An Exposure Assessment Study of Ambient Heat Exposure in an Elderly Population in Baltimore, Maryland

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Because of concern for heat-related mortality in vulnerable populations, particularly the elderly, practical epidemiologic methods are needed for the assessment of ambient heat exposure on individuals. We used a personal monitor to measure body temperature, ambient temperature, heart rate, and activity level of 42 elderly residents of Baltimore, Maryland, in the summer months of 2000. Each participant was monitored for approximately 48 hr to examine the association between ambient temperature and body temperature, using regression methods that account for highly correlated data within individuals. We also examined the associations of Baltimore temperature data with personal ambient temperature and body temperature. An average 0.15°F [95% confidence interval (CI), 0.05–0.25] increase in median body temperature was found for each 1°F increase in median ambient temperature. Heart rate and activity level were not found to be related to body temperature or ambient temperature, although heart rate was associated with activity level. Median heart rate increased an average of 0.17 (95% CI, 0.13–0.21) beats per minute for every unit increase in median activity level. Personal ambient temperature was slightly lower than Baltimore temperatures, whereas an association was not found between body temperature and Baltimore temperatures. The protocol established in this study for heat exposure assessment could feasibly be applied on a larger scale. *Key words:* activity level, aged, ambient temperature, body temperature, elderly, exposure assessment, heart rate, heat exposure, time–activity diary. *Environ Health Perspect* 110:1219–1224 (2002). [Online 15 October 2002]
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Excessive ambient heat exposures result in significant mortality to vulnerable populations (*1–4*). The elderly and young children may not be able to thermoregulate efficiently because of their higher sweating thresholds, thus increasing the risk of life-threatening consequences when their body temperatures rise (*5,6*). In the United States, an average of 274 people are direct victims of heat-related mortality each year, with the highest death rates occurring in persons at least 65 years of age (*7*). The actual magnitude of deaths may be notably greater than what has been reported, as there is presently no standard classification of heat-related deaths in the United States. Persons with chronic diseases of the heart or lungs may be more susceptible to the effects of high ambient temperatures, especially if they take certain medications (e.g., diuretics, beta blockers, and tranquilizers) that may limit adaptive responses (*8*). Housing characteristics and behaviors specific to the elderly, including living alone, living on higher floors of apartment buildings, lacking air conditioning, and keeping windows and doors closed for safety reasons, may also increase mortality risk from heat exposure (*9*). Approaches are needed for assessing unsafe levels of heat exposure and their determinants.

To date, methods of personal exposure assessment have not been applied to heat exposure. There is, however, an extensive literature on personal exposure assessment for air pollution (*10*), and we based our study design on the direct and indirect models of microenvironmental exposure that have been applied to specific air pollutants (*11*). A microenvironment refers to an area where the exposures of interest are sufficiently homogeneous for the purpose of exposure assessment over the time of observation. Total exposure takes into account the time spent in microenvironments with various concentrations of a particular contaminant (*12*). For temperature, total personal exposure reflects the time spent in particular microenvironments and the temperatures during that time. In direct exposure assessment, each individual has some form of personal exposure monitoring for a given time period. Indirect assessment relies on information provided by questionnaires or time–activity diaries and environmental measurements made in microenvironments. Time–activity diaries provide information about the distribution of time spent in different microenvironments; such data are particularly useful for dynamic exposures such as ambient temperature (*13,14*). As individuals move from outdoors to indoors to transportation environments, they can record their locations in detail so that the time can be linked to the concentration in the environment.

We examined the effect of personal heat exposure on body temperature in 42 elderly Baltimore, Maryland, residents using a direct approach. Ambient (indoor or outdoor) temperature, body temperature, heart rate, and activity level were monitored in each participant for approximately 48 hr. Ambient temperature served as a surrogate for heat exposure, whereas skin temperature was a proxy for core body temperature. Baltimore temperatures were also examined, representing the macroenvironmental heat exposures that are experienced by a large population and partially determine indoor temperatures.

Materials and Methods

Study design and population. We enrolled a convenience sample, consisting of the first 50 persons over 65 years of age who volunteered to participate in the study. Study recruitment took place in 1999 and 2000, and monitoring occurred over 48 hr for each participant from 15 May 2000 to 15 September 2000. Most participants (81%) were recruited from two large senior centers in Baltimore during group meetings. The other participants responded to study bulletins posted at apartment buildings in Baltimore and in community newsletters. The Institutional Review Board at the Johns Hopkins University Bloomberg School of Public Health approved this study before participants were recruited, and written informed consent was received from all participants in the study.

