The impending retirement of the baby-boom cohort, along with geometric growth in the relative size of the older population, will dramatically alter the public health challenges of the 21st century. Demographics ensure that the numbers of persons with dementia and cognitive decline will increase in the coming decades (Brookmeyer et al. 1998). The determinants of cognitive dysfunction with increasing age are complex, multifactorial, and synergistic, involving features of the physical and social environments, as well as endogenous biologic (e.g., genetic) and behavioral factors. Although results are not entirely consistent (e.g., Munoz et al. 2000), there is substantial evidence that neurobehavioral test scores, cognitive decline over time, and dementia risk vary substantially by race/ethnicity (Fillenbaum et al. 1998; Graham et al. 1998; Gurland and Katz 1997; Gurland et al. 1999; Hall et al. 2000; Launer et al. 1999; Perkins et al. 1997; Shadlen et al. 1999; Stern et al. 1994; Wiederhold et al. 1993). The underlying basis for these differences has not been clearly delineated. Potential explanations include uncontrolled confounding by socioeconomic status (SES), comorbid illnesses that could influence cognitive function (e.g., cardiovascular disease), and chronic stress associated with race/ethnicity that is not fully captured by traditional measures of race/ethnicity, SES, or other indicators of the social environment. Previous studies have a number of limitations, including populations that are too old, samples that are not representative of underlying target populations, and incomplete control for important confounding variables, especially SES.

In considering the role of the social environment, neighborhood-level (or contextual) factors must be distinguished from individual-level (or compositional) factors, and these have in fact been separate foci of interest in earlier studies (Diez Roux 2001; Glass and Balfour 2003; MacIntyre et al. 2002). Individual-level social variables that have been considered generally include those subsumed under the category of SES, which consists of such attributes as education, occupation, income, and wealth, but no prior studies have rigorously controlled for this set of measures. Although the evidence is compelling that individual SES is associated with cognitive function in late life, the pathways through which this association operates have yet to be elucidated.

Population-specific differences in the presence of disease, health outcomes, or access to health care have been termed health disparities, and understanding the causes of these disparities and eliminating them is a primary goal of the Health Resources and Services Administration, the National Institutes of Health, and other American public health and research agencies (e.g., U.S. Department of Health and Human Services 2000). The National Institute of Environmental Health Sciences [National Institutes of Health (NIH), Department of Health and Human Services] has an active research program designed to disentangle the roles that the natural, built, and social environments play in disease causation. Here we report on the Baltimore Memory Study, which is funded under the trans-NIH research program. We present the detailed methods of the study, describe the disparities in neurobehavioral test scores in a large community sample of 50–70-year-old individuals from selected neighborhoods in Baltimore, Maryland, and evaluate selected individual-level social, physical environmental, and behavioral factors that account partially for these racial/ethnic differences in test scores. This work represents a case study in multilevel, multidisciplinary research, aimed at integrating knowledge within and across biologic, environmental, social, behavioral, and mathematical sciences.

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Materials and Methods

**Study design.** The Baltimore Memory Study, one of the studies funded by the NIH’s Initiative to Eliminate Racial and Ethnic Disparities in Health is a cohort study of the multilevel determinants of cognitive decline in Baltimore city residents. The first of three study visits was completed between 30 May 2001 and 20 September 2002. We present analyses of cross-sectional data from the first study visit to describe the extent and magnitude of the disparities across race/ethnic groups on a battery of neurobehavioral tests designed to assess a full range of cognitive abilities in adults.

**Study population.** The target population consisted of 50–70-year-old residents of 65 contiguous neighborhoods in central and north Baltimore city who had lived within the greater Baltimore area for at least the previous 5 years. Neighborhoods were selected to ensure wide variability on characteristics of interest, including availability of services, socioeconomic deprivation, and racial composition, within and across race/ethnic groups.

