*Journal of Exposure Analysis and Environmental Epidemiology* (2001) 11, 231–252


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# The National Human Activity Pattern Survey (NHAPS): a resource for assessing exposure to environmental pollutants

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Because human activities impact the timing, location, and degree of pollutant exposure, they play a key role in explaining exposure variation. This fact has motivated the collection of activity pattern data for their specific use in exposure assessments. The largest of these recent efforts is the National Human Activity Pattern Survey (NHAPS), a 2-year probability-based telephone survey ($n$=9386) of exposure-related human activities in the United States (U.S.) sponsored by the U.S. Environmental Protection Agency (EPA). The primary purpose of NHAPS was to provide comprehensive and current exposure information over broad geographical and temporal scales, particularly for use in probabilistic population exposure models. NHAPS was conducted on a virtually daily basis from late September 1992 through September 1994 by the University of Maryland's Survey Research Center using a computer-assisted telephone interview instrument (CATI) to collect 24-h retrospective diaries and answers to a number of personal and exposure-related questions from each respondent. The resulting diary records contain beginning and ending times for each distinct combination of location and activity occurring on the diary day (i.e., each microenvironment). Between 340 and 1713 respondents of all ages were interviewed in each of the 10 EPA regions across the 48 contiguous states. Interviews were completed in 63% of the households contacted. NHAPS respondents reported spending an average of 87% of their time in enclosed buildings and about 6% of their time in enclosed vehicles. These proportions are fairly constant across the various regions of the U.S. and Canada and for the California population between the late 1980s, when the California Air Resources Board (CARB) sponsored a state-wide activity pattern study, and the mid-1990s, when NHAPS was conducted. However, the number of people exposed to environmental tobacco smoke (ETS) in California seems to have decreased over the same time period, where exposure is determined by the reported time spent with a smoker. In both California and the entire nation, the most time spent exposed to ETS was reported to take place in residential locations. *Journal of Exposure Analysis and Environmental Epidemiology* (2001) **11,** 231–252.

**Keywords:** *environmental pollutants, environmental tobacco smoke, exposure assessment, exposure modeling, exposure survey, household pollutants, human–activity patterns, human exposure, population survey, time activity, time budget.*

## Introduction

National-level exposure assessments are required for major policy decisions mandated under regulations of the Clean Air Act, as well as for other risk analyses and regulatory judgments of the U.S. Environmental Protection Agency (EPA). Concern has been broadened to include not only traditional industrial and mobile sources, but the consumer products and building materials with which a person

1. Abbreviations: CARB, California Air Resources Board; $C_6H_6$, benzene; CAPS, California Activity Pattern Surveys sponsored by CARB ($n$=1200 for ages under 12; $n$=1762 for ages 12 and over); CATI, computer-assisted telephone interview; CHAPS, Canadian Human Activity Pattern Survey ($n$=2381); $CHCl_3$, chloroform; CO, carbon monoxide; doer, a sampled individual who is in a specific microenvironment for non-zero time during a specified time interval; ETS, environmental tobacco smoke; HAPEM, Hazardous Air Pollutant Exposure Model; indirect approach, an approach to modeling human exposure by weighting pollutant concentrations by the time spent in different microenvironments; LBNL, Lawrence Berkeley National Laboratory; MCTBRP, Multinational Comparative Time Budget Research Project; microenvironment, the occurrence in a person's day of a unique combination of location and activity, although originally defined by Duan (1982) as a location of homogeneous pollutant concentration; $n$, sample size; NAAQS, National Ambient Air Quality Standards; NHAPS, National Human Activity Pattern Survey ($n$=9386); NHAPS-CA, the NHAPS California subsample ($n$=988); $NO_2$, nitrogen dioxide; $O_3$, ozone; PAH, polycyclic aromatic hydrocarbons; pNEM, probabilistic NAAQS Exposure Model; PSU, primary sampling unit; time budget, the original term for a person's time diary; RDD, random digit dial; SERD, smoking-exposure-related duration; SRP, self-reported proximity (to a smoker); TEAM, Total Exposure Assessment Methodology; U.S., United States; EPA, U.S. Environmental Protection Agency; VOCs, volatile organic compounds

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Received 30 September 1998; accepted 6 February 2001.

typically has frequent contact (Wallace, 1995; Ott and Roberts, 1998). The importance of activity pattern data has increased with the realization that many types of exposure to environmental pollutants occur indoors and stem, in large part, from indoor pollutant sources such as cigarettes (see, e.g., Wallace, 1996). Exposure monitoring studies have demonstrated how people's locations and activities can explain the variation in exposure to benzene, tetrachloroethylene, and other volatile organic compounds (Wallace et al., 1989, 1991; Thomas et al., 1991, 1993).

Human activity data are major inputs to human exposure models, such as the probabilistic National Ambient Air Quality Standards (NAAQS) Exposure Model (pNEM) (Johnson et al., 1996a,b) and the Hazardous Air Pollutant Exposure Model (HAPEM) (Glen, 1994; Glen and Shadwick, 1998), both of which require data on the occurrences and time sequences of activities. Until recently, the activity pattern information required as input to these exposure models has been limited with regard to geographic and temporal coverage. With the completion of the EPA-sponsored National Human Activity Pattern Survey (NHAPS), however, comprehensive national activity pattern information is now available (see Nelson et al., 1994; Robinson and Blair, 1995; and Klepeis et al., 1996). The EPA's Consolidated Human Activity Pattern Database (CHAD) provides for convenient access to the data collected as part of NHAPS and a number of other human activity pattern studies (see Glen et al., 1997; McCurdy et al., 2000).

The first section of this paper provides a brief history of human activity pattern study, starting from its genesis in sociological research and ending with the use of activity patterns in exposure models. The next two sections describe the NHAPS data collection methodology, including the NHAPS sampling design and sample characteristics. In the next section, we summarize unpublished results from some previous analyses (Klepeis et al., 1996; Tsang and Klepeis, 1996) and contribute some new analyses, which compare the time spent by NHAPS respondents to the time spent by respondents of the California Activity Pattern Survey (CAPS) (Jenkins et al., 1992; Wiley et al., 1991a,b) and the Canadian Human Activity Pattern Survey (CHAPS) (Leech et al., 1996). The final section contains a summary and conclusions.

## Historical perspective

### *The Sociological Study of Human Activity*

The long history of studies on human activities in the sociological literature contains frequent use of the term "time budget" (also known as "zeitbudget" or "budget de temps"). A time budget is conceptually similar to a person's money budget in that it summarizes the amount of time an individual spends in each of many activities over some time period (e.g., a day or a week). According to Michelson (1973):

> A time budget is a record, presented orally or on paper, of what a person has done during the course of a stated period of time. It usually covers a 24-hour day or multiples thereof. The record is taken down with precision and detail, identifying what people have done with explicit reference to exact amounts of time. It is usually presented chronologically through the day, beginning with the time that a person gets up in the morning.
>
> The information that is normally gathered in a time budget consists of the time an activity began, the time it ended, the nature of the activity *per se*, the persons who were present and active in the given activities, and, not the least, the exact location where the activity took place.

Early reviews of the historical development of time budget research are provided by Szalai (1966), Converse (1968), Ottensmann (1972), and Chapin (1974). This early research forms the basis for today's human activity pattern surveys (see the review by Ott, 1989).

The earliest documented studies of human activity in America are by Lundberg et al. (1934) and Sorokin and Berger (1939), with several time budget studies conducted in France during the 1940s (see Szalai, 1966). However, the idea that time budget studies could be used to compare cultural characteristics (McCormick, 1939) did not come to fruition until about 30 years later when the Multinational Comparative Time Budget Research Project (MCTBRP) (Szalai, 1972) tabulated data on 25,000 people in 12 countries (Belgium, Bulgaria, Czechoslovakia, France, East Germany, West Germany, Hungary, Peru, Poland, Union of Soviet Socialists Republics, United States, and Yugoslavia). This study allowed comparisons of activity patterns across many countries; but like most other activity pattern studies in the social science literature, it did not collect exposure-related information. Historically, time budget studies by social scientists usually did not even distinguish, specifically, whether a person was indoors or outdoors.

In 1989, Ott "reinterpreted" the codes from the MCTBRP activity pattern data for 44 U.S. cities (Robinson et al., 1972) to estimate the amount of time that people spend in-transit, outdoors, and indoors, and he concluded that employed persons in the U.S. spend only about 2% of their time outdoors, 6% of their time in transit, and 92% of

their time indoors. For the 11 other countries, he estimated that time spent in transit for employed men ranged from 1.5 h (6.2% of the day) in France and Belgium to 2.5 h (10.4%) in Lima, Peru, while the time spent outdoors ranged from 0.4 h (1.7%) in Torun, Poland, to 1.9 h (7.9%) in West Germany (based on 100 districts). Although Ott cautioned that these sociological time budget studies were not designed to estimate human exposure, his recoded estimates showed surprisingly small proportions of time spent outdoors by people in the 12 countries. He suggests that the large amount of time spent indoors is a fundamental characteristic of the human species, "The finding that emerges is that we are basically an indoor species." "In a modern society, total time outdoors is the most insignificant part of the day, often so small that it barely shows up in the total."

*Health and Human Activity*

As alluded to above, the critical problem with activity pattern studies found in the sociological literature is that they do not include many aspects of daily life that are important for environmental pollution exposure assessment, such as storing chemicals in the home, driving an automobile on crowded highways, living with a smoker, using gas appliances, visiting a dry cleaner, using solvents in the home, or filling a gas tank. Nor do they provide sufficient detail on the locations that people visit.

Using methods similar to those of the social scientists, researchers in the environmental health sciences in the 1980s began to collect activity pattern data as part of exposure and health research. For example, the following studies appeared in the literature of this period.

(1) Johnson (1983) and Akland et al. (1985) conducted a probability-based personal exposure field study of 1200 persons in Denver and Washington, DC, in which respondents carried personal monitors to measure their personal exposure to carbon monoxide (CO) while keeping diaries to record the activities and microenvironments they visited over 24 h. Schwab (1988) analyzed the activity patterns and CO exposures using the diary data from this study.

(2) Quackenboss et al. (1986) used a recall questionnaire to gather information on the times people spent in various locations, or microenvironments, in a study of personal nitrogen dioxide ($NO_2$) exposures and indoor and outdoor concentrations for 350 individuals in Portage, WI.

(3) Adair and Spengler (1989) reported findings on the activity patterns of over 1800 third and fourth grade children in six U.S. cities between 1984 and 1988.

(4) Freeman et al. (1989) used a seven-page questionnaire to obtain activity pattern information from 14 respondents over 14 days in Phillipsburg, NJ.

(5) Lichtenstein et al. (1989) studied the time–activity patterns of 973 respondents in Cincinnati, OH, using 3-day diaries to evaluate how much the activities of asthmatics differ from those of the general population.

(6) Schwab et al. (1989a, 1990) collected diary data on activity patterns from approximately 700 respondents in 500 households in Los Angeles in connection with a study of personal exposure to $NO_2$.

(7) Schwab et al. (1989b, 1992) report on time–activity data collected from 91 children in Kanawa Valley, WV, as part of a study of children's respiratory and sensory responses to air pollution. Schwab et al. (1991) explored the use of these diary data in linking exposure and dose by analyzing the self-reported exercise levels of the children.