Personal monitoring. After recruitment, an appointment was scheduled to begin the monitoring process. The first visit took place at a senior center, a community room, or the participant's home, depending on each participant's preference. In addition to information obtained on medication use, housing characteristics, and demographics, a self-administered heat exposure questionnaire was given to all study participants to assess individual risk profiles for adverse health outcomes during periods of high outdoor heat exposures. Body temperature, ambient temperature, heart rate, and activity level of each participant were recorded and stored every minute for 48 hr using a personal monitor, the Mini-Logger 2010 (Mini-Logger Corporation, Bend, OR). Because this monitor is compact and lightweight, it can be placed safely in a participant's pocket during the exposure assessment period.

Two temperature probes were used to monitor body temperature and ambient temperature. One of the probes was taped securely

on top of the skin underneath the side of the chest belt to approximate body temperature (without interfering with the heart rate monitoring). Another temperature probe was taped securely on top of the participant's clothing, such as on a shirt sleeve or jacket lapel, to monitor ambient temperature. Ambient temperature was defined as outdoor or room temperature, depending on whether the participant was outdoors or indoors, respectively. The Mini-Logger records temperatures from 83 to 108°F ± 0.1°F accuracy.

Each participant also wore a polar chest belt to monitor heart rate. Conductive heart pads in the belt detect electrocardiographic signals transmitted via radio signal to the Mini-Logger, eliminating the need for any wired connections for measuring heart rate. The range detected for heart rate is up to 250 beats per minute (bpm), with 1 bpm resolution and ± 1 beat accuracy.

Activity level was monitored with motion-sensitive mercury detectors located directly on the monitor. When movement was detected, an activity level was recorded proportional to the extent of movement, which could range from 0 to 65,535 counts per interval (cpi). The monitored activity level information was compared qualitatively with a time–activity diary completed by each participant to validate the data produced by the activity marker. Participants recorded their hourly activities in time–activity diaries, including their changing environments (i.e., from outdoors to indoors) and adaptation measures used during their entire monitoring period. Factors that can influence body temperature, such as use of air conditioning or fan, medication intake, infections, exercise, and alcohol intake, were reported. From this information, we were able to quantify the time spent by each participant in different microenvironments.

City temperature data. Baltimore data corresponding to the monitoring period were abstracted from the database of the National Climatic Data Center (Figure 1). The hourly average dry bulb temperature data from downtown Baltimore and the Baltimore-Washington International Airport (BWI) were used for this study. Two sites were chosen because one is located in the city and the other in a neighboring county, therefore supplying two comparisons with the personal monitor data. Urban temperatures are expected to be higher than the surrounding areas because of heat trapped in roads and buildings, a phenomena known as the "urban heat-island effect" (*15*).

Data analysis. The unit of analysis for this study was a person-hour, resulting in a maximum of 48 observations per participant. An hour was chosen to reflect the dynamics of indoor and outdoor temperature changes and the relationship between temperature exposure and body temperature (*16,17*). A shorter time interval (e.g., minutes) would not add much information, as the temperature data did not have much variation within an hour. A longer period (e.g., 6 or 12 hr), however, may result in aggregate measures that encompass, and therefore mask, variations of heat exposure.
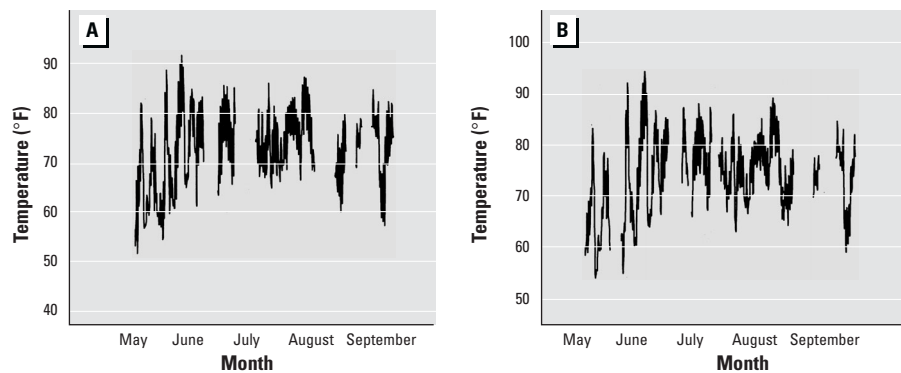