Baltimore city consists of 200 census tracts and 264 neighborhoods named by the city (termed “neighborhood statistical areas”). Baltimore city’s named neighborhood boundaries were defined by the Baltimore City Department of Planning in collaboration with the Johns Hopkins Center for Metropolitan Planning and Research in the late 1970s (Taylor 1979) and revised after the 1990 and 2000 censuses. In this study, we use the named neighborhoods, not census tracts, to define the geography of neighborhoods. The study area consisted of 81 contiguous neighborhood statistical areas using the 2002 definitions (these neighborhoods overlay approximately 60 census tracts; Baltimore City Department of Planning, Division of Urban Design, Baltimore, MD). A total of 1,140 study participants from 65 neighborhoods were enrolled in the study; most of the neighborhoods that did not provide study subjects had no residential population (e.g., Johns Hopkins University, areas of downtown). A total of 37 neighborhoods provided 10 or more study subjects, with a mean ± SD of 27 ± 19 study subjects per neighborhood (ranging from 10 to 86). The study was approved by the Committee for Human Research of the Johns Hopkins Bloomberg School of Public Health; all participants provided written, informed consent before testing, and all study participants were paid $50 for participating.

**Sampling households and neighborhoods.** The Maryland Department of Planning MdProperty View 2000 (MPV) database (Maryland Office of Planning, Baltimore, MD) was used to randomly select households for recruitment. Making use of Department of Assessments and Taxation data, the MPV database contains all property addresses within Baltimore city in a geocoded format (i.e., all properties occupy an x,y-coordinate position on a map). Each record represents a household and includes fields for parcel identification number, owner’s name, address, and ZIP code. The Stewart Directory (Stewart Directories, Inc., Cockeysville, MD) was used to supplement the MPV database with address-linked telephone numbers. Systematic differences in the recording of addresses were corrected before linking on the address field. The MPV database consisted of 233,267 properties, of which 207,309 records were residential addresses and 54,290 were in our study area. After accounting for multiunit properties (n = 599), the total number of residences in the study area was 64,037. Of these, there were 24,511 records with telephone numbers.

**Subject selection and recruitment.** A series of six random samples of households with telephone numbers (because it was not financially feasible to do home visits) was selected for recruitment until enrollment goals were reached. A total of 18,826 households with unique telephone numbers were selected and contacted to determine whether an eligible person resided there. Each household was called until a disposition could be established (Table 1) or until the household had been telephoned 10 times. Among the 2,351 subjects on whom eligibility was determined, 60.8% were scheduled for an enrollment visit. Of the 1,403 subjects scheduled for a clinic appointment, 1,140 (48.5% of subjects on whom eligibility was determined) were enrolled and tested. Overall, approximately 10% of selected residential units and 3% of apartments provided a scheduled subject.

**Data collection.** All data collection was performed by trained research assistants at the Baltimore Memory Study Clinic, located in north-central Baltimore city. Study participants first provided written, informed consent. Data were then collected in the following order: neurobehavioral testing, blood pressure, height, weight, spot urine collection, structured interview, and venipuncture; before departing, participants completed a satisfaction survey about the visit.

**Neurobehavioral battery.** Specific neurobehavioral tests were selected with four considerations in mind: a) variation by age, b) variation by race/ethnicity and SES, c) validity and reliability across the SES spectrum and in different race/ethnicity groups, and d) documented association of scores with at least one of our primary physical environmental exposures of interest (e.g., lead, mercury). We tried to minimize measurement error by race/ethnicity in the testing in three ways. First, technicians read each participant a standard statement that was designed to orient all participants to the purpose and format of the questions in a way that maximized comfort level and avoided any reference to testing as a means to evaluate individual ability. Second, testing was performed by both male and female technicians of white and African-American race/ethnicity with random assignment. Third, to avoid differential information bias by SES or race/ethnicity groups, we specifically selected tests that do not require complex verbal responses (e.g., Welch et al. 1995).

