Title: Increasing Ambient Temperature Reduces Emotional Well-Being

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INCREASING AMBIENT TEMPERATURE REDUCES EMOTIONAL WELL-BEING

Abstract

This study examines the impact of ambient temperature on emotional well-being in the U.S. population aged 18+. The U.S. is an interesting test case because of its resources, technology and variation in climate across different areas, which also allows us to examine whether adaptation to different climates could weaken or even eliminate the impact of heat on well-being. Using survey responses from 1.9 million Americans over the period from 2008 to 2013, we estimate the effect of temperature on well-being from exogenous day-to-day temperature variation within respondents' area of residence and test whether this effect varies across areas with different climates. We find that increasing temperatures significantly reduce well-being. Compared to average daily temperatures in the 50 to 60°F (10 to 16°C) range, temperatures above 70°F (21°C) reduce positive emotions (e.g. joy, happiness), increase negative emotions (e.g. stress, anger), and increase fatigue (feeling tired, low energy). These effects are particularly strong among less educated and older Americans. However, there is no consistent evidence that heat effects on well-being differ across areas with mild and hot summers, suggesting limited variation in heat adaptation.

Introduction

While the empirical link between heat exposure and mortality rates is well-established (Curriero et al., 2002; Deschênes & Greenstone, 2011; Gasparrini et al., 2015; Kovats & Hajat, 2008), little is known about the effect of heat exposure on mental health. Previous studies have focused on suicide mortality and indicate that heat exposure is associated with increased suicide rates (Basagaña et al., 2011; Kim et al., 2016; Maes, De Meyer, Thompson, Peeters, & Cosyns, 1994; Page, Hajat, & Kovats, 2007; Qi, Hu, Page, & Tong, 2015). One study has found an impact of heat exposure on hospital admissions for mental and behavioral disorders (Hansen et al., 2008). Related research in psychology and economics has suggested that heat exposure reduces emotional wellbeing (Keller et al., 2005), increases interpersonal aggression (Anderson & Anderson, 1998; Anderson & Bushman, 2002) and diminishes life satisfaction (Connolly, 2013; Denissen, Butalid, Penke, & van Aken, 2008; Lucas & Lawless, 2013; Schwarz & Clore, 1983). Together, these findings indicate that heat exposure may adversely impact mental health and that global climate change, by increasing exposure to extreme heat, could similarly have negative consequences for mental health (Berry, Bowen, & Kjellstrom, 2010).

In this study, we use survey data on 1.9 million Americans to examine the impact of ambient temperatures on emotional well-being. Our main goal is to provide evidence of a psychological link between heat exposure and emotional well-being, which could contribute to the impact of heat on mental health. Furthermore, while previous research focused on hospital admissions and suicide mortality, we obtain an estimate of the sub-clinical impact of ambient temperatures on individual's emotional well-being and quality of life in the U.S. population.

Finally, we explore empirically whether adaptation to hotter climates could potentially mitigate the effect of heat exposure on emotional well-being.

Direct exposure to ambient heat likely affects emotional well-being by causing heat stress and exhaustion (Kovats & Hajat, 2008), which is experienced as intrinsically unpleasant (Frederick & Loewenstein, 1999). Heat exposure may also alter mental states through thermo-sensitive physiological processes (Leon & Bouchama, 2015; Page et al., 2007). Emotional well-being may diminish because individuals are forced to stay indoors for extended periods, have to alter their daily schedules and face increased cooling expenditures, e.g., due to running air conditioners (Deschênes, 2012). Our outcome measure therefore captures potential well-being losses due to direct heat exposure and opportunity costs caused by heat avoidance.

Our data allow us to explore whether adaptation to heat exposure could lower the adverse effect of heat on emotional well-being. The U.S. represents a good test-case because of its diverse climate conditions, mobile population and available technology. Local climate conditions are a robust predictor of where in the U.S. Americans chose to live (Albouy, Graf, Kellogg, & Wolff, 2013). At least some Americans chose to live in areas with local climate conditions that optimally fit their preferences, e.g., areas with neither very cold winters nor extremely hot summers. Climate-driven migration therefore represents one mechanism of adaptation (Albouy et al., 2013; Deschênes & Moretti, 2009). Second, heating and cooling technologies like air conditioners are widely available (Barreca, Clay, Deschênes, Greenstone, & Shapiro, Forthcoming) so that individuals can avoid exposure to hazardous temperatures and can adjust indoor climates to subjectively optimal levels.