Figure 1. Baltimore hourly mean temperatures corresponding to the study period (summer 2000). (*A*) BWI. (*B*) Downtown Baltimore.
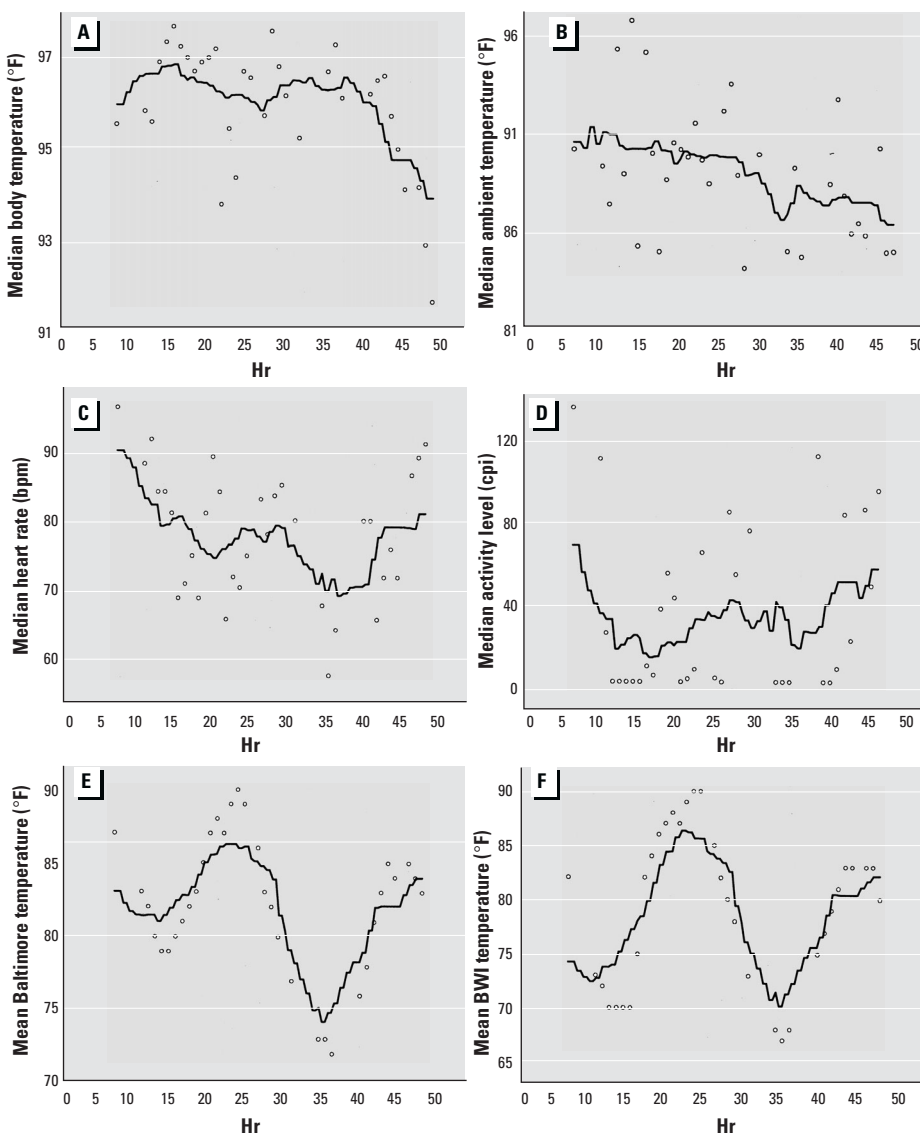

Figure 2. Hourly monitored data of one participant and corresponding Baltimore data for 48 hr. (*A*) Mean body temperature. (*B*) Median ambient temperature. (*C*) Median heart rate. (*D*) Median activity level. (*E*) Mean Baltimore temperature. (*F*) Mean temperature at BWI.