In parallel scientific efforts, environmental health scientists began developing mathematical exposure models based on human activity patterns. Fugas (1975) initially suggested a modeling approach for computing personal exposure to sulfur dioxide ($SO_2$), lead (Pb), and manganese (Mn) by summing the concentrations in the locations a person visited (home, work, streets, countryside), weighted by the time the person spent in each location. Subsequently, Duan (1982) suggested a formal mathematical approach to compute personal exposure by summing the pollutant concentrations in the "microenvironments" (defined by Duan as locations of homogeneous concentration) that each person visited, weighted by the time they spent in each microenvironment. Ott (1984) then developed a prototypical computerized exposure model based on the concepts of Fugas and Duan, referred to as the "indirect approach" to exposure assessment. A variety of mathematical models based on this approach were subsequently developed (see Quackenboss et al., 1986; Sexton and Ryan, 1988; Ott et al., 1992, 1998; Behar et al., 1993; Klepeis et al., 1994; MacIntosh et al., 1995; McCurdy, 1995, 1997; Johnson et al., 1996a,b; Miller et al., 1998a,b; Klepeis, 1999).

*Large-Scale Activity Pattern Studies*

Although exposure models require diary data on activity patterns, few large-scale population studies existed before 1990 to provide the necessary data. To help meet this need for activity pattern diary data for exposure assessment and modeling, the California Air Resources Board (CARB) conducted a probability-based diary study of the activity patterns of residents of California that included 1762 adults and adolescents from 1987 to 1988 and 1200 children from 1989 to 1990 (see Wiley et al., 1991a,b). Referred to as the CAPS in this paper[1], these data have been used in a variety of analyses:

- Phillips et al. (1990) examined appliance use and ventilation practices in California;

[1]We use the CAPS acronym to mean both the California survey of adults–youth and the survey of children under 12. Miller et al. (1998a) use CAPS to refer only to the study of children.

- Phillips et al. (1991) and Jenkins et al. (1992) provided summary statistics and investigated the proximity of Californians to indoor pollutant sources including a comparison of the times people spent in various microenvironments and the percentage of people who were engaged in various activities;
- Robinson (1991) and Robinson and Thomas (1991) compared California activities to national activities; and
- Robinson et al. (1993, 1994a,b, 1996), Ott et al. (1994), Klepeis et al. (1994), and Miller et al. (1998a,b) studied the potential exposure of Californians to environmental tobacco smoke (ETS).

NHAPS was conducted as a follow-up to CAPS, and was closely patterned after this landmark study. NHAPS is the first U.S. study with national scope that was designed to collect exposure-relevant information on human activity patterns. EPA's main purpose for collecting the NHAPS data was to provide diary records that could be used as inputs for computer-based human exposure models. A select panel of exposure scientists with diverse backgrounds (air pollution, pesticides, drinking water, exposure modeling) served as "subject matter experts" and helped insure that the NHAPS diary and questionnaires gathered the correct type of activity pattern data for use in estimating pollutant exposures.

Since the completion of NHAPS, two other exposure-related human activity surveys have emerged with data collection instruments and geographical scales similar to NHAPS. Both of the following studies make use of the computer-assisted telephone interview (CATI) instrument and, like NHAPS, collected daily diaries on the time spent in locations, activities, and in the presence of smokers:

- A national survey of 1200 Americans sponsored by the Electric Power and Research Institute (EPRI) from 1994 to 1995 that was focused on human exposure to soil (Robinson and Silvers, 2000); and
- The 9-month CHAPS, which surveyed 2381 Canadians from 1994 to 1995 with respondents in Toronto, Vancouver, Edmonton, and Saint John, NB (Leech et al., 1996, 1999).

## Data collection

NHAPS was a 2-year national probability telephone survey ($n$=9386) of the contiguous states conducted by the University of Maryland Survey Research Center with support from EPA. The telephone interviewing began in late September 1992, ended on October 1, 1994, and was divided into eight quarters with each quarter, except the first, exactly 3 months in duration. Each quarter of the study was composed of an independent random sample of households.

While NHAPS utilized methods from previous time diary studies, particularly CAPS (Wiley et al., 1991a,b; Jenkins et al., 1992), it was augmented to obtain more precise estimates of the time spent in microenvironments such as kitchens, restaurants, bars, automobiles, and outdoor travel. Many questions were also adapted from the comprehensive Environmental Inventory Questionnaire (Lebowitz et al., 1989) and from questionnaires used in the Total Exposure Assessment Methodology (TEAM) studies (Akland et al., 1985; Wallace et al., 1991) to help determine the population segments most likely to experience microenvironments with elevated pollutant concentrations. Supplemental questions were developed for pollutant sources not treated in the respondents' diary accounts such as solvents or gas appliances. All interviews were conducted from the Survey Research Center telephone interview facility in the College Park campus in Maryland using the CATI technology, which was developed by the Survey Research Center at the University of California at Berkeley. The interviewers averaged approximately 13 completed interviews for each day of the year. Each interview took about 20–30 min to complete, most of which were devoted to the diary but with some time allotted for demographic (e.g., age, gender, health status, ethnicity, educational attainment, and housing type) and supplemental (or "follow-up") exposure questions.

### *Selection of Subjects*

The target population for NHAPS was all persons residing in telephone-equipped households in the 48 contiguous states. Telephone households were selected using a standard two-stage random digit dial (RDD) sample design. The selection of telephone exchanges was stratified by the four major U.S. census regions (Northeast, Midwest, South, and West). All potential primary sampling units (PSUs; area code+telephone exchange+first two digits of phone number) were selected at the beginning of the study, but they were not initially screened for residential status. Immediately before the beginning of each quarter, the primary numbers for that quarter were screened to select PSUs for the second and final stages of selection.

In addition to the four census strata, the PSUs for each quarter were randomly assigned to either a weekend or weekday sample. Therefore, weekends and weekdays were sampled independently within each quarter. Since the study design required a person to recall the chronology of their activities for the prior day, the weekend sample was called only on Sundays and Mondays and consisted of either Saturday or Sunday time diaries. The weekday sample was called Tuesday through Saturday and consisted of Monday through Friday time diaries.

In households consisting of only adults (i.e., respondents 18 years of age or older), one adult was selected at random.

In households consisting of both adults and children (respondents 17 years of age or younger), a child was selected at random 60% of the time from among all child residents. The other 40% of the time an adult was selected at random from among all adult residents. These different probabilities of selection were used to control the ratio of adults-to-children interviews. To increase the number of children selected, the percentage of households in which children were selected was increased from 60% to 70% in quarters 6 through 8.

The "next birthday" selection method was used for within-household respondent selection. In the next birthday method, the interviewer asks to interview the adult (or child) residing in the household who will have the next birthday. This method provides a random respondent without having to ask intrusive questions about household composition.

All data on adults were collected directly from the selected respondent. For children under the age of 10, the adult in the household most knowledgeable about the child's activities completed a proxy interview for the child. For children aged 10–17, an adult respondent answered the general household and demographic questions. The 10- to 17-year-olds then answered the time diary and post-diary questions about their own activities.

**Table 1.** The NHAPS sample sizes and participation rates.

| | Number | % |
|---|---|---|
| Sample released[a] | 26,263 | – |
| Non-households[b] | 11,076 | – |
| Status unknown[c] | 279 | – |
| Households[d] | 14,908 | 100 |
| Interviews[e] | 9,386 | 63 |
| Refusals[f] | 2,944 | 20 |
| Non-contacts[g] | 1,870 | 12 |
| Other[h] | 708 | 5 |

[a]*Sample phone numbers* is the count of telephone numbers called for the study.
[b]*Non-households* include businesses, group homes such as nursing homes and dormitories, group quarters, disconnected numbers, fax machines, *etc.*
[c]*Status unknown* numbers were called at least 20 times but were never contacted; therefore, the household status could not be ascertained.
[d]*Households* include all telephone numbers that were determined to be a household.
[e]*Interviews* are all households where the selected respondent completed the interview through a time diary.
[f]*Refusals* are households that refused to complete the interview or terminated the interview before or during the diary section.
[g]*Non-contacts* include households in which only a home recorder or answering machine could be reached and households in which the respondent was identified but never reached for interview, even after at least 20 call attempts.
[h]*Other* are cases in which the respondent was unable to complete the interview due to lack of comprehension of English or some physical problem such as difficulty in hearing or speaking.

*Participation and Response Rates*

A total of 9386 interviews were collected during the 2-year, eight-quarter data collection period. If individuals did not have telephones (e.g., they were low-income or homeless), or if, when they were telephoned by an NHAPS interviewer, they were on vacation or away from home for an extended period of time, they were not included in the survey. These individuals are not expected to be large in number, but their omission could lead to some bias in survey statistics (e.g., calculations of time spent indoors).

For those Americans who were contacted by telephone, the survey response numbers and rates are shown in Table 1. The overall response rate is defined as the number of completed interviews ($n$=9386) divided by the total number of identified telephone households (14,908), which is 63%. This figure is fairly high given the mean time to complete each interview (25 min). When the number of interviews successfully completed (9386) is divided by the number of interviews attempted [completed interviews (9386)+refusals (2944)=12,330], the resulting cooperation rate is over 76%. This cooperation rate is relatively high for a survey that did not utilize financial or other incentives to increase participation.

*The Questionnaire*

Since the panel of expert reviewers for NHAPS concluded that a single 25-min interview could not include all the requirements for each topic area, it was decided to emphasize only air quality and drinking water (with a greater emphasis on air quality). This decision was based on the high priority given by EPA's Air Quality Office to human exposure models that require activity pattern data and the limited availability of such data. To accommodate both the drinking water questions and the air quality questions without making the interview unnecessarily lengthy, two different questionnaire versions, A and B, were developed and each was administered to one half of the sample, selected at random. Versions A and B both included demographic questions, a 24-h time diary, and a set of supplementary exposure questions emphasizing potential exposure to pollutants in either household air (version A) or water (version B). A smaller number of questions on each questionnaire version concerned exposures to pollutants in soil and food (see Table 2 for a list of background factors and question types).

*Twenty-Four-Hour Diary* The diary was the central component of both questionnaire versions. In their diaries, respondents reported all their activities for the previous day. Although time–diary data have often been used to measure the amount of time populations spent performing certain activities, perhaps the more important question for environmental pollutant exposure research is the pollutant level in the *location* where the activity occurs (and the

**Table 2.** Summary of factors and question types for versions A and B of the NHAPS questionnaire.

| Factors | Version A | Version B |
|---|---|---|
| Biological (age, race, gender) | Air — storage (gas cans, lawnmower, paints, mothballs, deodorizer, humidifier, windows open, door open) | Air — storage (gas, lawnmower, paints, solvents) |
| Status (employment, education)<br>Role (children, other adults, work hours, work evening, work outdoors) | Air — yesterday (smoking — home/away, others smoke, paints, open flame, glues, solvents, pesticides, floor wax, gas-powered equipment, cleaning agents, excessive dust, stain removers, perfumes, nail polish, gas station, gas stove, microwave, aerosol spray, heating, heavy traffic, roadway, parking garage, walk to car) | Air — last 6 months (renovations, paint, floors, addition, carpets, glues, sleep elsewhere, pesticides, vacuum floors, humidifier, gas stove, heat sources)<br>Water (shower/bath, dishwashing, washing machine, drinking water — bottle/tap, juices, soft drinks) |
| | Water (shower/bath, dishwasher, washing machine) | |
| Geographic (zipcodes — home, zipcodes — work, housing, structure, stories, rooms, carpet, basement, garage) | Ingestion (children — soil) | Water — last month (pool swimming) |
| Lifestyle (health) | 24-h diary (activities, locations, smoker present, hard breathing) | Ingestion (children — soil, seafood, blackened food) |
| | | 24-h diary (activities, locations, smoker present, hard breathing) |

Source: Robinson and Blair (1995).
Versions A and B of the NHAPS questionnaire were given to different randomly selected samples, each spanning the contiguous U.S.

length of time spent in that location). Thus, to address environmental exposure issues, the time–diary categories (codes) in NHAPS focused on the location in which activities occurred. Exposure-related activity coding was generally limited to activities of concern for their potential to increase exposure to environmental pollutants; e.g., activities that require higher breathing rates, such as sports, or activities that involve exposure to chemicals, such as painting and auto repair. The only part of the diary that concerned exposure-specific activity was the reported presence of a smoker during each location and activity combination (microenvironment).

