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Short communication

Does global warming contribute to the obesity epidemic?☆

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ABSTRACT

Endotherms must expend more energy to digest colder food, so they acquire more calories by eating food at a higher temperature than eating the identical food cold. A recent study shows that ownership of a microwave is associated with a small increase in BMI and obesity. The same logic applies to other substances that endotherms introduce into their bodies, like air. An analysis of the National Longitudinal Study of Adolescent to Adult Health (Add Health) shows that, net of sex, age, race, education, earnings, neighborhood characteristics, and exercise activities, atmospheric temperature is associated with small but statistically significant increases in BMI, weight, overweight, and obesity. Atmospheric temperature is more strongly associated than most exercise activities, and as strongly associated as age and population density. An average American might reduce weight by 15.1 lbs, BMI by 2.52 (half the difference between normal weight and obesity), and the odds of obesity by 54% by moving from Phoenix, AZ, to Barrow, AK, or, less dramatically, 5.7 lbs in weight, .95 in BMI (a fifth of the difference between normal weight and obesity), and 25% in the odds of obesity by moving mere 150 miles north to Flagstaff, AZ. Global warming under the worst-case scenario might produce an increase of 2.2 lbs in weight, .37 in BMI, and 12% in odds of obesity from 1961 to 2081.

Obesity is a health crisis, not only in the United States (Burkhauser et al., 2009; Cutler et al., 2003) and Europe (Berghöfer et al., 2008) but also in developing nations like China (Chen, 2008) and India (Ranjani et al., 2016). Yet *the* precise cause of the current obesity epidemic is not yet known (Cawley, 2010; James, 2008; Ross et al., 2016), possibly because there is no single cause. It is likely that there are a large number of causes, each contributing in a small way to the international epidemic.

A recent study (Kanazawa and von Buttlar, 2019) identified a hitherto neglected cause: widespread use of microwaves. Endotherms (warm-blooded animals) must expend their own energy to digest cold food in order to bring it up to the body temperature (Secor, 2009). They thus acquire more calories by eating hot food closer to the body temperature than eating the identical food cold (Wrangham, 2009, pp. 195–207). A widespread use of microwaves, which dramatically increase the food temperature in seconds, might therefore be another small contributor to the current obesity epidemic. Kanazawa and von Buttlar's (2019) analysis showed that, net of dietary habit (what and how much individuals eat), physical activities (how much and frequently they exercise), genetic predisposition, and other demographic factors, the ownership of a microwave was associated with an increase of .781 in BMI and 2.1 kg in weight, when the ownership of other kitchen appliances was not associated with increased BMI or weight.

Kanazawa and von Buttlar's logic, however, applies to other substances that endotherms introduce into their bodies, such as air. Just as endotherms must expend energy to increase the temperature of food they consume in their stomach to their body temperature, they must also expend energy to increase the temperature of air they consume in their lungs. A large number of controlled experiments indeed show that human subjects under constant observation in a sealed laboratory (respiration calorimeter) for anywhere from four to 84 hours expend more energy when the ambient temperature is reduced even by a few degrees (Blaza and Garrow, 1983; Dauncey, 1981;van Ooijen et al., 2004; Warwick and Busby, 1990;Westerterp-Plantenga et al., 2002;Wijers et al., 2007). The results of these laboratory experiments suggest that, all else equal, individuals living in colder climates, who breathe in and then must expend energy to warm up cold air in their lungs, may on average weigh less than individuals who live in warmer climates.

This logic suggests, among other things, that global warming might exacerbate the current obesity epidemic, albeit by a very small degree. In their comprehensive and systematic review, An et al. (2018) identified 50 published articles on the relationship between global warming and obesity epidemic, only 20 of which were original studies (the remainder mostly being reviews). Of the 20 "original studies," only seven were empirical studies; the rest were speculative, "modelling" studies that estimated, for example, what the rates of obesity would be if the global temperature