Before calculating hourly averages for all variables, we graphed and reviewed the data for each participant. The monitored data were defined as the beginning of the 54th minute to the 53rd minute of the following hour (e.g., from 0054 hr to 0153 hr) so that each hour in the personal monitoring data set would coincide exactly with the Baltimore temperature data. Each hour may contain < 60 min of data because missing values for heart rate were excluded; such missing values likely resulted from the chest belt slipping off the participant or the participant taking it off voluntarily (e.g., to shower). Body and ambient temperatures equal to 83.0°F were excluded from the study because 83.0°F was the lower limit of detection for the personal monitor and could reflect temperatures < 83.0°F. Most participants (88%) had < 48 hr of data because of these exclusions. Median values for body temperature, ambient temperature, activity level, and heart rate were used to limit the influence of outliers, although mean values were the only averages available for the Baltimore data. Each participant had individual body temperature, ambient temperature, activity level, and heart rate information as well as corresponding Baltimore data for approximately 48 hr. An example of one participant's data is shown in Figure 2. These plots were created using Kernel smoothing using S-PLUS software (18). Because only one personal monitor was used, every participant had a unique period of observation. Figure 3 contains the frequency distribution of hourly medians for the monitored measures.

Ambient temperature, heart rate, and activity level were compared with body temperature, and heart rate was also compared with activity level (Figure 4). A linear regression model using least squares was fit separately for each participant (18). As shown, interindividual variation was identified, as each participant had his/her own starting point and unique slope. To account for the heterogeneity between individuals, the random effects model of DerSimonian and Laird (19) was applied after combining data from all of the participants. Because repeated measurements were taken for the same person, statistical methods were also required to account for the high degree of intraindividual correlation. Thus, the mixed procedure for generalized estimating equations with an unstructured covariance matrix was applied for all monitored data using SAS software (20).

We examined several univariate and multivariate associations using the hourly median values of the personal monitored data in regression analyses. The association between ambient temperature and body temperature was examined. Next, the effect of ambient temperature, heart rate, and activity level on body temperature were assessed in a multivariate model. Because changes in heart rate or activity level may influence the mechanism by which ambient temperature affects body temperature, potential effect modification between ambient temperature and activity level and between ambient temperature and heart rate was also evaluated. In addition, the association between heart rate and activity level was examined. The hourly median body temperature and hourly median ambient temperature were compared in separate analyses with the hourly mean temperature for each monitoring site in Baltimore (downtown Baltimore or BWI). A general linear regression model was used to examine the relationship between hourly temperatures at downtown
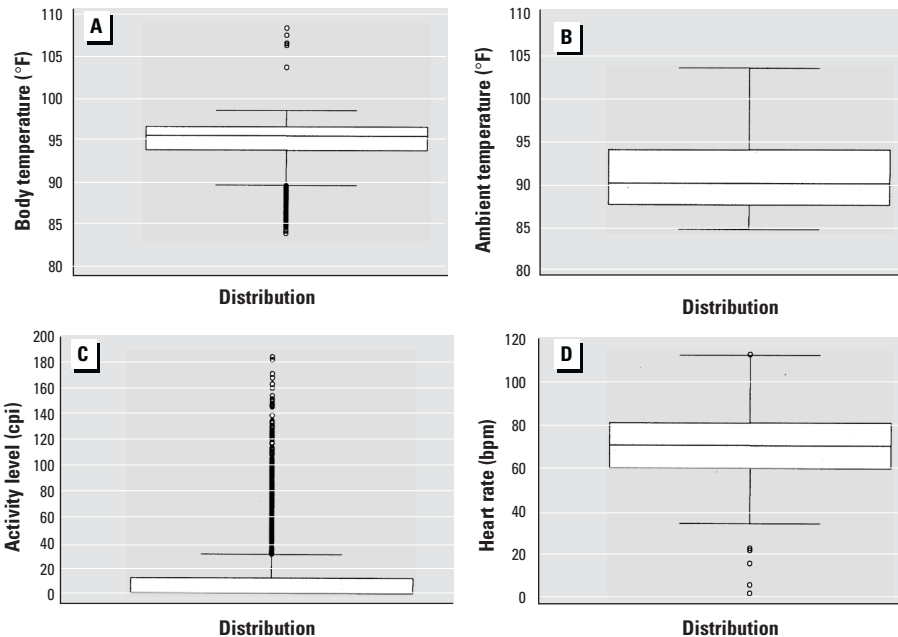