When respondents were asked whether or not there was someone else smoking during each of the microenvironments they visited, one's own smoking was not included. The question took the form: "Was there someone (else) present who was smoking during that activity and in that location?" The reported time spent in the presence of a smoker constitutes a measure of "potential" exposure (or a marker of exposure) to ETS. Previous investigators of the CAPS database, which contains answers to the same question on the presence of smokers as the NHAPS database, refer to the potential exposure as *self-reported proximity* (SRP) (Miller et al., 1998b) or *smoking-exposure-related duration* (SERD) (Robinson et al., 1994b).

There exists the possibility for bias in the NHAPS results for the time spent with a smoker, since two respondents may have reported the same amount of time with a smoker when the intensity of smoke (e.g., the number of smokers or number of cigarettes) was quite different. Actual exposure to ETS depends on both the mass of tobacco smoke emitted and building characteristics such as volume and air flow rates. Respondents also may have misjudged whether or not

**Table 3.** Distribution of the NHAPS respondents by selected demographic factors.

| Factor | Sample size | NHAPS (%) | U.S. census (%) |
|---|---|---|---|
| Male | 4,294 | 46 | 49 |
| Female | 5,088 | 54 | 51 |
| Under 5 years old | 499 | 5 | 8 |
| 5–17 years old | 1,292 | 14 | 19 |
| 18–64 years old | 6,059 | 65 | 61 |
| Over 64 years old | 1,349 | 14 | 13 |
| White | 7,591 | 81 | 83 |
| Black | 945 | 10 | 13 |
| Asian | 157 | 2 | 3 |
| Of Hispanic origin | 385 | 8 | 10 |
| Postgraduate education | 924 | 10 | 6 |
| College graduate | 1,247 | 13 | 20 |
| High school graduate | 2,612 | 28 | 32 |

There were 9,386 total respondents. Of the respondents, 187 (2%) did not report an age; 308 (3%) reported being a race not listed or did not report a race. For 1,968 (21%) of the respondents, no educational-level data were recorded. Census proportions are 1994 estimates from the U.S. Department of Commerce (1995, 1996).

a smoker was actually present *and* smoking. A smoker might have been present for only a small portion of the entire microenvironment (e.g., a smoker was present for only 10 min during a 60-min-long microenvironment), but the potential exposure (SRP or SERD) for that time period would be the same as if a smoker was actually present the entire time. In two out of the total 16 quarters of the NHAPS study, the respondents were asked to specify for what fraction of time in the microenvironment the smoker(s) was (were) present. This information may be useful in sorting out any bias for the study as a whole.

In the *Sample and Data Characteristics* section, we describe the structure of the NHAPS diary data including the location and activity categories.

*Supplemental Questions* In this section, we summarize some main features of the NHAPS supplemental exposure questions. More complete descriptions of these questions, including the results of data analysis, are given in Robinson and Blair (1995), Klepeis et al. (1996), and Tsang and Klepeis (1996).

The supplemental questions on both versions of the NHAPS questionnaire concerned occasions of potential exposure to specific pollutants such as particles, polycyclic aromatic hydrocarbons (PAHs), CO, ozone ($O_3$), $NO_2$, chloroform ($CHCl_3$), benzene ($C_6H_6$), and volatile organic compounds (VOCs) in general. These questions were included to supplement the respondents' diary accounts, since respondents might not have remembered to report the stop they made to buy gasoline while commuting to work or the stop they made at a dry cleaner during lunch time. The following exposure associations illustrate the basis for including particular questions:

- Activities involving cigarette smoke or wood burning may increase exposure to particles, PAH, CO, $C_6H_6$, and other VOCs;
- Activities involving gasoline (e.g., pumping gasoline into automobiles) may increase exposure to $C_6H_6$ and other VOCs;
- Driving in traffic and activities in a parking garage may increase exposure to $C_6H_6$, other VOCs, particles, PAH, and CO;

**Table 4.** Example 24-h recall diary containing beginning and ending times, activity, location, presence of a smoker, and time spent for 22 microenvironments visited on the diary day.

| Microenvironment number | Starting time | Ending time | Summary | Detailed activity | Simplified activity | Detailed location | Simplified location | Smoker? (1=Yes) | Time spent (min) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 00:00 | 01:45 | At night club | 77 | 0 | 405 | 90 | 1 | 105 |
| 2 | 01:45 | 02:00 | Traveled home after night club | 79 | 0 | 301 | 30 | 0 | 15 |
| 3 | 02:00 | 11:00 | Sleeping or napping | 45 | 0 | 105 | 10 | 0 | 540 |
| 4 | 11:00 | 11:05 | Brushed teeth | 44 | 40 | 104 | 10 | 0 | 5 |
| 5 | 11:05 | 11:15 | Preparing meals or snacks | 10 | 10 | 101 | 10 | 0 | 10 |
| 6 | 11:15 | 11:25 | Eating meals or snacks | 43 | 70 | 102 | 10 | 0 | 10 |
| 7 | 11:25 | 11:30 | Dressing or personal grooming | 47 | 0 | 102 | 10 | 0 | 5 |
| 8 | 11:30 | 11:37 | Traveling to play football | 89 | 0 | 306 | 40 | 0 | 7 |
| 9 | 11:37 | 13:37 | Playing flag football | 80 | 60 | 507 | 50 | 0 | 120 |
| 10 | 13:37 | 13:44 | Traveling to home | 79 | 0 | 306 | 40 | 0 | 7 |
| 11 | 13:44 | 13:54 | Preparing meals or snacks | 10 | 10 | 201 | 10 | 0 | 10 |
| 12 | 13:54 | 13:57 | Traveling to bar | 79 | 0 | 301 | 30 | 0 | 3 |
| 13 | 13:57 | 15:30 | At bar | 77 | 0 | 405 | 90 | 1 | 93 |
| 14 | 15:30 | 15:33 | Traveling from bar | 79 | 0 | 301 | 30 | 0 | 3 |
| 15 | 15:33 | 16:30 | Watching TV | 91 | 0 | 102 | 10 | 0 | 57 |
| 16 | 16:30 | 17:00 | Bathing or showering | 40 | 40 | 104 | 10 | 0 | 30 |
| 17 | 17:00 | 19:00 | Watching TV | 91 | 0 | 102 | 10 | 0 | 120 |
| 18 | 19:00 | 19:10 | Traveling to shopping | 39 | 0 | 301 | 30 | 0 | 10 |
| 19 | 19:10 | 19:25 | Shopping for food | 30 | 0 | 414 | 90 | 0 | 15 |
| 20 | 19:25 | 19:35 | Travel related to shopping for food | 39 | 0 | 301 | 30 | 0 | 10 |
| 21 | 19:35 | 21:00 | Watching TV | 91 | 0 | 102 | 10 | 0 | 85 |
| 22 | 21:00 | 24:00 | Studying | 54 | 0 | 102 | 10 | 0 | 180 |

The respondent, whose diary is shown in this table, was a Hispanic male from Connecticut between the ages of 18 and 24 who was interviewed on a weekend in the fall. See the Sample and Data characteristics section for a description of the simplified (i.e., recoded) locations and activities.

**Table 5.** Results of selected exposure-related supplemental NHAPS questions (unweighted).

| Question | Response |
|---|---|
| Did the respondent take a shower or bath yesterday, and if they did, for how long? (A) | 91% yes<br>44% 0–10 min<br>37% 10–20 min<br>13% 20–30 min |
| What type of fuel is used in the central furnace? (A) | 61% gas<br>18% electric<br>14% oil |
| Is any room heated with a wood stove? (B) | 6% yes |
| Is any room heated with a kerosene space heater? (B) | 2% yes |
| Is any room heated with a fireplace? (B) | 10% yes |
| Where is water obtained for household use? (B) | 81% public<br>15% private well |
| Is bottled water used? (B) | 43% yes |
| Did you smoke cigars yesterday? (B) | 1% yes |
| How many glasses of tap water did the respondent drink yesterday? (B) | 29% none<br>26% 1–2<br>27% 3–5<br>15% 6–20+ |
| How many times did the respondent wash their hands yesterday? (B) | 8% 2 or less<br>60% 3–9<br>28% 10–30+ |
| For how many hours did the respondent work with soil in the last month? (B) | 63% none<br>28% 0–24<br>5% 24–72<br>2% >72 |
| In what type of house does the respondent live? (A and B) | 21% apartment<br>68% detached single house<br>5% townhouse<br>7% other |

The NHAPS questionnaire version on which each question appears is indicated in parentheses (either A, B, or both A and B); results rounded to the nearest percentage point. Some of the percentages not listed could include missing, refused, or "don't know" responses.

- Activities involving hot water sources (e.g., hot showers, baths, boiling water) may increase exposure to disinfection byproducts such as $CHCl_3$;
- Activities involving gas stoves or ovens may increase exposure to $NO_2$ and CO;
- Activities involving solvents and paints may increase exposure to various VOCs; and
- Activities involving the use of dry-cleaned clothes may increase exposure to tetrachloroethylene, 1,1,1-trichloroethane, or aromatic solvents.

Version A (emphasizing "air" questions) contains most of the supplemental exposure questions on breathing rates and locations with potentially degraded air quality (see Table 2) including the presence of smokers. Additional questions on version A examined exposures both at work and at home to pollutants such as vapors from paints and solvents. Potential exposure to $C_6H_6$ was assessed by questions concerning time spent in gasoline stations or parking lots. Further questions were asked about respondent activities in near proximity to: (1) gas stoves, gas furnaces, and supplemental heating sources like wood or kerosene stoves; (2) aerosol spray products; (3) hot showers or baths; (4) room air fresheners, deodorizers, or mothballs; and (5) automobiles parked in attached garages.

The supplemental questions on version B (emphasizing "water" questions) include questions on tap water contact *via* drinking water and using tap water for such appliances as dishwashers, washing machines, and humidifiers. Other questions dealt with tap water contact through washing and bathing — either by rinsing dishes, baths, or showers. Separate questions were included about whether the door was open while taking a bath or shower and the use of exhaust fans. Another set of questions dealt with water sources, either from wells, piped-in utilities, or purchased in bottles.