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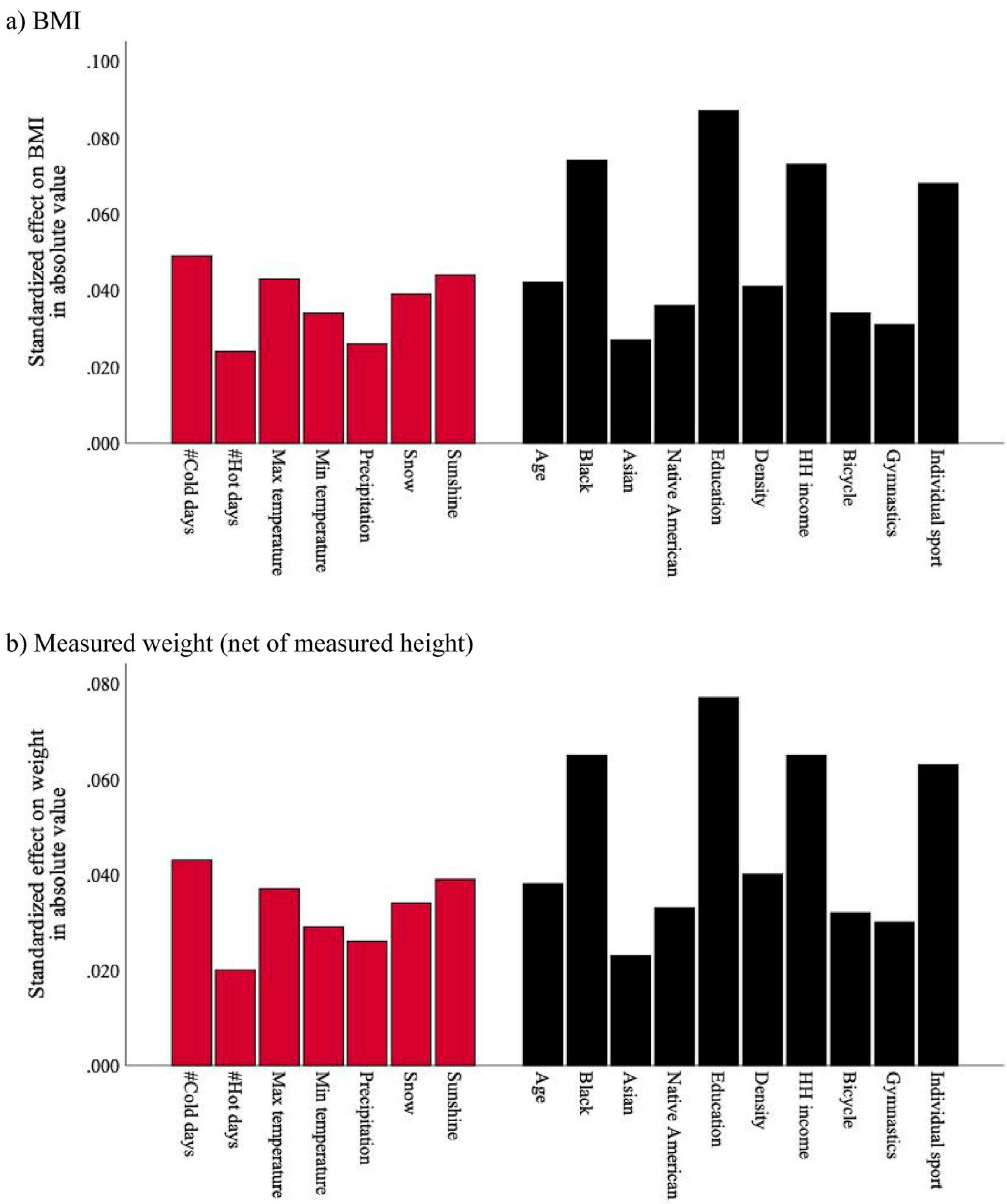


Fig. 1. Comparisons of standardized effect sizes in absolute value on the dependent variable: a) BMI, b) measured weight (net of measured height); c) overweight status; and d) obesity status.