Figure 3. Distribution of median monitored data for all participants (*n* = 42). (*A*) Body temperature. (*B*) Ambient temperature. (*C*) Activity level. (*D*) Heart rate.
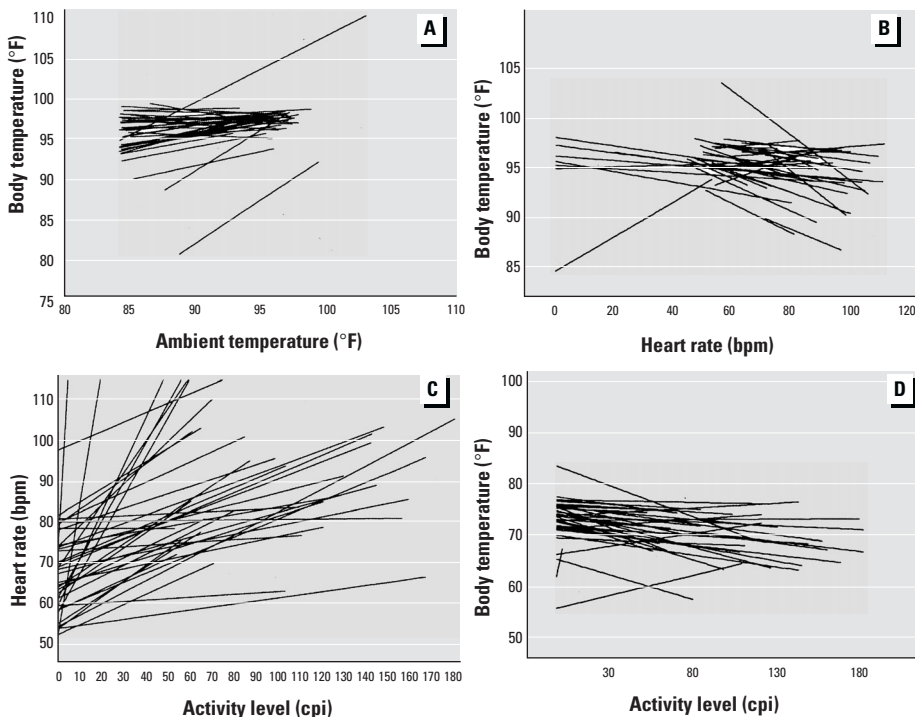

Figure 4. Univariate associations between body temperature and ambient temperature (*A*), body temperature and heart rate (*B*), heart rate and activity level (*C*), and body temperature and activity level (*D*) using hourly medians (*n* = 42).

Baltimore and at BWI, using the PROC REG procedure in SAS (*20*).

Results

Of the 50 participants recruited for this study, 42 were included in the analysis. Reasons for exclusion from the study were missing appointments to start the monitoring period (*n* = 3), withdrawing from the study at the beginning of the monitoring period (*n* = 4), and using the monitor incorrectly (*n* = 1). Eighty-six percent of participants resided in north and southeast Baltimore, whereas 14% lived in Baltimore County.

Demographics, housing characteristics, heat adaptation measures, and medical histories were characterized using the heat exposure questionnaires. As shown in Table 1, most study participants were between 70 and 84 years of age (79%), female (86%), widowed (50%), and white (91%). About 83% lived in a rowhouse or apartment complex, with 83%

Table 1. Characteristics of study participants.

Variable	Percent
Age (years)	
65–69	14
70–74	24
75–79	29
80–84	26
≥ 85	7
Sex	
Male	14
Female	86
Marital status	
Single	14
Married	31
Widowed	50
Divorced	5
Race	
White	91
Black	7
Hispanic	2
Type of residence	
Single-family home	17
Rowhouse/townhouse	43
Apartment	40
Living alone	
Yes	52
No	48
Security bars	
Yes	5
No	95
Number of floors in building	
1–4	83
≥ 5	17
Residing on which floor	
1–4	86
≥ 5	14
Air conditioner in home	
Yes	98
No	2
Medical history	
Lung disease	5
Asthma	0
Chronic obstructive pulmonary disease	0
Heart disease	23
Hypertension	50
Stroke	10
Medication intake	98

having only one to four floors in their building. Most had air conditioning in their homes (98%), and 68% had a central system. More than half (52%) lived alone, and almost all (95%) did not have security bars on their windows. Fifty percent of participants reported having a history of hypertension, 23% had heart disease, 10% had stroke, and 5% had lung disease. Most participants (98%) took several medications daily. As demonstrated in Table 2, the most common heat adaptation measures used by participants included wearing less clothing (93%), drinking more fluids (90%), going outdoors (88%), and using air conditioners (88%). According to the time–activity diaries completed by the participants, the majority of time was spent indoors (92% of total) and at home (78%), whereas only 7% was spent in transportation environments and 5% in the general outdoor environment (Table 3). All participants contributed a total of 1,520 person-hours of data, with a mean of 36 hr per participant.