Residential mobility and technology therefore allow individuals to move to and adapt to local climates. While these conditions exist in other developed countries too, the U.S. is a good test case because climate conditions vary more across regions, which provides useful identifying variation while keeping many other factors, e.g. available technology, constant. We exploit this identifying variation to test whether adaptation to local climates could perhaps mitigate or even eliminate any impact of ambient temperature on emotional well-being.

Finally, the issue of adaptation is relevant to understanding the future impact of global warming on well-being. If further adaptation occurs, the future impact of increased heat exposure due to global climate change may not result in a net well-being loss. Conversely, if we find that heat lowers well-being by the same amount across areas with mild and hot summers, this could be interpreted as evidence that adaptive potentials have been exhausted and that there is little room for further heat adaptation. In this case, it is more likely that the future impact of increased heat exposure will result in a net well-being loss.

Materials and Methods

We used the Gallup G1K dataset, which is based on telephone surveys of a random sample of 1,000 Americans that is conducted on 350 days per year. Our observation period covers the years 2008 to 2013. Our analysis included all measures explicitly referencing emotional well-being on the day prior to the day of interview. Specifically, respondents were asked “Did you experience the following feelings a lot of the day yesterday?” before interviewers went through the following list: enjoyment, worry, sadness, stress, anger, and happiness. We also included the following additional questions: “Did you smile or laugh a lot

yesterday?”, “Did you have enough energy to get things done yesterday?”, “Were you treated with respect all day yesterday?”, and “Did you feel well-rested yesterday?”. For each item, respondents could chose to answer “yes”, “no”, “don’t know”, or refuse to answer. Individuals in the last two response categories were dropped, reducing sample size by 4%, which resulted in a final sample of 1,854,746 individuals. The items included in the analyses were originally developed to capture hedonic well-being (Kahneman & Krueger, 2006), but are very similar to items used in common epidemiologic self-report mental health scales (see Appendix, p. 7., for further details).

We recoded the well-being measures into binary variables that took the value 1 for “yes” responses indicating the presence of positive feelings or the value 0 for “no” responses indicating the presence of negative feelings, i.e. the value 1 indicates reports of positive or absence of negative feelings. We performed principal component analysis on all ten items. The first component explained 53% of the total variation. Predicted scores of this component form our aggregate index of emotional well-being. After oblique rotation, we obtained three distinct components that jointly explained 74% of the total variation, and which we labeled positive emotions (happiness, enjoyment, smiling/laughter), negative emotions (anger, stress, worry, sadness, not treated with respect), and fatigue (well-rested, enough energy). The predicted scores for these components were also analyzed as dependent variables. All indices are standardized (mean = 0, standard deviation = 1). Further details on the index construction and results from principal components analysis are available in the Appendix (p. 4).

We linked the G1K survey to temperature data using information on the day of interview and respondents' self-reported zip codes. Respondents' zip codes were linked to Zip Code Tabulation Areas (ZCTAs) and, in combination with data on interview dates, matched to 24-hour average daily temperature records from the North American Land Data Assimilation System (NLDAS-2) forcing files, which provide hourly estimates of air temperature (K) 2 meters above ground level on a 0.125 x 0.125 degree grid. Air temperature is the main predictor of interest; total hourly precipitation and relative humidity (calculated from temperature, pressure and specific humidity) were included as control variables for robustness checks. For each respondent in our sample, we calculated the daily 24-hour average values of these variables at the centroid of the ZCTA. Our main exposure variable is 24-hour average temperature in respondents' ZCTA of residence on the day prior to the day of interview, which is the day to which outcome measurements refer.

To model the relationship between temperature and well-being, we used ordinary least squares (OLS) regression with sampling weights provided by Gallup and standard errors adjusted for clustering of respondents within ZCTAs. Because individuals residing in different areas differ in ways that are likely to be correlated with well-being and local temperatures, we control for area of residence fixed effects.(Burke, Hsiang, & Miguel, 2015) To reduce computation time, rather than controlling for >32,000 ZCTA fixed effects, we control for commuting zone fixed effects in our baseline specification. Specification checks (see Appendix, p. 16) show that this restriction does not affect temperature estimates. Using information on the county of residence, we identify individual commuting zones, which are similar to Metropolitan Statistical Areas

defined by the U.S. Census Bureau, but include rural counties, too. We observe 691 commuting zones. The resulting estimates are immune to biases resulting from unmeasured time-constant determinants of well-being shared by individuals residing in the same commuting zone. Furthermore, seasonal factors, e.g. variation in sunlight exposure (Buscha, Forthcoming), are correlated with well-being and temperature and therefore flexibly controlled for. The modeling approach closely follows recent contributions in climate economics (Burke et al., 2015; Deschênes & Greenstone, 2011).