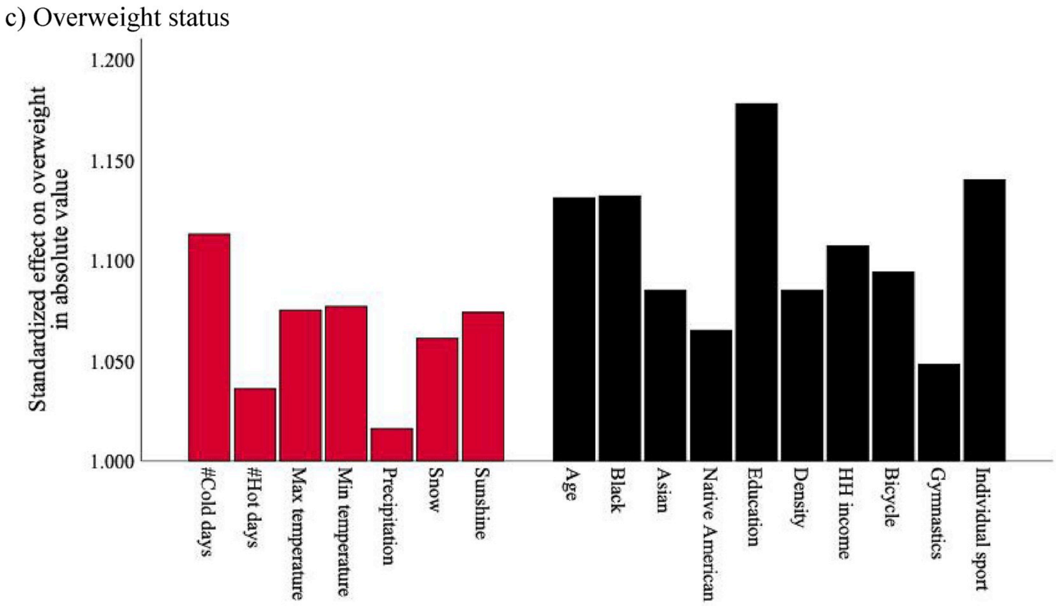
increased by certain degrees. Of the seven empirical studies, only two estimated the actual effect of temperature on individual BMI. van Hanswijck de Jonge et al., (2002) showed that environmental temperature during second and third trimester of gestation was significantly positively associated with BMI at adolescence among black females, nonsignificantly among white females, and not at all among males. Sloan (2002) showed, with a small convenience sample (n = 128), that female college students in Florida had lower BMI than those in Pennsylvania. This finding seemingly contradicts the prediction derived from Kanazawa and von Buttlar (2019). However, Sloan used only bivariate correlation (r) without any controls to estimate the association between temperature and BMI, and the direction of causality was ambiguous. For example, her results cannot rule out the possibility that teenage girls who have lower BMI prefer to attend colleges in Florida where they have greater opportunities to show off their bodies in warmer weather than in Pennsylvania.

In this paper, I use a large, nationally representative sample to estimate the effect of atmospheric temperature on BMI and obesity, to see if the findings from controlled laboratory experiments discussed above generalize to natural settings and have real-life health consequences. Specifically, I test the hypothesis that, net of all appropriate controls, indicators of warmness/higher temperature are associated with greater weight and obesity, and indicators of coldness/lower temperature are associated with lesser weight and obesity.

1. Empirical analysis

1.1. Data

National Longitudinal Study of Adolescent to Adult Health (Add Health) is a prospectively longitudinal study of a nationally representative sample of American youths, initially sampled when they were in junior high and high school in 1994–1995 (Wave I, n = 20,745, mean age = 15.6) and reinterviewed in 1996 (Wave II, n = 14,738, mean age = 16.2), in 2001–2002 (Wave III, n = 15,197, mean