## Sample and data characteristics

### *Coverage and Representativeness*

A comparison of the number of NHAPS respondents in each state shows generally good agreement with the 1990 U.S. census (U.S. Department of Commerce, 1992): the "relative comparisons" of most states are close to 1, where

**Table 6.** Geographical comparison of NHAPS minutes spent on the diary day for California (NHAPS-CA) versus the entire nation.

| Location | *n* | Overall mean (min) | Doer % | Doer *n* | Doer mean (min) |
|---|---|---|---|---|---|
| *NHAPS-nation* | | | | | |
| In a residence | 9196 | 990 | 99.4 | 9153 | 996 |
| Office–factory | 9196 | 78 | 20.0 | 1925 | 388 |
| Bar–restaurant | 9196 | 27 | 23.7 | 2263 | 112 |
| Other indoor | 9196 | 158 | 59.1 | 5372 | 267 |
| In an enclosed vehicle | 9196 | 79 | 83.2 | 7596 | 95 |
| Outdoors | 9196 | 109 | 59.3 | 5339 | 184 |
| *NHAPS-CA* | | | | | |
| In a residence | 930 | 979 | 99.6 | 927 | 983 |
| Office–factory | 930 | 73 | 19.3 | 187 | 379 |
| Bar–restaurant | 930 | 34 | 26.4 | 260 | 128 |
| Other indoor | 930 | 166 | 61.9 | 542 | 269 |
| In an enclosed vehicle | 930 | 80 | 84.4 | 775 | 95 |
| Outdoors | 930 | 108 | 59.1 | 592 | 182 |

Means and percentages have been calculated using sample weights, whereas the sample sizes *n* and Doer *n* are raw counts.

a relative comparison of NHAPS and U.S. census proportions is defined as the ratio of the percentages in each state of the U.S. Census data to the NHAPS percentages. The only state that was oversampled in NHAPS with a relative comparison under 0.5 was Montana. States that were undersampled at a relative comparison over 1.5 were Vermont, Mississippi, North Dakota, and Idaho. The 20 sampled states (including Washington, DC) that did not have at least 100 NHAPS respondents were Delaware, the District of Columbia (DC), Idaho, Iowa, Kansas, Kentucky, Maine, Mississippi, Montana, Nebraska, Nevada, New Hampshire, New Mexico, North Dakota, Rhode Island, South Dakota, Utah, Vermont, West Virginia, and Wyoming. At 12–18 respondents each, Vermont, Wyoming, North Dakota, and Idaho had the fewest respondents of any sampled state. Note that residents of Alaska and Hawaii were excluded in the NHAPS sample design frame. The states that had more than 500 NHAPS respondents were California, Florida, New York, Pennsylvania, and Texas.

The percentage of NHAPS respondents sampled in each of the 10 EPA Regions and each of the four census regions is comparable to the population observed in the 1990 U.S. census (U.S. Department of Commerce, 1992) with relative comparisons near 1. There is a sufficient sample size in each EPA Region to perform detailed statistical analyses with a low of 340 NHAPS respondents in EPA Region 8. Each of the four U.S. Census regions had approximately 2000–3000 respondents.

The NHAPS sample proportions for gender, age, race, and educational attainment match the estimated 1994 proportions (U.S. Department of Commerce, 1995, 1996) reasonably well (see Table 3). The worst agreement is for the proportion of college graduates (13%/20%=0.65), which may be due to the large number of missing data values (20% of the respondents had missing values for their educational attainment).

The number of respondents in each quarter of the NHAPS study was fairly uniform (approximately 13% per quarter), except for the first, when only 7.8% of the respondents was interviewed. The proportion of respondents interviewed during each season (winter, spring, summer, fall) ranged from 20% to 27%. Most of the respondents were interviewed on a weekday (67%), which is somewhat smaller than the ideal proportion (5/7=71%) since weekends were intentionally oversampled.

*Sample Weights* Weights are available for the NHAPS database that correct the sample based on the increased selection probability of households with multiple phones, the different selection probabilities for adults and children, seasonal quarter, and census region, and the oversampling of weekends. Klepeis et al. (1996) have devised post-stratification weights that incorporate the original weights,

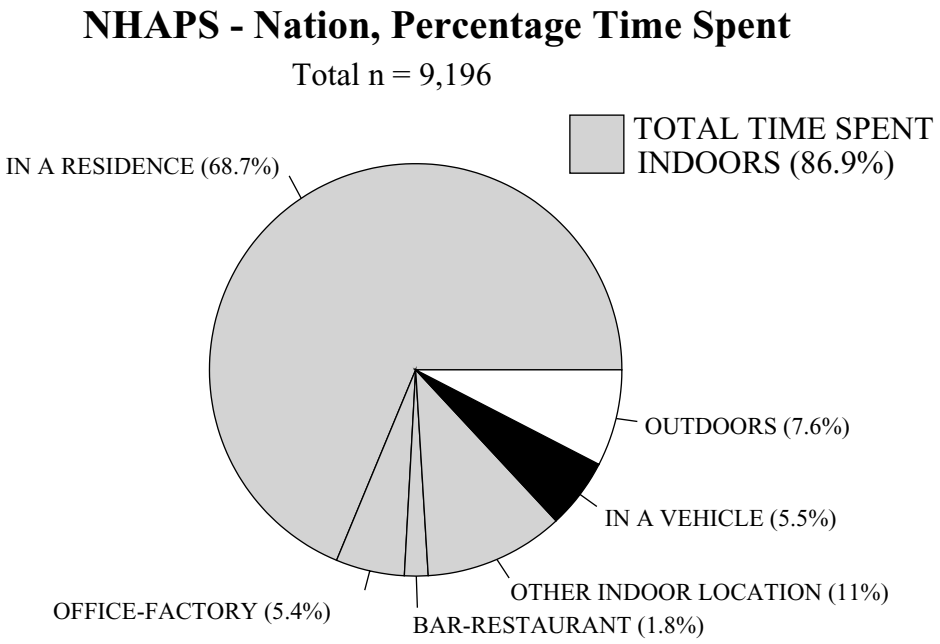


**Figure 1.** Pie chart showing the mean percentage of time the NHAPS respondents spent in six different locations on the diary day (weighted). Time spent indoors (composed of time in a residence, in an office or factory, in a bar or restaurant, or in some other indoor location) is represented by lightly shaded slices. The percentages in the figure are the mean percentages taken over individual percentages for people in the NHAPS sample. Individual percentages were calculated from the time spent in each location over the total amount of time spent, which was equal to 24 h (1440 min) for each individual (see Table 6 for the number of doers for each location).

but also adjust the NHAPS sample to match population proportions for age and gender. Gender and age data were obtained from the 1990 U.S. Census (U.S. Department of Commerce, 1992). The desired day-of-week and season proportions are absolute quantities (i.e., 1/4 for each season and 1/7 for each day of the week). The resulting post-stratification weight assigned to each NHAPS respondent can be used to calculate weighted statistics across any combination of factors for age, sex, season, census region, and day of week. Weights could not be assigned to respondents with missing age or gender variables, and these individuals were excluded from weighted calculations (missing $n=190$ across the nation; missing $n=58$ in California). In this paper, we use the post-stratification weights to calculate weighted means, histograms, and proportions (see Cochran, 1977 for a good treatment of sampling methodology, including formulae for calculating unbiased estimators). The reader should note that a comparison of weighted and unweighted results showed only a small discrepancy for most calculated statistics.

*Location and Activity Categories*

Table 4 gives an example 24-h diary for a single individual, a Hispanic male from Connecticut. Each diary record contains the beginning and ending times for each microenvironment the respondent visited, uniquely determined by a single combination of location and activity codes. Each record also contains a code for whether or not a smoker was present and if the respondent was "breathing hard."

The original 83 location codes that were used to encode the NHAPS respondents' whereabouts are split into categories for each respondent's own house, a friend's or someone else's house, traveling, some other indoor location, and some "other" outdoor location (see Klepeis et al., 1996; Tsang and Klepeis, 1996). For the calculations of time spent that we present in the *Data Analysis* section, a reduced set of six locations was used: residence, office–factory, bar–restaurant, other indoor location, enclosed vehicle, and outdoors. In this grouping scheme, residential locations at one's own home were not differentiated from residential locations at someone else's home (i.e., respondent locations were grouped into a residential category even if the original NHAPS code states that they were at someone else's house). The vehicle location includes travel inside cars, trucks, buses, trains, airplanes, boats, and public transit. Travels outdoors *via* motorcycle, bicycle, walking, or stroller, or waiting for transit outdoors were all grouped into the outdoor location. The other indoor grouping includes all the remaining indoor locations such as malls, stores, schools, churches, other public buildings, autorepair shops, health clubs, laundromats, salons, and parking garages. Note that these locations may be associated with very different, and potentially very high, exposures. Locations were not divided, specifically, according to work-related activities. The only location category that can be associated with work-related activities is office–factory. It is not possible to determine — based on location alone — whether work-related activities were occurring in any of the other locations, since, e.g., respondents that are in stores, restaurants, bars, or hospitals could be present either as patrons or staff.

There are 91 distinct activity codes for the 24-h recall portion of the NHAPS database (see Klepeis et al., 1996; Tsang and Klepeis, 1996). Although specific activities are not analyzed in the current paper, Klepeis et al. present an attempt to create broad exposure activity categories based on the available data. The original NHAPS categories were regrouped into eight categories each containing nearly 2000 episodic occurrences or more: cooking/food preparation; laundry/dishes/cleaning kitchen; housekeeping; bathing/showering/washing/using bathroom; yardwork/gardening/car or house-maintenance; sports/exercise; eating/drinking, and some "other" activity. The most frequent activities in the other exposure activity category — into which 73% of the microenvironments (distinct occurrences

**Table 7.** Geographical comparison of NHAPS minutes spent with a smoker on the diary day for California (NHAPS-CA) versus the entire nation.

| Location with a smoker | *n* | Overall mean (min) | Doer % | Doer *n* | Doer mean (min) |
|---|---|---|---|---|---|
| *NHAPS-nation (17% of respondents reported being cigarette smokers; weighted)* | | | | | |
| All locations | 9196 | 163 | 43.8 | 3949 | 372 |
| In a residence | 9196 | 78 | 25.6 | 2331 | 305 |
| Office–factory | 9196 | 16 | 4.3 | 394 | 363 |
| Bar–restaurant | 9196 | 14 | 10.0 | 951 | 143 |
| Other indoor | 9196 | 19 | 7.6 | 725 | 247 |
| In an enclosed vehicle | 9196 | 11 | 14.5 | 1340 | 79 |
| Outdoors | 9196 | 24 | 11.4 | 1038 | 213 |
| *NHAPS-CA (14% of respondents reported being cigarette smokers; weighted)* | | | | | |
| All locations | 930 | 114 | 36.9 | 332 | 309 |
| In a residence | 930 | 45 | 16.5 | 164 | 270 |
| Office–factory | 930 | 9 | 3.4 | 26 | 280 |
| Bar–restaurant | 930 | 13 | 8.0 | 82 | 168 |
| Other indoor | 930 | 19 | 7.4 | 58 | 252 |
| In an enclosed vehicle | 930 | 5 | 8.3 | 82 | 58 |
| Outdoors | 930 | 23 | 11.0 | 108 | 209 |

Means and percentages have been calculated using sample weights, whereas the sample sizes *n* and Doer *n* are raw counts. The time spent with a smoker does not include one's own smoking.

in the diary database) was grouped — were sleeping/napping, watching television, and dressing.

## Data analysis

Klepeis et al. (1996) and Tsang and Klepeis (1996) provide detailed analyses of the time that NHAPS respondents reported spending in locations and activities on the diary day, as well as the results of the more than 150 supplemental and demographic questions. These analyses include an examination across categories such as gender, race, age, years of education, employment status, weekday/weekend, season, and region. Additional results of the auxiliary questions and time use issues are discussed in Robinson and Blair (1995). In this section, we present selected results to provide a basis for making broad comparisons between demographic groups within NHAPS and other activity pattern studies.