Figure 3 shows box plots with the median, minimum, and maximum values for each of the four monitored measures. The median body temperature was approximately 96°F, and the median ambient temperature was 91°F. Most participants were generally

Table 2. Heat adaptation measures used by study participants.

Adaptation	Percent[a]
Turning air conditioning on	88
Opening windows	57
Drinking more fluids	90
Avoiding the outdoors	60
Going outdoors	88
Wearing less clothing	93
Taking cold baths/showers	45
Going to a public place with air conditioning	57
Swimming	19
Turning fan on	62

[a]Includes responses of "always," "usually," or "sometimes."

Table 3. Time expended in several microenvironments by study participants.

Microenvironment	Total (%)
Total indoors	92.1
Home	
Social center	77.6
Work	4.8
Store	2.4
Visiting friend/relative	2.3
Eating at a restaurant	1.6
Movie theater	1.4
Other (exercise, church, bar, library, salon)	1.7
Total outdoors	5.0
General	3.3
Eating at a restaurant	0.7
Tennis	0.6
Outdoor shopping mall	0.4
Total in-transit	6.8
Car/taxi	5.4
Bus	0.8
Walking	0.6

inactive (86%), with some exceptions, accounting for the outliers in the distribution for activity level. The average heart rate was approximately 70 bpm, in the normal range for elderly persons (*21*).

Table 4 presents the results of several statistical models for estimating the effect of ambient temperature, heart rate, and activity level on body temperature in the summer of 2000 using hourly medians. In model 1, an increase of 1°F in ambient temperature was estimated to increase average body temperature by 0.15°F [95% confidence interval (CI), 0.05–0.25] in the summer months. With the addition of heart rate and activity level in model 2, the effect of ambient temperature was slightly reduced (β = 0.12°F; 95% CI, 0.04–0.20), and the effects of heart rate and activity level were not significant ($p > 0.05$). We also examined interactions between ambient temperature and activity level and between ambient temperature and heart rate in predicting body temperature (data not shown) but found no significant associations ($p > 0.05$). A positive association was demonstrated between activity level and heart rate. For every count per interval increase in activity level, heart rate increased by an average of 0.17 bpm (95% CI, 0.13–0.21).

Next, we examined the effect of average hourly Baltimore temperatures on body temperature. As demonstrated in models 3 and 4, temperatures recorded at BWI and downtown Baltimore had negligible effects on body temperature. Personal ambient temperatures were lower compared with temperatures at BWI (β = –0.19°F; 95% CI, –0.23 to –0.15) and downtown Baltimore (β = –0.19°F; 95% CI, –0.23 to 0.13). A strong correlation between hourly temperatures at BWI and downtown Baltimore was found (r^2 = 0.62). Average hourly temperatures recorded at downtown Baltimore were an average 0.63°F (95% CI, 0.53–0.73) higher than temperatures at BWI, consistent with the urban heat-island effect.

Discussion

We developed methods for investigating the effect of ambient heat exposure on personal body temperature and applied the methods to an elderly volunteer population. Both microenvironmental (temperature probe on participant's clothing) and macroenvironmental (Baltimore temperatures) measurements were used as indicators for ambient temperature. Skin temperature was used as a proxy for core body temperature because it would not be feasible to measure core body temperature for 48 hr. We refined our model using time–activity diaries to summarize outdoor and indoor hourly exposures. The most common microenvironment for the elderly in this study consisted of indoor spaces in their homes, whereas much less time was spent in

outdoor or transportation environments (Table 3). This study was conducted in the summer, when average outdoor and indoor temperatures are greater compared to other seasons, so that heat effects could be assessed. The summer months of 2000 did not provide any data during high ambient temperatures or heat waves. Nonetheless, a positive association was found between ambient and body temperatures. The finding of the anticipated relationship between heart rate and activity level (24,25) suggests that the personal monitor provided valid data.