Specifically, we estimate variants of the following model, where we use subscripts i to denote individuals, j to denote commuting zones ($j = 1, \dots, 691$), m to denote survey months ($m = 1, \dots, 12$), s to denote contiguous US states ($s = 1, \dots, 48$), c to denote calendar weeks ($c = 1, \dots, 312$) and y to denote calendar years ($y = 2008, \dots, 2013$):

$$Y_{ijmscy} = \alpha_{jm} + \sum_{k=1}^7 \beta_k T_k + \lambda_{sy} + \mu_c + X\gamma + \varepsilon_{ijmscy}$$

The continuous temperature variable is split into a categorical variable with eight bins, denoted T_k , with seven temperature coefficients β_k to be estimated. For β_k to have a causal interpretation, we assume that the correlation between temperature dummies and the idiosyncratic error term ε is zero conditional on the other covariates, i.e., within ZCTAs, day-to-day variation of temperatures is uncorrelated with unmeasured determinants of well-being.

To make this assumption more plausible, we flexibly control for both location of residence and season fixed effects by including α_{jm} commuting zone by month fixed effects, i.e.

one fixed effect per commuting zone and survey month. Our baseline model also adjusts for λ_{sy} state by calendar year fixed effects to capture unobserved state- and year-specific well-being shocks, e.g., caused by the recession unfolding during the observation period, which could induce a spurious correlation between temperature and well-being. Furthermore, we adjust for μ_c calendar week fixed effects, i.e. one fixed effect per year and calendar week, to adjust for common year- and week-specific events that could affect well-being across the US, such as holidays or election outcomes, and be correlated with temperature. Finally, X is a matrix of additional covariates. In the baseline model, X only includes weekday fixed effects. For specification checks reported in the Appendix (p. 16), we add socio-demographic and climate control variables. We show that our results are consistent across multiple specifications, which suggests that the day-to-day temperature variation within respondent's areas of residence is as good as randomly assigned.

Our baseline model does not impose a particular functional form on the temperature effect. In the Appendix, we report results from analyses using temperature polynomial functions. None of our conclusions was substantially affected by functional form issues, and we discuss the main issues behind different modeling approaches in the Appendix (p. 23). We also explored whether lagged or future temperature values affect well-being after temperature on the day of interview is conditioned on, but found no evidence that this is the case (Appendix, p. 11).

To test for heat adaptation, we compared the well-being temperature response functions across U.S. regions defined by summer climate. For each ZCTA, we calculated the average summer temperature (June, July, August) during the five years preceding the year of interview.

We then generated an indicator variable classifying each respondent as living in an area with above median or below median summer time temperatures. We added this indicator variable to the baseline model and also added interactions between this indicator and all other variables in the baseline model.

Our null hypothesis is that the temperature well-being response function is constant across different climate regions. In turn, we interpret significant differences in the response function as evidence supporting adaptation, specifically if we find a significantly weaker effect of heat on well-being among individuals living in areas with typically hot compared to mild summers. This testing approach faces the challenge that average summer temperature and heat exposure are positively correlated. We observe much fewer extreme heat exposures in areas with mild compared to areas with hot summers (Appendix Table A10). Our tests therefore have less statistical power in the tails of the temperature distribution compared to the center. Similarly, it becomes more difficult to identify the correct functional form of the temperature effect in the tails of the temperature distribution. The Appendix (p. 23) discusses these analyses further, explores issues of statistical power, functional form and reports results from additional tests. However, the additional evidence is consistent with the evidence and conclusions drawn here.

