes a focus-group study (8 to 10 people at a time) that eventually included 771 individuals who were selected randomly from the RMRS system, as was

[32] 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.

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 years old with arthritis was 44.1%. Clark compared this estimate to the 1984 NHIS, which showed a 55.0% incidence of arthritis in the 70+ year-old population.

Dunlop et al. (2002) report data on changes in functional limitations in older individuals over a 6-year period using data from the Longitudinal Study of Aging (LSOA). The LSOA is a prospective survey of community-dwelling people 70 years old when first interviewed in the 1984 NHIS. 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 as follows.

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 years—68% were overweight or obese, and they had about two chronic medical conditions total (= 2.1 ± 1.2).

Another longer term study of seniors is reported by Gill and Gahbauer (2005). This paper describes a sample 552 people 70 years old that had no baseline disability in four essential activities of daily living: (1) bathing, (2) dressing, (3) walking inside the house, and (4) 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 mo after the study began. The median age of the sample by this time was 81.5 years (range: 75 to 101); 67.2% were female, and 89.7% were white. About 46.2% of them had arthritis.

Another underexplained study of community-dwelling people in an unnamed location is reported in Ho et al. (2002). Because 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., 2000). 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 (52.6% [42]; 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 years old 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 years, 29% aged 75 to 79 years, and 31% 80 years. 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, whereas 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% cross-sectional participants and by 44.6% of the longitudinal 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 and 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 years old living in the community (noninstitutionalized). The mean age is 77.9 years ± 4.9, with a range of 60 to 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 had one or more physical limitations and did not participate in regular vigorous physical activity. A high proportion had other chronic conditions (see Table AP-1). See the discussion of this study below.

Table AP-1. Co-morbidity Associated with Arthritis Without ADL Limitations

	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

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.

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 who subsequently participated in an exercise program (Stewart et al., 2001). The mean age of the sample was 74.1 years ± 5.6), with a range of 65 to 90 years; 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 years old in two counties in southern New Mexico as part of a 3-year study of the health needs of southwestern U.S. 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 years, with a range of 60 to 92 years. Fifty-seven percent of the Hispanic and Caucasian respondents (separately) stated that they had arthritis.

A study of multiple chronic conditions in Seattle older people 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+ years 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 was 65 to 69 years (23%), 70 to 74 years (30%), 75 to 80 years (24%), 81-84 years (15%), and 85 years (8%). Most of the respondents were white, 91%, and 4% were black. The proportion of the sample with arthritis was 26%.

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 years, and 35% of the sample was between 50 and 64 years of age. The average age was 68.4 years ± 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 three groups experiencing different intervention approaches, with the range being 62.5% to 75.0%). The mean age of the sample was 76.9 years (SD: 5.7), and 83.3% were female.

A study that provides estimates for rheumatoid arthritis, 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 seniors in Leisure World, Laguna Hills, CA. This is a retirement community and 13,451 people participated in the study for 13 years on average. The age of study participants varied between 44 and 101 years at entry, with a mean of 73.5 years. Overall, 5.9% of them had rheumatoid arthritis, and this percentage changed only marginally with BMI. The prevalence of rheumatoid arthritis by BMI category was as follows.

Underweight (BMI <18.5)	5.8%
Normal (BMI 18.5-24.9)	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 caused by 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 years old 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 mo.

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, UT, 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, who 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 older Mexican-Americans who 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 8-year period (1993-2001). The data depicted come from the baseline, 1993-1994. Cognitive capability is defined using the 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 on 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 years ± 7.1. The proportion of residents having heart disease, both the "non-demented independently functioning" and those with dementia, is much greater than in 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 to 6 years, and 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), which, like the Schmader et al. (1998) study, is part of Duke University's long-term, community-based study of 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 L. 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 L. Wang et al. (2006). For dementia-free people 65 years old, 16% had coronary heart disease, and 6% had cerebrovascular disease, compared with 26% and 14%, respectively, for seniors

Table AP-2. Co-morbidity 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 and abbreviations:

CIND = Cognitive impairment but no dementia

MI = Myocardial infarction

SD = Standard deviation

Note 1: Percentage of sample taking: **0** prescription drugs-24.6; **1-4** drugs-61.3; **5+** drugs-27.2%

Note 2: Percentage of sample taking: **0** prescription drugs-38.3; **1-4** drugs-56.0; **5+** drugs-5.7%

with dementia (both statistically significant at $p<0.001$ using a Wilcoxon rank sum test at $\alpha=0.05$.