The 90-min test battery consisted of the following tests in this order (for details, see Table 2): Boston Naming Test (Kaplan et al. 2001; every second item of the 60 items was administered, to shorten the test), Raven’s Coloured Progressive Matrices (Psychological Corporation, San Antonio, TX; Raven 1965; Raven et al. 1995), Rey Complex Figure copy, Rey Auditory Verbal Learning Test (RAVLT) immediate recall (Schmidt 1996), Purdue Pegboard (dominant hand, nondominant hand, both hands, and assembly) (model 32020; Lafayette Instrument Corporation, Lafayette, IN; LIC 1999), Stroop Test (A, B, and C forms), Trail-Making Tests A and B, Symbol Digit Pairing Association Learning, Rey Complex Figure delayed recall, finger tapping (dominant, nondominant), RAVLT delayed recall, RAVLT recognition, Simple Reaction Time (with the Standard Reaction Time Tester; Software Science, Cincinnati, OH; Wilkinson and Houghton 1982), Letter Fluency, and Category Fluency (Table 2). The complete test session was recorded on audiotape, and a random sample was regularly reviewed to evaluate quality. Neurobehavioral tests were scored by two technicians, and discrepancies were corrected by review and agreement.

**Structured interview.** The structured interview obtained information on self-report of...
race/ethnicity [using the Census 2000 method distribution summarized in Table 3 (Grieco and Cassidy 2001]), housing and residential history, instrumental activities of daily living, medications (including detailed questions about current and historical use of nonsteroidal anti-inflammatory medications, estrogens, and oral birth control), childhood lead poisoning history, medical history, vascular risk factors (the Rose Questionnaire; Rose 1962), and chronic conditions. We also gathered data on a range of psychosocial and behavioral factors, including depressive symptoms [using the Center for Epidemiologic Studies depression scale (Ratloff 1977)], self-efficacy (adapted from Pearlin and Schooler 1978), history of alcohol and tobacco consumption, social networks (Glass et al. 1997), anxiety symptoms (Symptom Checklist-90 revised, anxiety scale only; Derogatis et al. 1973, 1976), and social and productive activities from the Enacted Function Profile (Glass 1998), received social support (Barrera 1980), and self-rated health and quality of life (both measured as single-item global measures).

Individual-level SES. Recognizing the weaknesses in existing approaches to individual SES, we developed and tested a new instrument that assesses individual and household SES along three dimensions: educational status, occupational status, and household wealth (Figure 1). The entire SES assessment tool consists of 110 questions and takes approximately 17 min to administer. Educational status includes measures of self-reported years of education completed (attainment) as well as credentials acquired (e.g., degrees, certificates, trade school). We used information from both attainment and credentialing to create a nine-level ordinal index of educational status.

Table 2. Description of neurobehavioral testing battery, Baltimore Memory Study, 2001–2002.

| Test name            | Units of outcome | Range   | Cognitive domain                      |
|----------------------|------------------|---------|---------------------------------------|
| Boston Naming        | Number correct   | 7–30    | Language                              |
| Category Fluency     | Number correct   | 17–106  | Language                              |
| Coloured Progressive Matrices | Number correct | 3–36    | Nonverbal reasoning/ general intelligence |
| Finger tapping (mean of three trials) | Number of taps | 7.8–67.4 | Simple motor speed                   |
| Dominant hand        | Number of taps   | 6.8–61.8| Simple motor speed                   |
| Nondominant hand     | Number of taps   | 7–92    | Language                              |
| Purdue Pegboard (mean of three trials) | Number of pegs | 2.7–18.3 | Eye-hand coordination/ manual dexterity |
| Nondominant hand     | Number of pegs   | 1–18    | Eye-hand coordination/ manual dexterity |
| Both hands           | Number of pegs   | 1–19.3  | Eye-hand coordination/ manual dexterity |
| Assembly             | Number of pieces | 2.7–47.3 | Executive abilities                   |
| RAVLT                |                  |         |                                       |
| Trials 1–5           | Number correct   | 15–73   | Verbal learning                       |
| Recognition<sup>a</sup> | Number          | –16–15  | Verbal memory                         |
| Delayed recall       | Number correct   | 0–15    | Verbal memory                         |
| Rey Complex Figure   | Score            | 1–36    | Visuo-construction/ visuosensation    |
| Copy                 | Score            | 0–27    | Visual memory                         |
| Delayed recall       | Score            | 0.19–0.95| Psychomotor speed                    |
| Simple Reaction Time (mean of 64 trials) | Seconds | –31–276 | Executive abilities                   |
| Stroop Test          | Seconds          | 1–21    | Visual memory                         |
| C form minus A form  | Seconds          | 12–256  | Executive abilities                   |
| Symbol Digit Paired Associate Learning | Number correct | 17–408  | Executive abilities                   |

<sup>a</sup>In study subjects. <sup>b</sup>Number correct minus number incorrect.