Results

Figure 1A shows OLS estimates from our baseline model of the effect of exposure to temperatures within 10°F intervals on the aggregate index of emotional well-being. The response function shows the estimated change in well-being due to a day spent in a given temperature interval relative to a day spent in the reference interval of 50 to 60°F (10 to 16°C). While

temperatures from 20 to 70°F (-7 to 21°C) have no effect, exposure to one day averaging 70-80°F (21 to 27°C) reduces well-being by 1.6% of a standard deviation ($p < 0.01$). Days above 90°F (32°C) reduce well-being by 4.4% of a standard deviation ($p < 0.01$). Very cold days (less than 20°F or -7°C) are associated with a 3.1% of a standard deviation well-being increase ($p < 0.01$). These results are robust to the inclusion of an extensive set of demographic, socio-economic, and health control variables, ZCTA fixed effects, and controls for relative humidity and precipitation (Appendix, p. 16).

We observe significant reductions in well-being during hot temperatures for all three sub-components of well-being (Figure 1, B-D). Positive emotions (Figure 1, C) exhibit the least consistent temperature response: heat effects are no longer statistically significant after adjusting for all potential confounders (Appendix, p. 16), while moderately cold (20 to 40°F), but not very cold ($< 20^\circ\text{F}$) days are associated with slight reductions in well-being. Negative emotions (Figure 1, D) and fatigue (Figure 1, B) respond in a similar way as aggregate emotional well-being. The fatigue component shows the strongest association with temperature.

To test if temperature effects on emotional well-being vary across different sub-populations, we added group indicator variables to the baseline regression model and interacted the group indicator with the temperature indicator variables. Joint F -tests on the interaction terms indicate that age ($p < 0.001$) and education ($p < 0.001$) are significant moderators, but yield no evidence of effect moderation by gender ($p = 0.89$). While temperature effects on 18-45 year-olds are small and fail to reach statistical significance at conventional levels (Figure 2, A), we observe well-being enhancing effects of very cold temperatures and more sizeable negative effects of

moderately hot and very hot days among individuals aged 46+ (Figure 2, B). Education is also an important moderator. Less educated individuals are more sensitive to temperature variation, experiencing larger decreases (increases) in well-being at high (low) temperatures (Figure 2, C). Heat effects do not reach statistical significance for individuals with more than a high school degree (Figure 2, D).

To put these effect sizes in perspective, we computed unadjusted well-being gaps by gender and education. Compared to men, women's levels of well-being are 11% of a standard deviation lower ($p < 0.001$), which is consistent with gender gaps in morbidity (Case & Paxson, 2005) and life satisfaction (Stevenson & Wolfers, 2009). Reflecting enduring socio-economic differentials in health and well-being (Mirowsky & Ross, 2003), levels of well-being are 7% (11%) higher among individuals with a bachelor (graduate) degree compared to individuals with a high school degree. This suggests that the estimated magnitude of the transitory reduction in well-being during very hot days is substantial, particularly among older and less educated Americans.

Figure 3 displays the marginal effects of exposure to temperatures in a given interval relative to the reference interval of 50-60°F (10 to 16°C) for areas with mild and hot summers. We display 95% confidence intervals as grey areas for mild summer areas, and as dashed lines for hot summer areas. Consistent with adaptation to heat in hot summer areas, the effect of temperatures in the 80-90°F range on well-being is weaker in areas with hot vs. mild summers ($p < 0.05$). However, the effects of exposure to temperatures above 90°F are nearly identical across areas, as are the effects of other temperature exposures. A joint F-test on the interaction

terms between climate area and temperature suggest that observed differences in temperature responses across areas are not statistically significant ($p\text{-value} = 0.26$).

Discussion

Our results indicate that ambient temperatures in excess of 70°F, and especially above 90°F, significantly reduce emotional well-being. The magnitude of these effects appears meaningful when compared to well-being gaps between genders and education groups. We found no consistent evidence suggesting that individuals living in areas with mild and hot summers respond differently to heat exposure, suggesting a limited role for heat adaptation to mitigate the impact of heat on well-being in the contemporary U.S.

Heat-related well-being losses are likely generated in part by direct heat exposure through thermo-sensitive physiological mechanisms resulting in sleep disturbance, exhaustion, and heat stress (Kovats & Hajat, 2008). These may trigger fatigue, or alter mental states resulting in reduced emotional well-being (Keller et al., 2005) or increased aggression (Anderson & Bushman, 2002; Hsiang, Burke, & Miguel, 2013; Ranson, 2014). Furthermore, by potentially diverting time and money away from activities and investments that increase well-being, defensive investments (e.g., air conditioning) and avoidance behavior (e.g. substituting indoor activities for time spent outside) may also reduce well-being (Deschênes & Greenstone, 2011; Zivin & Neidell, 2014).