Most of our results are based entirely on the NHAPS diary data rather than answers to the supplemental questions. We present broadly grouped statistics on the time that NHAPS respondents spent in six different locations (residence, office–factory, bar–restaurant, some other indoor location, enclosed vehicle, and outdoors) including the time that they spent with a smoker. We also make comparisons to the CAPS of adults and youth over age 12 (1987–1988) and of children under age 12 (1989–1990) (see Wiley et al., 1991a,b; Jenkins et al., 1992) and the 9-month CHAPS of Toronto, Vancouver, Edmonton, and Saint John, NB (1994–1995) (see Leech et al., 1996).

Although the minute-by-minute 24-h recall diaries are the main subject of the current analysis, the NHAPS database also provides exposure assessors with a large variety of yes-or-no and categorical questions on exposure-related activities and household conditions. Table 5 presents results from a small selection of unweighted results from the supplemental NHAPS questions that will be useful to risk and exposure assessors, including policy makers.

### *Calculation Methodology*

The NHAPS statistics we present in this paper have been weighted using the sample weights described above (unless otherwise noted); they were generated using the freely available R system for data analysis and graphics (Ihaka and Gentleman, 1996). The CAPS statistics were generated using the TIMEWT set of sample weights included in the CAPS databases.

Since the NHAPS diaries span a single 24-h period, most of our calculations use this as the primary time interval (i.e., we present limited results for breakdowns by time of day). The mean proportion of time spent in different locations is

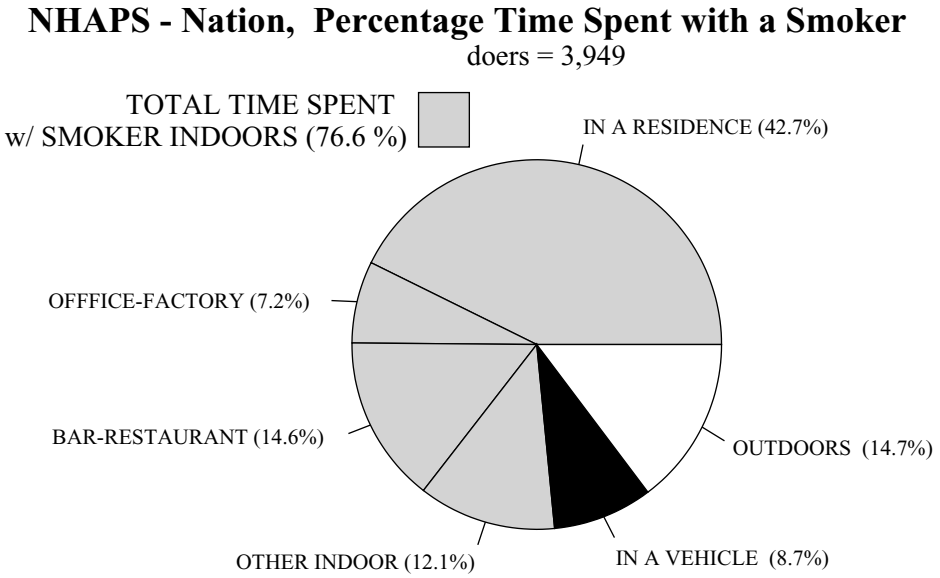


**Figure 2.** Pie chart showing the mean percentage of time the NHAPS respondents spent *with a smoker* in six different locations on the diary day (weighted). Time spent indoors (composed of time in residence, in an office or factory, in a bar or restaurant, or in some other indoor location) is represented by lightly shaded slices. The percentages in the figure are means taken over individual percentages for people in the NHAPS sample that reported being with a smoker for at least 1 min on the diary day (the doers). Individual percentages were calculated as the time spent in the presence of a smoker in each location divided by the total amount of time spent with a smoker (see Table 7 for the total number of doers and the number of doers for each location). (Please see the text for a discussion of SRP-SERD biases inherent in the NHAPS database with respect to the time respondents reported spending with a smoker.)

calculated by taking the mean of the total number of minutes each respondent spent in each location and dividing by 1440 min (24 h).

The total time spent with a smoker on the diary day varies from person to person; so that individual percentages of time spent with a smoker in each location use a different denominator for each person. The mean percentage of time spent with a smoker was calculated by simply averaging over the individual percentages.

Different numbers of respondents spent time in each location (both with and without a smoker) on the diary day and also at different times of day. Those who spent at least 1 min in each location, either across the entire day or for any particular time interval, are called the "doers." In each results table, we present the weighted proportions of daily doers alongside overall means and doer means (i.e., means taken across only the doers).

*NHAPS: The Nation*

Of any location visited on the diary day, the lowest percentage of doers was 20% for office–factory (see Table 6). Of the total time spent by all respondents on the diary day, 69% was spent, on average, in a residence (Figure 1). Approximately 87% of the time was spent indoors and 5–6% in a vehicle — with the remaining 7–8% spent outdoors. These results are comparable with U.S. time budgets reported by Robinson and Thomas (1991) from a 1985 study and Canadian time budgets reported by Leech et al. (1996). For both of these two studies, which span a period of about 10 years, respondents reported spending

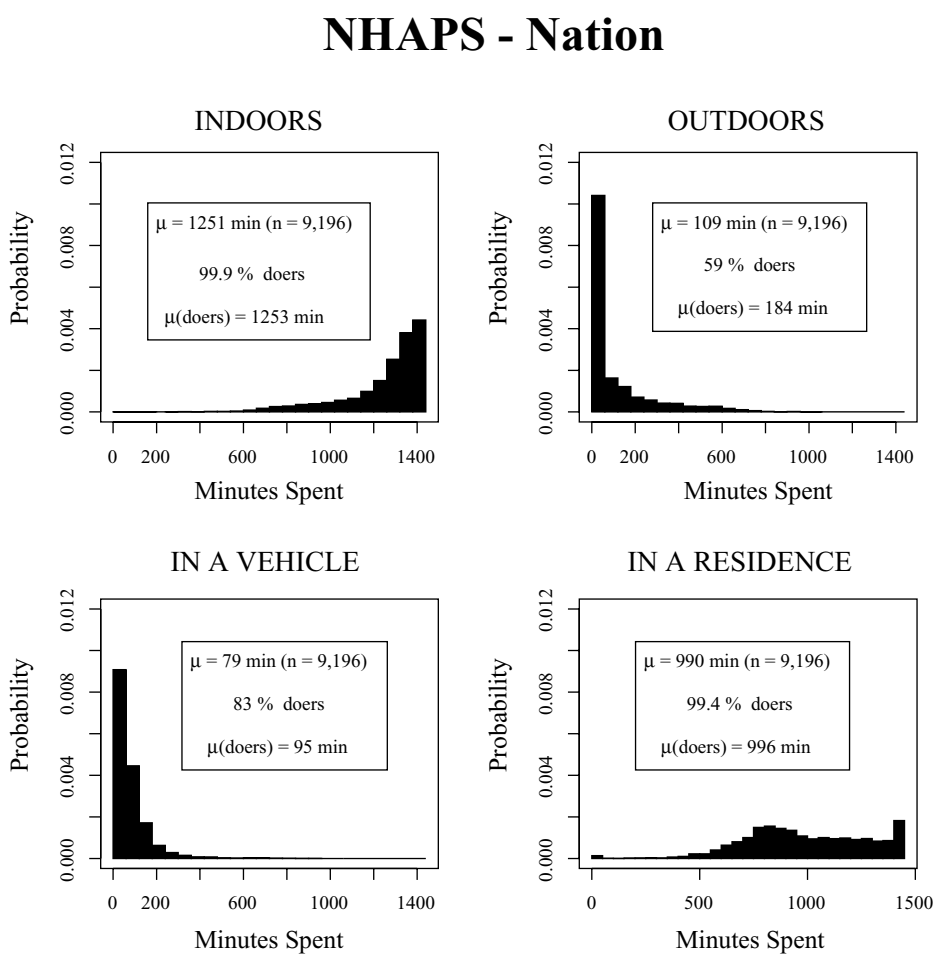


**Figure 3.** True histograms calculated from the weighted number of minutes that NHAPS respondents spent indoors, outdoors, in an enclosed vehicle, and in a residence. The time each individual spent in a residence is a subset of his total time spent indoors. While the histograms for the first three locations are strongly skewed (either right or left) with low variability, the time spent in a residence is highly variable and has three distinct modes: a small one for those who spent no time in a residence on the diary day; a middle one for those who spent much of their day away from home; and a third mode for those who were at home for most or all of the diary day. The overall weighted mean number of minutes spent, $\mu$, is provided on each graph, which, like the histograms, includes individuals who spent zero time in each location. The weighted percentage of respondents, $\mu$ (doers), who spent at least 1 min in each location (the doers) is also provided along with the weighted mean number of minutes they spent.

89% of the time spent indoors with 5% in a vehicle and 6% outdoors.

There may be some negative bias in the NHAPS results for time spent outdoors, since those who were away from a home for extended periods (e.g., on vacation or homeless) were not included in the survey. These individuals may be more likely than those who were at home to spend large quantities of time outdoors. On the other hand, there may be positive bias due to neglecting institutionalized and/or hospitalized individuals. In addition, the surprisingly small amount of outdoor doers (59%; see Table 6) suggests that the brief amounts of time that people might spend walking to their car or taking out the garbage, for example, were not included in the diaries. Questions in the supplemental portion of the NHAPS diary may be useful in understanding the magnitude of this missing time. It seems unlikely, though not impossible, that this unaccounted time contributes an appreciable amount to the total time spent outdoors.

In the NHAPS sample, 56% of respondents was never with a smoker (the non-doers), and was therefore not included in the calculation of percentages (see Table 7 for the percentage of doers in each location). The average percentage of time spent with a smoker in residences was 43%; it was 15% for bars and restaurants and 9% for an enclosed vehicle (Figure 2).

The shape of the distribution for time spent indoors is extremely positively skewed (a high proportion of long times), while time spent outdoors and in a vehicle is extremely negatively skewed (a high proportion of short times) — resulting in low variability (see Figure 3). In contrast, the variability in the time spent in a residence is very high; the distribution has three distinctly different modes corresponding to those respondents spending no time at home (less than 1%; see Table 6), those spending more than half their day at home, and those spending the entire diary day at home.

For some exposures, it is useful to determine the precise times of the day that the respondents are in certain locations or engaging in specific activities, since exposures to some air pollutants can depend on temporal trends. For example, the amount of time that a person spends outdoors during the day will greatly affect his exposure to ground-level ozone. As illustrated by Figure 4, the NHAPS database provides information on how the proportion of persons in different locations changes by time of day. Here, we see that over 90% of respondents is in a residence from about 11 PM to 5 AM, and, as expected, the largest proportions of respondents in schools, public buildings, offices, and factories occur between 7 AM and 5 PM.