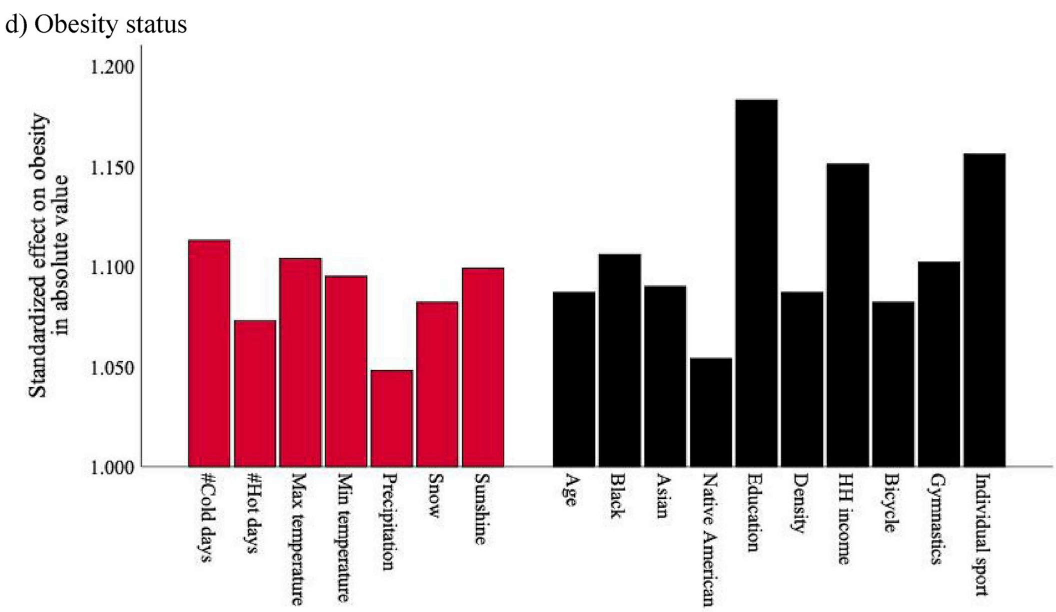


Fig. 1. (*continued*)

age = 22.0), and in 2007–2008 (Wave IV, n = 15,701, mean age = 29.1). All variables included in the empirical analyses came from Wave IV, except for race, which was last measured in Wave III. See additional details of sampling and study design at http://www.cpc.unc.edu/projects/addhealth/design.

1.2. Dependent variable: measured height and weight

Interviewers measured each respondent's height with a carpenter's square and a steel tape measure in cm (to the nearest .5 cm) and weight with a digital scale in kg (to the nearest .1 kg). From the measured height and weight, Add Health computed each respondent's BMI, and from their BMI, I constructed binary measures of their overweight (BMI > 25) and obesity (BMI > 30) status (1 if overweight or obese, 0 otherwise).

1.3. Independent variables: climate

Add Health Wave IV contextual data include climate variables at the level of the respondent's census tract. The climate variables include: 1) mean number of annual days with temperatures lower than 32 °F; 2) mean number of annual days with temperature higher than 90 °F; 3) mean maximum daily temperature; 4) mean minimum daily temperature; 5) mean annual total precipitation in inches; 6) mean annual snowfall in inches; 7) mean annual total sunshine hours. Variables 1 and 5–6 are indicators of cold temperature predicted to be negatively associated with weight and obesity, and variables 2–4 and 7 are indicators of warm temperature predicted to be positively associated with weight and obesity.

1.4. Control variables: demographic and socioeconomic variables

Prevalence of obesity varies by sex, age, race and socioeconomic status, so I control for the respondent's sex (0 = female, 1 = male), age (in years), race (with three dummies for black, Asian, and Native American, with white as the reference category), education (measured by 13-category ordinal scale from 1 = 8th grade or less to

13 = completed post-baccalaureate professional education, here treated as interval); and earnings (natural log of personal earnings in $1 K).

1.5. Control variables: neighborhood characteristics

Some neighborhood characteristics are expected to affect the rates of obesity among the residents. More densely populated urban areas tend to provide greater means of public transportation and facilitate walking; poorer neighborhoods are more likely to be "food deserts" with greater access to fast food chains and less access to fresh fruits and vegetables (Diez Roux and Mair, 2010); and residents of high-crime neighborhoods might be more likely to stay indoors and avoid physical activities outdoors (An et al., 2017). I therefore control for the natural log of the population density (number of persons in thousands per square kilometer) in the respondent's census tract, the natural log of the median household income in the last 12 months in the respondent's census tract, and the total number of adult arrests per 100 K population in the respondent's county in 2007.

1.6. Control variables: physical activities

Add Health asked how many days in the past week (0–7) the respondents engaged in a host of physical activities: 1) bicycle, skateboard, dance, hike, hunt or yardwork; 2) use of a physical fitness or recreation center in the neighborhood; 3) golf, fishing, bowling, softball or baseball; 4) gymnastics, weight lifting or strength training; 5) individual sports such as running, wrestling, swimming, cross-country skiing, cycle racing or martial arts; 6) rollerblade, roller skate, downhill ski, snow board, racquet sports or aerobics; 7) strenuous team sports such as football, soccer, basketball, lacrosse, rugby, field hockey or ice hockey; and 8) walk for exercise. Because physical activities are expected to affect or be affected by obesity, I control for the frequency of all eight types of physical activities.