Table 3. Distribution of study subjects by race/ethnicity, a Baltimore Memory Study, 2001–2002.

| Race/ethnicity<sup>a</sup> | No. (%) | For analysis |
|---------------------------|---------|--------------|
| White                     | 598 (52.5) | Reference group |
| White/Native American     | 14 (1.2) | Reference group |
| Black/African American    | 474 (41.7) | Black |
| African American/mixed    | 30 (2.6) | Black–mixed race/ethnicity |
| Asian or Hawaiian         | 9 (0.8)  | Other |
| Native American           | 11 (1.0) | Other |
| Missing or refused        | 4 (0.4)  | Other |
| Total                     | 1,140 (100.0) |            |

<sup>a</sup>Study participants could self-report as many of these race/ethnicity categories as they desired. <sup>b</sup>Number of study participants reported they were Hispanic or Latino; of these, seven reported white race/ethnicity and four reported black or African-American race/ethnicity.
tests, a negative coefficient indicates that test performance declines with increasing values of the predictor variable. Educational attainment was modeled as a categorical variable in nine categories, using high school graduate with trade school or other credential as the reference group (because this was a large category in the middle of the range; Table 4).

Linear regression was used to evaluate differences in neurobehavioral test scores in three race/ethnicity groups, with whites as the reference group: Subject reported black only, black and another race/ethnicity, or other race/ethnicity. In model 1, the base model, differences by race/ethnicity were adjusted for age, sex, and testing technician. Next, in model 2, these differences were additionally adjusted for educational attainment (nine categories), occupational status (four categories), household income (ln-transformed), and household assets (ln-transformed). Finally, in model 3, these differences were adjusted for the covariates in model 2 as well as blood lead, smoking status, a negative coefficient indicates that test performance declines with increasing values of the predictor variable. Educational attainment was modeled as a categorical variable in nine categories, using high school graduate with trade school or other credential as the reference group (because this was a large category in the middle of the range; Table 4).

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Models of neurobehavioral test scores by race/ethnicity. We compared the results of the three models of neurobehavioral test scores. In the base model (model 1; Table 6), controlling for age, sex, and testing technician, African Americans performed significantly worse than whites on each of the 20 neurobehavioral tests. The differences were large and appeared in all cognitive domains, including those assessed by tests with and without potential for differential measurement properties by race/ethnicity. In the base model, examination of standardized coefficients (after Z-transformation of the neurobehavioral test scores) revealed that, on average across all neurobehavioral tests, African Americans performed 0.64 standard deviation (SD) unit worse than whites (SD of these differences across all neurobehavioral tests = 0.16; the differences ranged from 0.39 for Purdue Pegboard dominant to 1.02 for Boston Naming). For a normally distributed outcome, a span of 4 SDs encompasses approximately 95% of the distribution, so on average, 0.64 SD units is approximately 16% worse performance (0.64 + 4).

In model 2, adjusting for the variables in model 1 and household income, household assets, educational attainment, and occupational status, the average difference in test performance of African Americans compared with whites on each of the 20 neurobehavioral tests.

| Variable                              | African American | White*       |
|---------------------------------------|------------------|--------------|
| No.                                   | 339              | 368          | 244          |
| Body mass index (kg/m², mean ± SD)    | 32.3 ± 7.4       | 28.7 ± 5.7   | 28.6 ± 7.1   | 28.4 ± 5.1   |
| Blood lead level (µg/dL, mean ± SD)   | 3.2 ± 2.0        | 4.5 ± 2.8    | 3.0 ± 1.9    | 4.4 ± 2.8    |
| History of diabetes [n(%)]            | 90 (26.5)        | 27 (20.0)    | 42 (11.4)    | 26 (10.7)    |
| Taking anxiolytic medications [n(%)]  | 11 (3.2)         | 3 (2.2)      | 31 (8.4)     | 10 (4.1)     |
| Taking antidepressant medications [n(%)] | 10 (2.9)       | 3 (2.2)      | 58 (15.8)    | 14 (5.7)     |
| Never used tobacco products [n(%)]    | 151 (44.5)       | 29 (21.5)    | 141 (38.3)   | 83 (34.0)    |
| History of stroke [n(%)]              | 15 (4.4)         | 11 (8.1)     | 10 (2.7)     | 1 (0.004)    |
| Consumed alcoholic beverage in past month [n(%)] | 115 (33.9) | 78 (57.8)   | 260 (70.7)   | 190 (77.9)   |