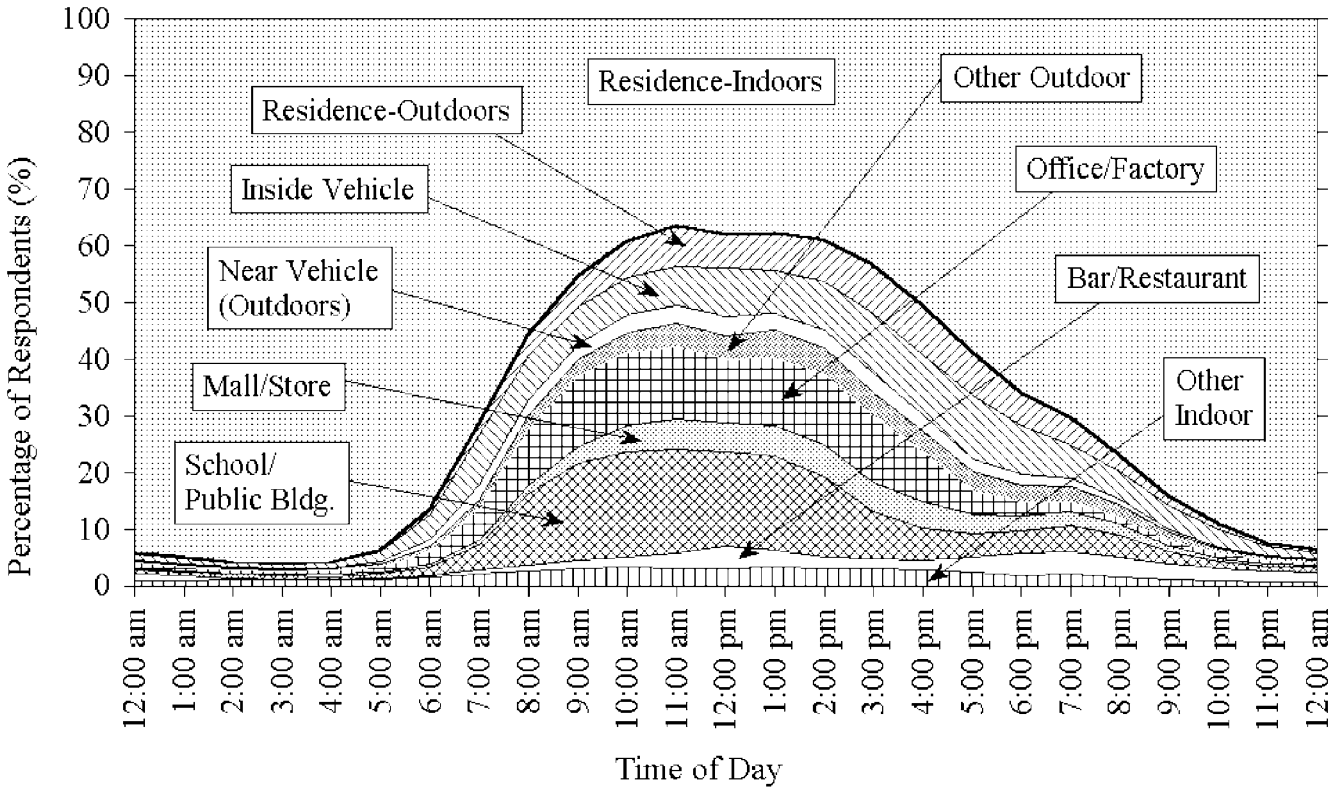


**Figure 4.** Stacked plot showing the weighted percentage of NHAPS respondents in each of 10 different locations according to the time of day. The original minute-by-minute diary data have been smoothed for clarification.

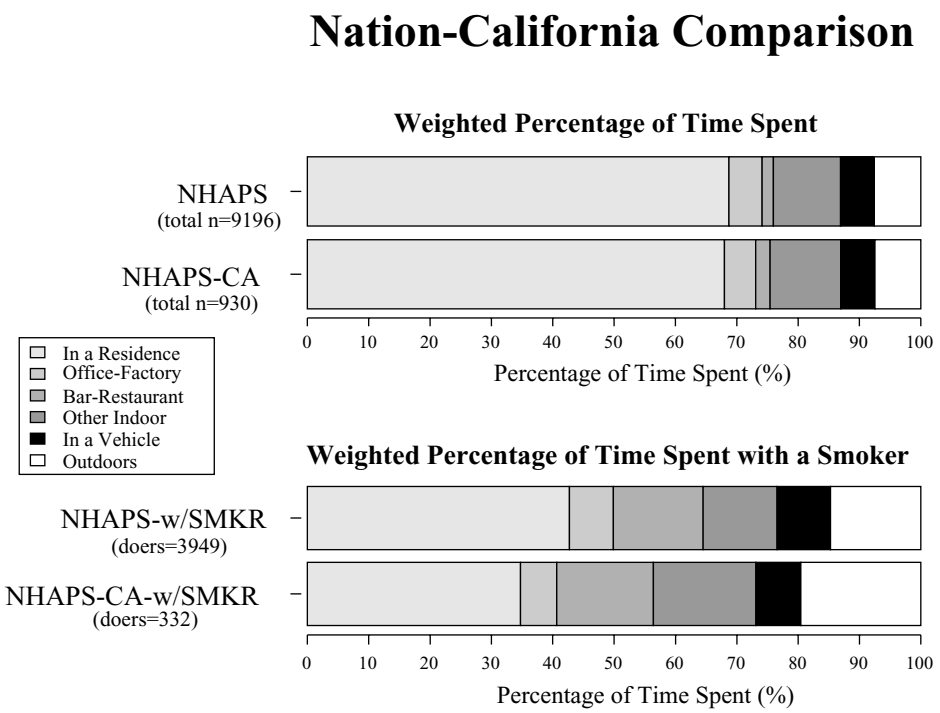


**Figure 5.** Comparison of the weighted percentage of overall time spent and time spent *with a smoker* in each of six locations for all of the NHAPS respondents (the entire national sample) and for the California-based NHAPS respondents (NHAPS-CA) (see Tables 6 and 7 for the total number of doers in each location). (Please see the text for a discussion of SRP-SERD biases inherent in the NHAPS database with respect to the time respondents reported spending with a smoker.)

*NHAPS: California Versus the Nation*

In Figure 5, we see that the mean percentages of time spent in the six grouped locations and the mean times spent with a smoker are very similar for the national NHAPS sample and the California subsample (NHAPS-CA). The overall means of time spent for each location (calculated over the entire sample, including those who spent zero time in a particular location), the proportion of doers (those who spent at least 1 min in a particular location on the diary day), and the mean time spent by the doers are very close for the two samples (Table 6).

The largest mean time spent in any location is nearly 1000 min (~17 h) for the residential location for both the nation and California by itself. For both geographic groups, nearly 100% percent of the respondents reported being in a residence at some time on the diary day. The largest mean time spent with a smoker (Table 7) was for offices and factories at 363 min/day for the nation and 280 min for California, followed by the residential location at 305 and 270 min, respectively. The lower means for California in these locations account for the somewhat lower mean time spent with smokers across all locations (372 *vs.* 309 min). California also appears to have a slightly lower number of persons spending time with a smoker (44% *vs.* 37% across all locations), apparently driven by the lower number of persons spending time with smokers in residences (26% *vs.* 17%) and, perhaps, the somewhat lower number of reported cigarette smokers (17% in the nation *vs.* 14% in California, all ages).

*NHAPS Versus CAPS*

A comparison between the NHAPS California subsample (NHAPS-CA) and CAPS allows us to observe the trends in activity patterns over time (from the late 1980s to the early-to-mid-1990s) and to evaluate the consistency between these two studies, which have fairly similar methodologies. The studies had the same survey instrument (i.e., CATI), but CAPS was a stratified sample of California and NHAPS-CA was not (although the overall NHAPS sample was indeed stratified; see the above discussion on the NHAPS data collection methodology).

As we observed in a comparison of the national NHAPS sample and NHAPS-CA, there is little difference between the mean percentage of time spent in each of the six locations between NHAPS-CA and CAPS for both adults and youth (age 12 and over) and for children under age 12 (see Figure 6 and Table 8). However, there are sizable

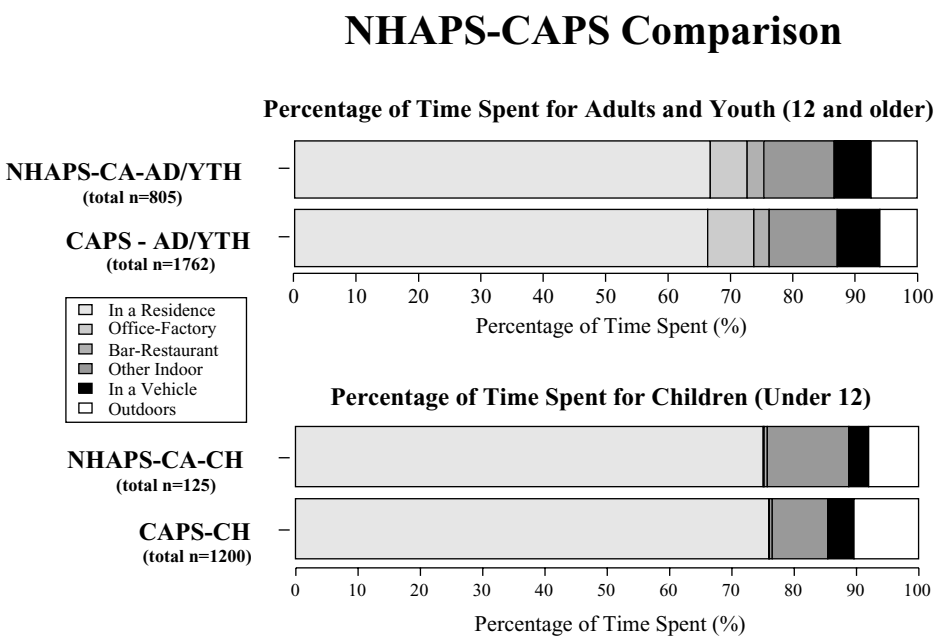


**Figure 6.** Comparison of the weighted percentage of time spent and time spent *with a smoker* in each of six locations for adult–youth and child NHAPS respondents and for adult–youth and child CAPS respondents. The children are under age 12. Both samples cover the entire state of California (see Tables 8 and 9 for the total number of doers in each location). (Please see the text for a discussion of SRP-SERD biases inherent in the NHAPS database with respect to the time respondents reported spending with a smoker.)

differences for the time spent with a smoker (i.e., for the mean time spent and the percentage of doers; see Table 9).

In both surveys, children under 12 spent small amounts of time in offices, factories, bars, and restaurants (overall means of 2–7 min, doer means of 40–60 min, and negligible percentages of time; see Figure 6). Our results show that children in California under the age of 12 spend a larger percentage of time indoors and outdoors and a lower percentage in vehicles than do adults. These are the same results as reported for Canada (Leech et al., 1996).

Since the adult/youth sample contributes the bulk of NHAPS-CA respondents ($n$=805 for adult/youth *vs.* $n$=125 for children), there were not enough California children respondents in NHAPS to calculate reliable statistics for the time spent with a smoker in different locations. However, from the statistics for children across all locations (see Table 9), we see that while the doer mean across all locations matches the CAPS mean fairly well (222 *vs.* 204 min), the percentage of doers is much lower for NHAPS-CA (20% *vs.* 38%). In the 1994–1995 CHAPS study of four Canadian cities, 30% of children reported being with a smoker (Leech et al., 1999). According to the results from CAPS alone, residences were (by far) the location where children had the longest mean time spent with a smoker (314 *vs.* 174 min for outdoors, the next highest mean). For CHAPS, children also experienced the most time with smokers in the residence. Twenty-five percent of CAPS children reported being with a smoker in a residence, whereas less than 13% reported being with a smoker in any of the other locations.

The adult/youth age group has ample sample size and can, therefore, provide an opportunity to observe the change in time spent with a smoker in each location from the earlier CAPS study to the later NHAPS study (see Table 9). As with the children, there appears to be a large reduction in the time spent with smokers over the period from the late 1980s (CAPS) to the early- to mid-1990s. The fact that the two studies have similar data collection instruments and the total time spent in each location match so well suggests that the differences in time spent with a smoker are due to real changes in human activity over the 5-year period.