1.7. Results

Supplementary Tables 1–4 present the full results of multiple OLS regressions, estimating the associations between atmospheric temperature and measured BMI and measured weight (net of measured height), and of binary logistic regressions, estimating the associations between atmospheric temperature and overweight and obesity status. As predicted, all climate variables had significant associations with measured BMI, measured weight, and overweight and obesity status, and all statistical associations were in the predicted direction. Net of sex, age, race, education, earnings, neighborhood characteristics, and physical activities, measures of cold temperature (number of cold days, total precipitation, and snowfall) were negatively associated, and measures of hot temperature (number of hot days, maximum daily temperature, minimum daily temperature, and sunshine hours) were positively associated, with all dependent variables. On average, Add Health respondents living in hotter climates were heavier than their counterparts living in colder climates.

Even though childhood intelligence affects adult obesity (Kanazawa, 2013, 2014) and even though there is some evidence that the average intelligence of a population is negatively associated with temperature (Kanazawa, 2006, 2008), controlling for Add Health respondents' childhood intelligence does not at all alter the results presented in Supplementary Tables 1–4. Similarly, even though the number of hours spent watching TV in the past week is consistently and significantly ($p < .001$ in all equations) positively associated with BMI, weight, overweight and obesity, controlling for it in equations in Supplementary Tables 1–4 either does not alter the results at all or, in some cases, very slightly strengthens the associations with climate variables.

Fig. 1 compares the standardized effect sizes in absolute values of all statistically significant predictors in the predicted direction in the regression analyses.[1] It shows that climate variables had larger associations with the measures of obesity than any other variables included in the regression equations except for being black, education, mean household income, and frequency of participation in individual sports. The climate variables had comparable effects to age and population density. Since we all know that we get more obese as we get older, as our metabolism slows down with age (Lührmann et al., 2009; Manini, 2010), and individuals living in urban areas are leaner because they walk and use public transportation more frequently, it is surprising that atmospheric temperature has just as strong an association with body weight as age and population density. Atmospheric temperature also had a slightly stronger effect than frequencies of bicycling and gymnastics, and no other physical activities (except for individual sports) statistically significantly reduced weight.

Is climate confounded with culinary culture? One potential alternative explanation for the strong association between atmospheric temperature and obesity is that temperature is confounded with culinary culture.[2] The southern US is warmer than the northern US, and the traditional Southern cuisine, perhaps best exemplified by the recipes of the celebrity chef Paula Deen, is typically rich and fattening, with ample servings of butter and cream (Shikany et al., 2015). So individuals in warmer climates may be more likely to be obese, not because they inhale warmer air but because they partake of high-calorie cuisine.

Add Health is extremely concerned with protecting the privacy of its survey respondents, and does not include any potential clues to their individual identity, including their state of residence or even region of the country. So I cannot control for Southern residence in my statistical analysis. The closest instrument I have available in the data set is political conservatism. The American South, which is known for its Southern cuisine, is also more politically conservative and Republican. Controlling for the proportion of registered voters in the county who were Republican at Wave III did not at all alter the results. I would also note that the cities in the US with the highest mean temperatures are in the desert Southwest (Arizona, Texas, California, and Nevada), not in the traditional South or Deep South most closely associated with the Southern cuisine. Far more people live in the desert Southwest than in the South, with California and Texas being the most and second-most populous state in the US, respectively. The Tex-Mex is not particularly fattening (Urban et al., 2013).

2. Discussion

Endotherms must expend their own energy to increase the temperature of substances that they introduce into their body to the body temperature. This is true of food in their stomach, which is why the ownership of a microwave might contribute in a small way to increased BMI and obesity (Kanazawa and von Buttlar, 2019). Endotherms must also expend their own energy to increase the temperature of air in their lungs, and, as a result, human subjects in laboratory experiments expend more energy when the ambient temperature is decreased even by a few degrees (Blaza and Garrow, 1983; Dauncey, 1981; van Ooijen et al., 2004; Warwick and Busby, 1990; Westerterp-Plantenga et al., 2002; Wijers et al., 2007). This physiological mechanism has real-life consequences for individuals living in different climates. The analyses of the Add Health data showed that, net of sex, age, race, education, earnings, neighborhood characteristics, and physical activities, individuals living in warmer climates have higher BMI and weight, and

[1] Frequencies of playing golf and walking for exercise were statistically significantly *positively* associated with the dependent variables. It is unlikely that playing golf and walking increase the weight. It is more likely that overweight and obese individuals are more likely to engage in these physical activities as a means of losing weight.

