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Cognitive function and short-term exposure to residential air temperature: A repeated measures study based on spatiotemporal estimates of temperature

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ABSTRACT

Few studies have examined the association between ambient temperature and cognitive function, or used exposure to temperature at a given address instead of a single stationary monitor. The existing literature on the temperature-cognition relationship has mostly consisted of experimental studies that involve a small sample size and a few specific temperature values. In the current study, we examined the association between residential air temperature and Mini-Mental State Examination (MMSE) scores, a quantitative measurement of cognitive function, in a longitudinal cohort of elderly men. Residential air temperature was estimated by a novel spatiotemporal approach that incorporates satellite remote sensing, land use regression, meteorological variables and spatial smoothing in the Northeastern USA. We then applied logistic regression generalized estimating equations to examine the relationship between residential temperature (range: -5.8–25.7 °C), and the risk of low MMSE scores (MMSE scores ≤ 25) among 594 elderly men (1085 visits in total) from the Veterans Affairs Normative Aging Study, 2000–2008. Sensitivity analysis on visits wherein subjects lived within 30 km of the clinic center in Massachusetts or aged ≥ 70 years was also evaluated. A statistically significant, U-shaped association between residential air temperature and low MMSE score (p-value$=0.036$) was observed. Sensitivity analysis suggested that the estimated effect remains among individuals aged ≥ 70 years. In conclusion, the data suggest that risk of low MMSE scores is highest when temperature is either high or low, and lowest when ambient temperature is approximately within 10–15 °C in a cohort of elderly men. Further research is needed to confirm our findings and assess generalizability to other populations.

1. Introduction

In the era of population aging, impairment in cognitive function among elderly people is a global burden (Ferri et al., 2005). Cognitive declines in the elderly are associated with fall risk, nursing home admission, hospitalization, congestive heart failure, and mortality (Almeida and Flicker, 2001; Bassuk et al., 2000; Chodosh et al., 2004; Gaugler et al., 2007; Muir et al., 2012). Studies also reported that elderly people are at an increased risk of morbidity and mortality during heat waves (Bobb et al., 2014; Gronlund et al., 2014; Knowlton et al., 2009). It is possible that short-term temperature-related cognitive declines contribute to this increased risk. For instance, temperature-induced declines in cognition may lead to poor decision-making ability and executive function (Muller et al., 2012; Racinais et al., 2008). Hence the elderly may not be aware of the need of cooling, hydration, or escaping the heat and put themselves at an elevated risk of danger during heat waves.

There is convincing evidence that cognitive function can be affected by environmental factors, such as air pollution, sunlight, and greenness (Kent et al., 2009; Power et al., 2011; Salthouse,

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2013; Wells, 2000). Researchers have examined the relationship between cognitive function and temperature, but the findings are mixed: some found worse cognition related to cold or heat, while others did not observe any change (Leavitt et al., 2012; Muller et al., 2012; O'Brien et al., 2007; Pilcher et al., 2002; Racinais et al., 2008; Schlader et al., 2015). In addition, most of the published work consisted of experimental studies in which the sample size was small and/or only a few specific values of temperature were inspected (Makinen et al., 2006; Muller et al., 2012; Racinais et al., 2008). The association of cognitive function with temperature, especially temperature across a wide range, is still unclear.

Elderly people are very likely to spend most of their time at their residence. Therefore, it is crucial to understand how residential temperature plays a role in their health. A recent study demonstrated that temperature at a subject's residential address had far stronger associations with birth outcomes than temperature from an airport monitor (Kloog et al., 2015). In the current study, we used a novel spatiotemporal approach to estimate short-term exposure to residential air temperature for participants from the Normative Aging Study, and analyzed the relationship between residential air temperature and cognitive function. To the best of our knowledge, this study, for the first time, provides evidence on the association of air temperature with cognitive function in a large sample with repeated measures.

2. Material and methods

2.1. Study sample

The Veterans Affairs Normative Aging Study (NAS) was established in 1963 by the Department of Veterans Affairs, and is an ongoing longitudinal study of aging that enrolled 2280 community-dwelling, healthy men living in the Greater Boston area (Bell et al., 1972). Participants were free of known chronic medical conditions at enrollment and have undergone examinations every 3–5 years. Beginning in 1984, all exams were conducted at 3 year intervals; starting in 1993, these exams included the Mini-Mental State Examination (MMSE) as a cognitive assessment. All participants provided written informed consent. This study was reviewed and approved by the Institutional Review Boards of all participating institutions.