Dementia obviously affects what people do, especially their leisurely activities. We could uncover only 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[33] 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 find any other paper on this topic.

AP.D.2 Arthritis as the Reference Health Problem

Seniors 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) provide 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 older adults with arthritis, 15.4% also have diabetes, 26.2% have heart disease, 11.3 % have pulmonary disease, 20.2% are obese, and 7.1% have had a stroke. All of these conditions were statistically significant higher than in seniors without arthritis, using a χ^2 test at an $\alpha=0.05$, except for stroke (6.5% for seniors 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 older individuals having Alzheimer's in three different longitudinal panel studies, called "cohorts" in the paper. All three studies used the MMSE test to define Alzheimer's. The proportion of cohorts diagnosed with Alzheimer's varies widely among the studies. One cohort is from the Chicago Health and Aging Project (CHAP), a population-based study in a biracial community; the average age of its participants is 79.6 years ± 7.4; 52% were female, and 51% were African-American. One-third of this cohort had Alzheimer's. 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 U.S. States. The mean age of this cohort was 76.6 years ± 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 years ± 6.0; 65.2% were female, 17.5% were African-American, and 89.0% of this cohort had Alzheimer's. The high percentage for the RADC population is to be expected, because the facility treats Alzheimer's patients.

Many older 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 U.S. 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 significantly more cases of mild dementia (70.6%) than NHs (50.7%; $p<0.001$), but the type of test used is not provided). Conversely, NHs 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/ALs versus 10.1% for NHs, 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% and 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% to 24%; for increasing ADL dependency, it is 4% to 6% for people with mild dementia and about 1% for moderate or severe dementia.

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

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, which often are scored from 0 to 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 United States (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. It 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: (1) osteoarthritis, (2) rheumatoid arthritis, and (3) septic arthritis. The most common joint disorder is osteoarthritis, having the symptoms listed above, but it sometimes involves a bone spur. The cartilage becomes rough because of wear over the years, leading to pain, etc. Rheumatoid arthritis affects females more than it does males, and it is an autoimmune disorder. The connective tissue adjacent to a joint becomes inflamed, and the immune defense system works to reduce it but functions improperly, thickening joint membranes and eroding cartilage and, if it continues, bones, associated tendons, and ligaments. Bursitis and tendonitis often are included as subsets 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)? and (2) Do you sometimes have pain, stiffness, or swelling in your joints?

BLSA—Baltimore Long-Term Study on Aging (Johns Hopkins)

BMI—Body mass index (weight in kilograms/height in m**2)

Bronx Aging Study—See Verghese et al., 2003. The study uses the following tests to define dementia: the Blessed Test (Blessed Information-Memory-Concentration Test), the Wechsler Adult Intelligence Scale (verbal and performance IQ), the Fuld Object-Memory Evaluation test, and the 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, high blood pressure, and 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 and Gahbauer, 2006)

CIND—Cognitive impairment, nondementia

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

Co-morbidity—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 because of 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 and Guralink (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)

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 noninstitutionalized older adults undertaken by the University of Michigan and sponsored by the National Institute of Aging

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

IADL—Instrumental ADLs (Song et al., 2006). IADLs include physical limitations (four tasks using lower and upper extremities: [1] walking several blocks, [2] climbing several flights of stairs without resting, [3] pushing/pulling large objects, and [4] lifting/carrying >10 lb) and task limitations (five specific tasks: [1] preparing hot meals, [2] going grocery shopping, [3] using a telephone, [4] taking medications, and [5] managing money).

ICD-9—*International Classification of Diseases, version 9*

ICF—The *International Classification of Functioning, Disability, and Health,* World Health Organization, Switzerland (2001) (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—Three tests assessing time orientation, visuospatial skills, visual memory, and associative word fluency

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 reinterviewed at 2-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 nondemented elderly person with isolated cognitive and minimal functional impairment (Royall et al., 2005)

MMSE—Mini-Mental State Exam (see also 3MS). A 30-point 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 another for 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, and eating), mobility (lower body) activities (walking across a room, walking several blocks, and climbing stairs), and strength (upper body) activities (pushing furniture and lifting 10 lb). 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 more than three times per week (Song et al., 2006)
SPB—Systolic blood pressure

SPPARCS—Study of the Physical Performance and Related Changes in Sonoman's project (Johns Hopkins)

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—A longitudinal study of SBP over 30 years. It began in the early 1960s as a prospective cardiovascular epidemiology study at 10 California corporations (Swan et al., 1998).

WHAS II—Women's Health and Aging Study

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