Our results support the existence of a psychological link between heat exposure and mental health that could be a contributing factor behind the association between heat exposure

and suicide mortality (Kim et al., 2016; Maes et al., 1994; Page et al., 2007; Qi et al., 2015). Furthermore, our results are consistent with and provide evidence of mechanisms mediating the effect of temperature on economic activity and interpersonal aggression. U.S. studies have found that county-level income and hours worked in occupations with high weather exposure decrease with increasing temperatures (Deryugina & Hsiang, 2014; Zivin & Neidell, 2014). We show that heat exposure increases reports of fatigue, suggesting that heat may lower economic output by reducing productivity (Heal & Park, 2013). Furthermore, we find that heat exposure increases negative emotions, e.g. feelings of anger, which could contribute to the observed association between heat and interpersonal aggression (Anderson & Bushman, 2002; Hsiang & Burke, 2013; Hsiang et al., 2013).

Our results also indicate that relative to temperatures in the 50 to 60°F range, very cold temperatures reduce both negative emotions and fatigue. Low temperatures may reduce negative emotions by reducing aggressive feelings and arousal (Anderson & Bushman, 2002), which is consistent with research indicating a lower incidence of violent crime at cold temperatures (Ranson, 2014). Cold, especially unusually cold days relative to seasonal norms, may also be perceived as invigorating (Anderson & Anderson, 1998). This “bracing cold” effect might explain the fatigue-reducing impact of very cold days.

Future research should clarify the mechanisms that put less educated and older Americans at risk, which would facilitate the implementation of policies to protect those most vulnerable to heat exposure. At present, there are several candidate explanations for these disparities, such as pre-existing health conditions (older and less educated Americans; Mirowsky

& Ross, 2003), greater exposure to heat due to lack of adequate air conditioning (less educated), and increased probability of working outdoors (less educated; Zivin & Neidell 2014). With the share of older Americans in the overall population and economic inequalities on the rise, it is important to better understand how these processes are intertwined with exposure risks and vulnerability to climate change.

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FIGURES

Figure 1. The effect of temperature exposure (°F) on emotional well-being on the day prior to the respondent's interview. Panel **A** shows the temperature response of the aggregate well-being index. Panels **B-D** show results for its components: fatigue (**B**), positive emotions (**C**), and negative emotions (**D**). To facilitate interpretation, we reversed the response scale for fatigue (**B**) and negative emotions (**D**) so that a positive temperature effect indicates increased fatigue or reports of negative emotions. Well-being measures (y-axes) are standardized with mean zero and standard deviation one. Temperature exposure (x-axes) is measured as the 24-hour average daily temperature on the day prior to the respondent's interview in their zip code tabulation area (ZCTA). Each panel shows the estimated effect (with 95% confidence intervals, dashed lines) of being exposed to temperatures in a given interval relative to the reference interval of 50 to 60°F.

Figure 2. The effect of temperature exposure (°F) on emotional well-being on the day prior to the respondent's interview, stratified by younger (ages 18-45, Panel **A**), older (ages 46+, Panel **B**), less educated (max. high school degree, Panel **C**) and more educated (more than a high school degree, Panel **D**) populations. The well-being index (y-axis) is standardized with mean zero and standard deviation one. Temperature exposure (x-axis) is measured as the 24-hour average daily temperature on the day before the respondent's interview in their zip code tabulation area (ZCTA). Each panel shows the estimated effect (with 95% confidence intervals) of being exposed to temperatures in a given interval relative to the reference interval of 50 to 60°F.

Figure 3. The effect of temperature exposure (°F) on emotional well-being on the day prior to the respondent's interview by average summer temperature in respondent's zip code tabulation area (ZCTA). Well-being (y-axis) is standardized with mean zero and standard deviation one. Temperature exposure (x-axis) is measured as the 24-hour average daily temperature on the day prior to the respondent's interview in their ZCTA. Marginal effects of being exposed to temperatures in a given interval relative to the reference interval of 50 to 60°F (10 to 16°C) for areas with mild and hot summers are displayed. 95% confidence intervals are shown as grey areas for mild summer areas and dashed lines for hot summer areas.