[2] I thank Coltan Scrivner for making this point.

are more likely to be overweight and obese than those living in colder climates. The effect of atmospheric temperature on obesity is stronger than the effect of most physical activities, and is about as strong as the effect of age and population density. Only being black, education, mean household income, and frequency of participating in individual sports have greater impact on obesity than atmospheric temperature.

A major limitation of the study is the use of correlational survey data (Add Health), as it is impossible to establish causality clearly with correlational data and all survey data depend for their quality on the respondents' willingness to provide truthful answers. However, the weaknesses usually associated with the use of correlational survey data are mitigated in the current study for three reasons. First, the current study is a replication in natural settings of findings from earlier experimental studies that clearly established the causal effect of ambient temperature on energy expenditure in controlled laboratory settings (respiration calorimeters) (Blaza and Garrow, 1983; Dauncey, 1981; van Ooijen et al., 2004; Warwick and Busby, 1990; Westerterp-Plantenga et al., 2002; Wijers et al., 2007). Second, the key dependent variables (height and weight, from which their BMI and overweight and obesity statuses were computed) were *not* derived from self-reports (as in earlier waves of Add Health). Instead, in Wave IV that I used in this study, the respondents' height and weight were measured by the interviewer. (The respondents were also asked to self-report their height and weight in survey questions in Wave IV, but I did not use these self-report measures.) While there is still some measurement errors in interviewer-measured height and weight, there is no room for respondents' conscious or unconscious misrepresentation. Third, the key independent variables (the climate variables) were added to the data by Add Health researchers from information available from published sources. They were *not* provided by the respondents, and there is therefore no room for respondent misrepresentation.

Given that human ancestors migrated out of Africa and populated the entire globe with extremely varying temperatures in the last 50,000 years (Oppenheimer, 2003), one might wonder why humans don't possess evolved physiological mechanisms to adapt to the local climate and adjust their metabolic setpoint.[3] One possibility is that, with high levels of physical activities and constant shortage of food, overweight and obesity were never adaptive problems that our ancestors had to solve during most of human evolutionary history.

The coefficient estimates for the mean maximum daily high temperature (Column (3) in Supplementary Tables 1–4) suggest that an average American might potentially lose 15.1 lbs in weight and 2.52 in BMI (50.3% of the difference between normal weight and obesity), and reduce the odds of obesity by 54%, by moving from Phoenix, AZ (with the mean annual daily maximum temperature of 87 °F in 2010) to Barrow, AK (with the mean annual daily maximum temperature of 17.3 °F). Less dramatically, the same individual might lose 5.7 lbs in weight and .95 in BMI (18.9% of the difference between normal weight and obesity), and reduce the odds of obesity by 25%, by moving from Phoenix, AZ, mere 150 miles north to Flagstaff, AZ (with the mean annual daily maximum temperature of 60.9 °F).

Compared to geographic relocation, global warming is expected to have a much smaller effect on obesity. The latest estimate of future increase in temperature under the worst-case scenario of global warming is 10.2 °F from 1961 to 2081 (2 SDs above the point estimate under the high scenario RCP8.5) (Wuebbles et al., 2017). An increase of 10.2 °F might produce an increase of 2.2 lbs in weight, .37 in BMI (7.3% of the difference between normal weight and obesity), and 12% in the odds of obesity in an average American before the end of the current century. In other words, global warming even under the worst-possible scenario would have about half as strong an effect on obesity as owning a microwave. I would hasten to add, however, that researchers have identified other potential mechanisms through which global warming might exacerbate the obesity epidemic, and some scientists believe that obesity epidemic itself might contribute to global warming, whereby, for example, more obese individuals are more likely to drive automobiles to their destinations rather than walk or ride bicycles (An et al., 2018).

More research is clearly necessary firmly to establish the effect of geographic location and average temperature on weight and obesity, especially in other locations and countries. In using cross-cultural data involving multiple nations, however, it is important to control for the cuisine – what and how much people in different cultures eat – because ethnic cuisines vary in their caloric contents (Urban et al., 2013). In this respect, relevant data collected in single nations that are latitudinally (and altitudinally) spread (such as Italy, Chile, and Japan), providing greater variations in temperatures, will be more useful than data collected from longitudinally spread nations like the United States (although the US is still more latitudinally spread than Italy or Japan in absolute terms).

[3] I thank Mara Mather for making this point.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.envres.2019.108962.

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