There is a 22% decrease in the total number of adult/youth doers (persons exposed to second-hand smoke in all locations) from CAPS to NHAPS-CA (62% down to 40%). The percentage of doers in the residence and office–factory — the locations with the largest doer mean times spent — dropped from 26% to 17% and 13% to 4%, respectively, over the time period. The number of doers in bars and restaurants fell by almost half, going from 19% to 9%. However, the doer means do not drop (as they do slightly for the overall means, since there are fewer doers) and even increase dramatically for some locations; the bar–restaurant doer mean increases from 93 min in CAPS to 178 min in

NHAPS-CA, the outdoor doer mean goes from 121 to 210 min, and the mean in other indoor locations (e.g., public buildings, malls, and stores) rises from 160 to 254 min. Possible explanations are that smokers are asked or required to smoke in circumscribed locations where they contribute to longer exposure times for others or that policies have reduced casual exposures but not dominant ones.

The reduction in the number of reported cigarette smokers (20% for CAPS adults/youth *vs.* 16% for NHAPS-CA adults/youth) may have contributed to some of the changes in the number of doers and the time spent with a smoker for Californians of all ages. The California Department of Health Services (1998) reports a similar drop in cigarette smoking prevalence (20% in 1990 down to 17% in 1994). With the passage of a statewide California ordinance (AB13; effective January 1, 1995[2]) that prohibits smoking in enclosed workplaces, we might expect that, in recent years, the total time spent with a smoker in California has dropped even further. Miller et al. (1998a) predict a reduction of 25–40% in adult ETS exposure in California between the late 1980s and the late 1990s. However, smoking in the home and automobile may be less affected,

**Table 8.** Comparison of minutes spent on the diary day for NHAPS California respondents (NHAPS-CA) versus CAPS.

| Location | *n* | Overall mean (min) | Doer % | Doer *n* | Doer mean (min) |
|---|---|---|---|---|---|
| *NHAPS-CA adults and youth (12 and over)* | | | | | |
| In a residence | 805 | 961 | 99.6 | 802 | 966 |
| Office–factory | 805 | 85 | 22.0 | 182 | 388 |
| Bar–restaurant | 805 | 38 | 28.9 | 243 | 133 |
| Other indoor | 805 | 162 | 62.4 | 478 | 260 |
| In a vehicle | 805 | 86 | 86.0 | 682 | 100 |
| Outdoors | 805 | 106 | 58.8 | 508 | 181 |
| *CAPS adults and youth (12 and over)* | | | | | |
| In a residence | 1762 | 954 | 99.3 | 1755 | 961 |
| Office–factory | 1762 | 106 | 32.6 | 515 | 327 |
| Bar–restaurant | 1762 | 36 | 37.0 | 624 | 97 |
| Other indoor | 1762 | 157 | 70.2 | 1225 | 223 |
| In a vehicle | 1762 | 98 | 87.2 | 1516 | 113 |
| Outdoors | 1762 | 86 | 61.7 | 1112 | 140 |
| *NHAPS-CA children (under 12)* | | | | | |
| In a residence | 125 | 1081 | 100 | 125 | 1081 |
| Office–factory | 125 | 2 | 3.3 | 5 | 60 |
| Bar–restaurant | 125 | 7 | 11.4 | 17 | 65 |
| Other indoor | 125 | 188 | 59.2 | 64 | 318 |
| In a vehicle | 125 | 46 | 75.0 | 93 | 62 |
| Outdoors | 125 | 115 | 61.1 | 84 | 188 |
| *CAPS children (under 12)* | | | | | |
| In a residence | 1200 | 1093 | 99.7 | 1196 | 1097 |
| Office–factory | 1200 | 2 | 4.3 | 48 | 42 |
| Bar–restaurant | 1200 | 6 | 12.7 | 176 | 49 |
| Other indoor | 1200 | 128 | 59.4 | 700 | 216 |
| In a vehicle | 1200 | 61 | 76.0 | 887 | 80 |
| Outdoors | 1200 | 149 | 83.5 | 994 | 178 |

Means and percentages have been calculated using sample weights, whereas the sample sizes *n* and Doer *n* are raw counts.

**Table 9.** Comparison of minutes spent *with a smoker* for NHAPS California respondents (NHAPS-CA) versus CAPS.

| Location with a Smoker | *n* | Overall mean (min) | Doer % | Doer *n* | Doer mean (min) |
|---|---|---|---|---|---|
| *NHAPS-CA youth and adults (12 and over) (16% of respondents reported being cigarette smokers; weighted)* | | | | | |
| All locations | 805 | 126 | 39.8 | 308 | 317 |
| In a residence | 805 | 46 | 17.1 | 147 | 271 |
| Office–factory | 805 | 11 | 4.0 | 26 | 280 |
| Bar–restaurant | 805 | 15 | 8.6 | 79 | 178 |
| Other indoor | 805 | 22 | 8.5 | 57 | 254 |
| In a vehicle | 805 | 5 | 9.6 | 78 | 57 |
| Outdoors | 805 | 26 | 12.5 | 103 | 210 |
| *CAPS youth and adults (12 and over) (20% of respondents reported being cigarette smokers; weighted)* | | | | | |
| All locations | 1762 | 176 | 61.6 | 1014 | 285 |
| In a residence | 1762 | 63 | 26.3 | 430 | 238 |
| Office–factory | 1762 | 35 | 13.2 | 187 | 268 |
| Bar–restaurant | 1762 | 18 | 19.2 | 320 | 93 |
| Other indoor | 1762 | 32 | 20.3 | 338 | 160 |
| In a vehicle | 1762 | 11 | 11.3 | 206 | 94 |
| Outdoors | 1762 | 17 | 13.9 | 255 | 121 |
| *NHAPS-CA children (under 12)*[a] | | | | | |
| All locations | 125 | 44 | 19.8 | 24 | 222 |
| *CAPS children (under 12)* | | | | | |
| All locations | 1200 | 77 | 37.9 | 483 | 204 |
| In a residence | 1200 | 56 | 24.6 | 314 | 227 |
| Office–factory | 1200 | 0.024 | 0.26 | 3 | 9 |
| Bar–restaurant | 1200 | 3 | 4.8 | 70 | 54 |
| Other indoor | 1200 | 3 | 4.4 | 66 | 59 |
| In a vehicle | 1200 | 5 | 8.9 | 120 | 52 |
| Outdoors | 1200 | 12 | 12.7 | 174 | 92 |

[a]The NHAPS-CA children sample size is too small to calculate statistics for each location.

Means and percentages have been calculated using sample weights, whereas the sample sizes *n* and Doer *n* are raw counts. The time spent with a smoker does not include one's own smoking.

[2]AB13 banned smoking in California workplaces on January 1, 1995 — with an exception for bars, clubs, and casinos. That exception was extended until January 1, 1998 when smoking was banned in all bar–restaurants throughout the state.

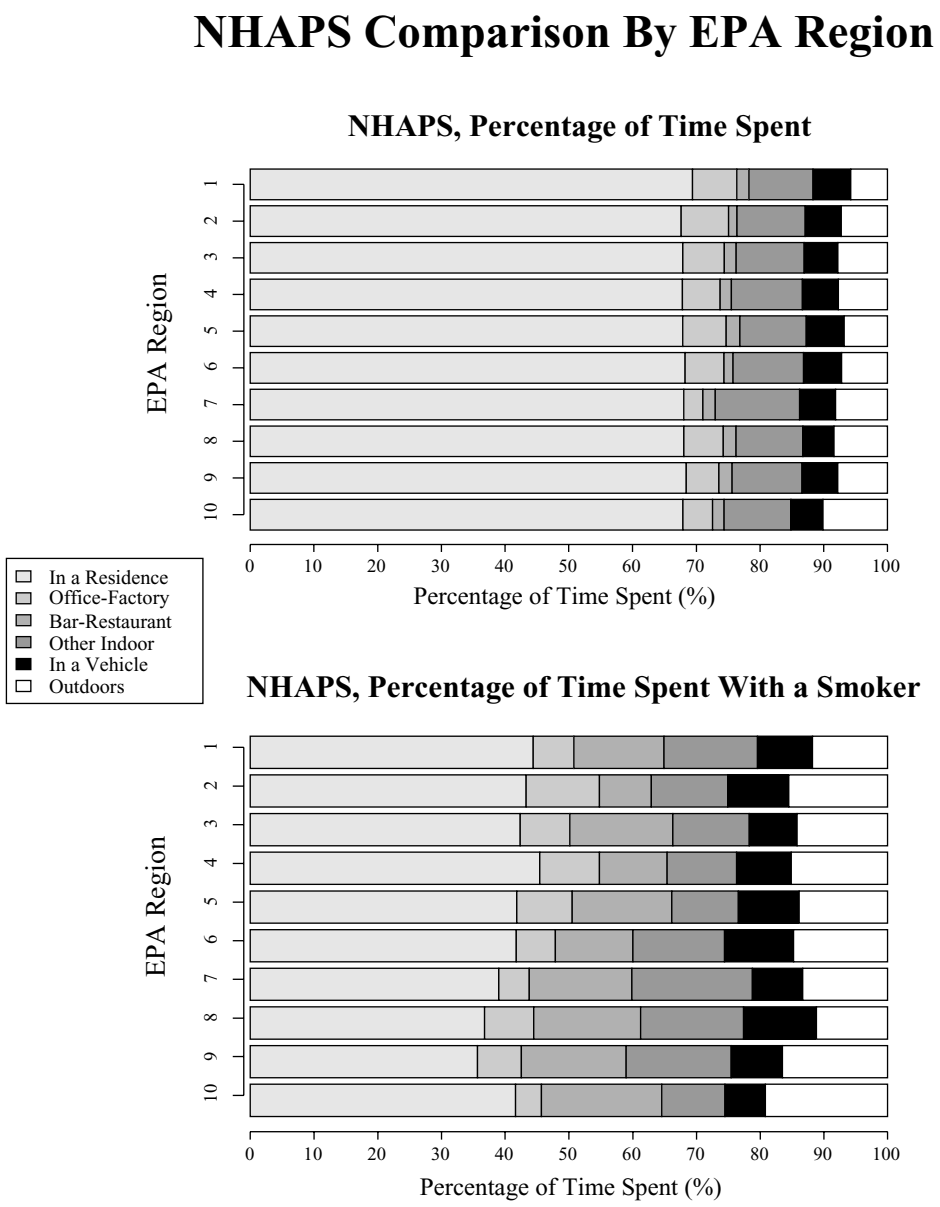


**Figure 7.** Comparison of the weighted percentage of time spent and time spent *with a smoker* in each of six locations across the 10 U.S. EPA regions (see Table 11 for the number of doers in each location and EPA region). The states comprising each EPA region are listed in Tables 10 and 11. (Please see the text for a discussion of SRP-SERD biases inherent in the NHAPS database with respect to the time respondents reported spending with a smoker.)

with residences and cars remaining the locations where children spend substantial amounts of time with smokers.

*Variation Across EPA Regions*

Surprisingly, we do not see much difference in the mean percentage of time spent in different locations across the 10 EPA regions. The percentage of time spent with a smoker is also very consistent across these geographically and climatically distinct areas. The similarities are illustrated in Figure 7. The percentage of doers in each location and the mean doer times spent are also very close across the EPA regions (Table 10). Differences are larger for comparisons of percentage doers and doer mean for the time spent with a smoker (Table 11), but the statistics are still very comparable. The states that comprise each EPA region are listed in Table 11.