- Based on self-reported years of education plus additional questions on high school equivalency (i.e., GED), trade school and other credentials, and highest degree obtained. - Trade, nursing, or other similar credential. - The reference group in the analysis. - One person was missing information on education.
- Other race/ethnicity groups were not tabulated because of small sample sizes. - Includes 14 subjects who reported both white and Native American race/ethnicity.
whites declined by 25.8% compared with the base model (Table 6). Each of the four dimensions of SES was an independent and consistent predictor of neurobehavioral test scores. Educational attainment, occupational status, household income, and household assets were associated \((p < 0.05)\) with 20, 9, 5, and 13 of the 20 neurobehavioral tests, respectively. Lower levels of education (the lowest two categories, Table 4) were associated with worse performance on all or almost all tests, whereas the highest two categories were associated with better performance on generally all tests except those with manual dexterity components (e.g., Purdue Pegboard, finger tapping, Simple Reaction Time). Occupational status was associated with several verbal tests (e.g., Boston Naming, RAVLT, Letter Fluency). There was no apparent prominent domain in which income associations were observed, whereas assets were associated with better performance on virtually all tests except Rey Complex Figure and RAVLT.

Finally, in model 3, also adjusting for blood lead, time of day of testing, taking medications for anxiety, history of diabetes, taking medications for hypertension, tobacco use, history of stroke, alcohol consumption, and body mass index, the average difference in test performance of African Americans compared with whites declined by 35.1% in relation to the base models (Table 7). However, significant differences persisted between African Americans and whites in these models. Examination of standardized coefficients revealed that after this adjustment, on average across all neurobehavioral tests, African Americans still had scores that were 0.43 SD units lower than those of whites (ranging from 0.12 for Purdue Pegboard dominant to 0.84 for Boston Naming).

**Discussion**

In a large, community-based population sample of adults 50–70 years of age, randomly selected from the general population in Baltimore, there were large differences in neurobehavioral test scores by race/ethnicity in all assessed cognitive domains; these differences declined by approximately 25% after adjusting for individual SES and another 10% after adjusting for additional individual factors mainly relating to health and health-related behaviors. However, after potential confounders were included in the model, large differences in the cognitive test scores were still observed across three race/ethnicity groups. Each of the four dimensions of SES was an independent predictor of neurobehavioral test scores, suggesting that studies may not be able to rely on simple surrogates of SES (e.g., years of education) when examining race/ethnic differences.

Studies have demonstrated that the determinants of cognitive dysfunction, cognitive decline, and neurodegenerative disease are complex and multifactorial, and encompass biologic, environmental, behavioral, and social pathways. For example, a higher risk of Alzheimer’s disease is consistently observed among those with low education levels (Evans et al. 1993, 1997a, 1997b; Geerlings et al. 1999; Graham et al. 1998; Gurland et al. 1999; Hall et al. 2000; Letenneur et al. 1999;
by neighborhood by the proportion of African Americans in the study neighborhoods. Although this is an imperfect way to evaluate differential recruitment or participation by race/ethnicity, the lack of a trend is reassuring and supports the notion that the study subjects represent the source population with telephones.

In summary, we observed large differences in neurobehavioral test scores by race/ethnicity. The differences became smaller but did not disappear after adjusting for SES, selected health measures, and health-related behaviors. Future analysis will continue to disentangle the complex web of determinants of cognitive dysfunction, with a broad set of determinants under investigation.

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