We restricted study subjects to those who completed cognitive testing at least once and whose home address was available for us to estimate residential temperature from the spatiotemporal model between 2000 and 2008. In total, 594 subjects with 1085 visits were included in this study. 225 (37.9%) of the individuals had one visit, 247 (41.6%) had two visits, and 122 (20.5%) had three during the study period.

2.2. Cognitive function

In the study, cognitive function was measured by the Mini-Mental State Examination (MMSE). The MMSE contains questions on attention, arithmetic, language use, comprehension, etc. It is commonly used in clinical and research settings as a tool to quantitatively assess cognitive impairment and to screen for dementia (Tombaugh and McIntyre, 1992). Subjects had the MMSE test at every visit. That is, there were 1085 assessments on 594 individuals in this study.

2.3. Spatiotemporal assessment of residential temperature

A novel spatiotemporal approach that incorporates satellite remote sensing, land use regression, meteorological variables and spatial smoothing was used to generate temperature data in the Northeastern USA. Details can be found elsewhere (Kloog et al., 2012; Kloog et al., 2014). Briefly, mixed-effects regression was used to calibrate Moderate Resolution Imaging Spectroradiometer (MODIS) surface temperature with monitored air temperature on a daily basis. Because surface temperature may be unavailable due to cloud cover or retrieval errors, we additionally used a generalized additive mixed model with land use terms, local monitoring data, and spatial smoothing to obtain surface temperature estimates. We then applied out-of-sample 10-fold cross-validation to assess the accuracy of the predictions. Our prediction model performance was excellent for days with surface temperature observations as well as for days without (mean out-of-sample $R^2=0.946$ and $R^2=0.941$, respectively).

We linked each subject's home address with the spatiotemporal model within 1×1 km to estimate 24-h mean temperature at residence for the study period 2000–2008. Exposure was defined as the mean temperature on the day of each examination or the preceding few days.

2.4. Statistical analysis

Typically, a score ≤ 24 in the MMSE test is used to suggest a positive screen for dementia. Few subjects in our study had MMSE scores below that level, so we created a binary indicator for low MMSE scores (defined as scores ≤ 25) as previous studies did so (Power et al., 2011). We dichotomized the MMSE score and analyzed the risk of low scores versus high scores in part of because of the ceiling effect of MMSE (Tombaugh and McIntyre, 1992). We conducted logistic regression with generalized estimating equations (GEE) to examine the association between residential temperature and low MMSE scores (Liang and Zeger, 1986), with an exchangeable covariance. In the final model, we adjusted for the following covariates measured at each visit: age (continuous), education (<12, 12–16, >16 years), alcohol consumption (≥ 2 drinks/day, <2 drinks/day), body mass index (BMI, computed as weight [in kilograms] divided by height [in square meters]), smoking status (never, former, current smoker), dark fish consumption (≥ 1 time/week, <1 time/week), physical activity (<12, 12 to <30, ≥ 30 metabolic equivalent hours per week), computer experience (yes, no), English as first language (yes, no), percentage of census tract that is nonwhite (continuous), percentage of census tract ≥ 25 years of age with a Bachelor's degree or higher (continuous), and season (spring: March-May, summer: June-August, fall: September-November, winter: December-February) (Power et al., 2011; Power et al., 2013).

We hypothesize that temperature may have adverse effects on cognitive function when the weather is cold or hot. Therefore, we included a quadratic term of temperature to allow for this pattern. Because study participants visited the Veterans Affairs clinic center in Boston in the morning after an overnight fast and abstinence from smoking, we took temperature on the previous day before visit, i.e., lag 1 day's temperature, as the exposure metric. In addition, we performed a sensitivity analysis on people who lived within 30 km of the clinic center (accounted for 62% of all visits) in Massachusetts, as it is likely that those who lived far away were not at home but rather on the way to the clinic center on lag 1 day. A sensitivity analysis among men aged ≥ 70 years old (accounted for 75% of all visits) was also conducted.

Data management was performed with SAS 9.3 (SAS Institute Inc.), and data analysis was performed with R 3.1.2 (http://www.r-project.org/).

3. Results

Table 1 summarizes the baseline characteristics of the study sample. At baseline, a total of 89 subjects (15%) had a low MMSE