One should keep in mind that the respondents were interviewed during all four seasons, and the results we present are averaged over individuals who provided diaries throughout the year. Nevertheless, it is interesting to observe that persons living in the upper mid-western area of the country (EPA Region 5), with its cold winters and mild

**Table 10.** NHAPS minutes spent on the diary day by EPA region.

| Location | *n* | Overall mean | Doer % | Doer *n* | Doer mean |
|---|---|---|---|---|---|
| *EPA Region 1* | | | | | |
| In a residence | 572 | 1000 | 99.3 | 569 | 1006 |
| Office–factory | 572 | 100 | 23.2 | 127 | 430 |
| bar–restaurant | 572 | 28 | 23.9 | 146 | 115 |
| Other indoor | 572 | 145 | 58.9 | 323 | 246 |
| In an enclosed vehicle | 572 | 85 | 83.9 | 465 | 101 |
| Outdoors | 572 | 83 | 56.1 | 319 | 148 |
| *EPA Region 2* | | | | | |
| In a residence | 965 | 974 | 99.9 | 964 | 975 |
| Office–factory | 965 | 107 | 26.8 | 228 | 400 |
| Bar–restaurant | 965 | 19 | 17.0 | 196 | 110 |
| Other indoor | 965 | 154 | 59.2 | 571 | 260 |
| In an enclosed vehicle | 965 | 82 | 81.1 | 768 | 101 |
| Outdoors | 965 | 104 | 61.9 | 594 | 168 |
| *EPA Region 3* | | | | | |
| In a residence | 1089 | 978 | 98.9 | 1081 | 989 |
| Office–factory | 1089 | 94 | 22.7 | 235 | 413 |
| Bar–restaurant | 1089 | 27 | 20.5 | 241 | 132 |
| Other indoor | 1089 | 153 | 57.5 | 634 | 267 |
| In an enclosed vehicle | 1089 | 76 | 82.4 | 880 | 92 |
| Outdoors | 1089 | 112 | 58.3 | 627 | 193 |
| *EPA Region 4* | | | | | |
| In a residence | 1713 | 977 | 99.7 | 1709 | 980 |
| office–factory | 1713 | 85 | 20.5 | 335 | 416 |
| bar–restaurant | 1713 | 26 | 22.3 | 399 | 115 |
| Other indoor | 1713 | 160 | 58.6 | 1008 | 273 |
| In an enclosed vehicle | 1713 | 82 | 86.2 | 1437 | 95 |
| Outdoors | 1713 | 111 | 55.1 | 920 | 201 |
| *EPA Region 5* | | | | | |
| In a residence | 1651 | 977 | 99.0 | 1639 | 987 |
| Office–factory | 1651 | 98 | 24.1 | 376 | 408 |
| Bar–restaurant | 1651 | 31 | 27.1 | 442 | 114 |
| Other indoor | 1651 | 150 | 57.5 | 948 | 260 |
| In an enclosed vehicle | 1651 | 86 | 85.1 | 1388 | 101 |
| Outdoors | 1651 | 98 | 53.9 | 888 | 181 |
| *EPA Region 6* | | | | | |
| In a residence | 1019 | 983 | 99.5 | 1015 | 988 |
| Office–factory | 1019 | 88 | 22.1 | 214 | 398 |
| Bar–restaurant | 1019 | 21 | 23.3 | 239 | 90 |
| Other indoor | 1019 | 159 | 59.4 | 584 | 267 |
| In an enclosed vehicle | 1019 | 86 | 86.2 | 853 | 100 |
| Outdoors | 1019 | 104 | 58.0 | 597 | 179 |
| *EPA Region 7* | | | | | |
| In a residence | 418 | 980 | 99.1 | 415 | 989 |
| Office–factory | 418 | 43 | 12.5 | 60 | 344 |
| Bar–restaurant | 418 | 28 | 26.1 | 111 | 108 |
| Other indoor | 418 | 190 | 63.3 | 257 | 301 |
| In an enclosed vehicle | 418 | 81 | 83.8 | 344 | 97 |
| Outdoors | 418 | 117 | 58.5 | 234 | 201 |
| *EPA Region 8* | | | | | |
| In a residence | 340 | 981 | 98.8 | 338 | 992 |
| Office–factory | 340 | 89 | 23.6 | 68 | 376 |
| Bar–restaurant | 340 | 29 | 24.4 | 80 | 117 |
| Other indoor | 340 | 151 | 59.2 | 204 | 256 |
| In an enclosed vehicle | 340 | 70 | 84.5 | 281 | 83 |
| Outdoors | 340 | 121 | 60.3 | 203 | 200 |
| *EPA Region 9* | | | | | |
| In a Residence | 1239 | 985 | 99.7 | 1235 | 988 |
| Office–factory | 1239 | 74 | 19.9 | 257 | 371 |
| Bar–restaurant | 1239 | 30 | 24.9 | 338 | 121 |
| Other indoor | 1239 | 158 | 59.3 | 723 | 266 |
| In an enclosed vehicle | 1239 | 81 | 83.6 | 1028 | 96 |
| Outdoors | 1239 | 112 | 63.8 | 789 | 176 |
| *EPA Region 10* | | | | | |
| In a residence | 380 | 978 | 99.6 | 378 | 982 |
| Office–factory | 380 | 67 | 18.4 | 74 | 365 |
| Bar–restaurant | 380 | 26 | 27.1 | 103 | 97 |
| Other indoor | 380 | 151 | 61.8 | 220 | 244 |
| In an enclosed vehicle | 380 | 72 | 80.7 | 298 | 90 |
| Outdoors | 380 | 146 | 69.1 | 261 | 211 |

Alaska (AK) and Hawaii (HI) were not sampled as part of NHAPS.
Means and percentages have been calculated using sample weights, whereas the sample sizes *n* and Doer *n* are raw counts (see Table 11 for the states comprising each EPA region).

summers, spend nearly the same percentage of time outdoors, on average, as most parts of the country, including the southwestern area (EPA Region 9) with its hot summers and mild winters. These results are consistent with U.S. *versus* Canada comparisons.

## Summary and conclusions

It is clear from studies of personal exposure that human activity patterns are crucial in identifying and determining human exposure to environmental pollutants. Activity pattern data, such as that in the NHAPS database, may be used to estimate the prevalence and duration of population exposure, especially for high-risk groups, to many environmental pollutants (such as tobacco smoke). For example, we can make the following general observations based on activity pattern data alone:

- Americans spend 87% of their time indoors and 6% in an enclosed vehicle (on average);

**Table 11.** NHAPS total minutes spent with a smoker on the diary day by EPA region.

| EPA Region | *n* | Overall mean (min) | Doer % | Doer *n* | Doer mean (min) |
|---|---|---|---|---|---|
| (1) New England: CT, ME, MA, NH, RI, VT | 572 | 172 | 47.8 | 269 | 360 |
| (2) North Atlantic: NJ, NY | 965 | 170 | 47.5 | 437 | 357 |
| (3) Mid Atlantic: PA, DE, DC, MD, VA, WV | 1089 | 179 | 43.8 | 453 | 409 |
| (4) South Atlantic: AL, FL, GA, KY, MS, NC, SC, TN | 1713 | 198 | 46.3 | 759 | 429 |
| (5) Midwest: IL, IN, MI, MN, OH, WI | 1651 | 179 | 47.0 | 751 | 380 |
| (6) South Central: AR, LA, OK, TX, NM | 1019 | 170 | 44.6 | 438 | 380 |
| (7) Central: IA, KS, MO, NE | 418 | 168 | 43.8 | 176 | 384 |
| (8) North Central: ND, SD, CO, MT, UT, WY | 340 | 118 | 33.0 | 112 | 359 |
| (9) Pacific: AZ, CA (HI)[a], NV | 1239 | 125 | 37.5 | 459 | 333 |
| (10) Mountain: (AK)[a], ID, OR, WA | 380 | 162 | 39.5 | 151 | 409 |

Means and percentages have been calculated using sample weights, whereas the sample sizes *n* and Doer *n* are raw counts. The time spent with a smoker does not include one's own smoking.
[a]Alaska (AK) and Hawaii (HI) were not sampled as part of NHAPS.

- The percentage of time spent indoors, outdoors, and in vehicles is fairly invariant across people in different parts of the U.S. (on average);
- Americans and Canadians spend similar amounts of time indoors, outdoors, and in vehicles (on average);
- From sociological studies, it appears that the time Americans spend indoors has remained fairly uniform over the past few decades;
- Forty-four percent of Americans spends time with a smoker each day (ca. 1992–94);
- Of any location, Americans spend the largest percentage of time with a smoker in residences (43%, calculated as an average across individual respondent percentages ca. 1992–94); and
- The number of people spending time with smokers in California has decreased between the late 1980s and the mid-1990s (when NHAPS was conducted).

When combined with measurements and/or models of pollutant emission, activity pattern data that possess high time resolution can be used to provide estimates of actual population exposures caused by a variety of different pollutant sources. These population exposure models make it possible to estimate, with increased precision, the frequency distribution of exposure across a population, as well as the likely change in the distribution when exposure to a particular pollutant source is modified (e.g., by a change in human behavior).

In the future, investigators may want to consider a number of improvements upon the NHAPS survey design. For example: (1) The NHAPS survey was limited to a single 24-h period for each respondent and, therefore, did not consider any day-to-day variation in the behavior of each respondent. To examine diurnal cycles in human behavior, future studies should sample individuals on multiple days. (2) The NHAPS results on the reported presence of a smoker may be biased.[3] The diary question on the presence of a smoker did not require all respondents to specify the portion of time that a smoker was actually present in each microenvironment. For example, a smoker might have been present for only 10 min when the total time spent in the microenvironment was an hour or more. In such a case, the reported time spent exposed to a smoker would be 1 h, a large positive bias. Future studies should collect more precise information on the presence of smokers and/or other pollutant sources.

## Acknowledgments

The research described in this article has been funded, wholly or in part, by the U.S. Environmental Protection Agency under Cooperative Agreement CR816183 with the University of Maryland, under contract 68-W5-0011 to Lockheed Martin Services Group, and as part of a the Human Exposure and Dose Simulation University Partnership (HEADSUP) among Lawrence Berkeley National Laboratory (LBNL), Stanford University, and EPA (agreement number DW89931890). It has been subjected to Agency review and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

[3]There are also a number of other recognized biases which are expected to have a small impact on average statistics. These other biases include the following: (1) the survey was limited to individuals residing in homes with telephones; (2) the survey did not include individuals who were on vacation, away from home for extended periods, or homeless, and who may, therefore, spend more time outdoors than those who were actually surveyed; (3) the survey did not include people in institutions/hospitals who might spend less time outdoors; and (4) the diaries may be missing brief periods of time that people spent outdoors such as might occur when one walks to a car or store, or takes out the garbage.

The preparation of this manuscript — including the data analyses — was also funded, in part, by the Tobacco-Related Disease Research Program (TRDRP) of California (award no. 6RT-0118).

The authors thank the University of Maryland's Survey Research Center for designing NHAPS, conducting the NHAPS data collection and data management activities, and for assisting in the data analysis phase of the study. The authors also thank W.W. Nazaroff for reading and commenting on the manuscript, particularly in pointing out important sample biases, A.B. Bodnar and R. Maddalena of LBNL for reviewing the manuscript, and the anonymous peer reviewers for their thoughtful suggestions.

Finally, we thank the following distinguished group of scientists who served on the NHAPS panels. Mel Kollander, Stanley Presser, and Lance Wallace served on the survey design panel; Steve Colome, Naihua Duan, Peggy Jenkins, Paul Lioy, and Barry Ryan served as the peer review panel; and the subject matter expert panel consisted of Julian Andelman, Michael Firestone, Patrick Kennedy, Ted Johnson, Thomas McCurdy, and James Repace.

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