We selected an elderly population because they are vulnerable to heat effects due to their impaired adaptation abilities. Prior investigations have evaluated the relationship between temperature and mortality and mortality subsequent to heat waves; they suggested that temperature is positively associated with mortality, and that mortality significantly increased after heat waves, particularly for elderly persons (2–4,17,24–26). For example, a 1.8°F increase in temperature was associated with a 1% (95% CI, 0.4–2.1) increase in all-cause mortality and a 3% (95% CI, 0.1–6.0) increase in respiratory mortality in Christchurch, New Zealand [adapted from Hales et al. (24)]. Approximately 500 heat-related fatalities resulted from a heat wave in Chicago in 1995 (2). The strongest associations were reported among persons over 65 years of age.

Previous studies have examined the physiologic mechanisms involved in decreased thermoregulation of elderly persons when body temperatures are elevated and have developed a physiologic model to understand heat stress effects (27). However, none has examined the direct effects of ambient heat exposure on personal body temperature nor incorporated health status and behavioral adaptation. Our study provides a tool to evaluate the changes in ambient temperature and body temperature to expand the research done on the association between ambient temperature and mortality. Heat-related mortality occurs when elevated ambient temperature increases body temperature. We need refined and validated models to predict those who are at risk and conditions that will result in increased risk. Although we did not find an

association of ambient temperature with skin temperature, our sample size was small and the temperature range was limited. A larger study could provide the data needed for model development.

Heat-related illnesses are potentially preventable in high-risk populations through public education and warnings and through behavioral adaptations such as air conditioning use (2) and increased fluid intake (28). Currently, over 70% of homes in the United States have air conditioning, and by 2050, most homes are predicted to be equipped with central or room systems (8). However, populations with lower socioeconomic status who are vulnerable to heat-related mortality, such as populations living in the inner city and the elderly, may still have no or limited access to air conditioning. Furthermore, with limited energy supply, the high costs of cooling in some locations, and increasing demand when ambient temperatures rise, additional interventions may be necessary. The most common adaptation measures to ambient heat exposures in our study included wearing less clothing, drinking more fluids, using air conditioning, or going outdoors. Adaptations to heat exposure are particularly relevant to elderly persons living in urban environments, who may be at increased risks. The exposure assessment methods developed in this study should be useful for assessing the consequences of specific adaptations.

Limitations of this study should be considered in interpreting the findings. Although significant associations were found for the effect of ambient temperature, there was insufficient sample size and power to construct multivariate models. Furthermore, a larger population would be needed to quantify the benefits of the adaptation measures used by participants. The 42 participants were volunteers selected as a convenience sample, and healthier individuals may have been more likely to participate than the sicker, higher-risk elderly population. Few participants had high-risk housing characteristics such as living on higher floors of apartment buildings (14%) or having security bars on their windows (5%), although more than half lived alone. The study population had a higher percentage of air conditioners in their homes than the Baltimore

elderly population in general, as well as more whites and more females (29). Thus, the study population was not representative of the targeted poor, sick, elderly population, or the general elderly population in Baltimore.

One goal of this study was to establish a protocol for future studies to monitor and evaluate individual risk from ambient heat exposure. A total of 1,520 person-hours of data were collected from 42 elderly individuals, offering one of the first data sets on ambient heat exposure of an elderly population. As a next step, this type of exposure assessment study should be extended to a larger elderly population in multiple geographic areas. Monitoring more than one individual at the same time would also be informative to evaluate interindividual variation. Furthermore, sweating thresholds and several effect modifiers (e.g., sex, age, socioeconomic status, body mass index, air conditioning use, and other behavioral adaptations) should be examined. The resulting data would be useful for identifying high-risk persons, informing communitywide intervention plans, and developing better heat advisory warnings.

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Table 4. Association between hourly median body temperature and ambient temperature, heart rate, activity level, and Baltimore temperatures.

	Model 1 β (95% CI)	Model 2 β (95% CI)	Model 3 β (95% CI)	Model 4 β (95% CI)
Ambient temperature[a]	0.15 (0.05–0.25)	0.12 (0.04–0.20)	—	—
Heart rate[b]	—	−6.0 (−16.0–4.0)[e]	—	—
Activity level[c]	—	−8.0 (−12.0–4.0)[e]	—	—
BWI temperature[d]	—	—	−4.0 (−0.04–0.04)[e]	—
Downtown temperature[d]	—	—	—	−2.0[e] (−0.04–0.04)

[a]Hourly median ambient temperature (°F). [b]Hourly median heart rate (bpm). [c]Hourly median activity level (cpi). [d]Hourly mean downtown/BWI temperature (°F). [e]Per 1,000.

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