Preventive Medicine Reports 38 (2024) 102541

Contents lists available at ScienceDirect

Preventive Medicine Reports

journal homepage: www.elsevier.com/locate/pmedr

Cold weather isolation is worse in poor and non-white neighborhoods in the United States

Karl Vachuska

Department of Sociology, University of Wisconsin-Madison, United States

ARTICLE INFO

Keywords:
Social isolation
Neighborhoods
Racial inequality
Temperature
Mobility patterns

ABSTRACT

Social isolation can cause a variety of adverse physical and mental health effects and is central to understanding broader social disparities among marginalized groups in the United States. This study aims to assess whether temperature variation is associated with daily social isolation at the neighborhood level. I test a series of two-way fixed effects models to see if mean daily temperature is associated with individuals spending the entire day at home, as measured using smartphone data, across a sample of 45 million devices in 2019 in the United States. Using interaction terms, I specifically examine heterogeneity in temperature effects by neighborhood racial composition and socioeconomic status. The two-way fixed effects models reveal highly statistically significant negative coefficients for the interaction between temperature and neighborhood proportion Black, temperature and neighborhood proportion Hispanic, and temperature and neighborhood residential disadvantage, in predicting the probability of spending the entire day at home. In marginal terms, the findings indicate the gap in the probability of spending the entire day at home between an all-Black neighborhood and an all-White neighborhood grows by nearly 10 percentage points from the warmest day of the year to the coldest day of the year in some parts of the United States. My models highlight how residents of poor and majority Black and Hispanic neighborhoods experience disproportionate social isolation in the form of a greater propensity to spend the entire day at home.

1. Introduction

Recent evidence suggests Americans' self-reported feelings of loneliness are growing (Luchetti et al., 2020). Social isolation and loneliness are associated with an assortment of health issues, including poor sleep quality, hypertension, poor cognitive function, depression, anxiety, and a weakened immune system (Holt-Lunstad et al., 2010; Griffin et al., 2020; Boss et al., 2015). Additionally, social isolation is associated with a decline in an individual's support network, which can exacerbate economic insecurities and have other social consequences (Lim, 1996). People who are socially isolated tend to have fewer opportunities to engage in activities that support physical and mental well-being. In extreme cases, social isolation is associated with self-harm and suicide (Heuser and Howe, 2018).

While isolation has been discussed in the public health literature as an individual condition, sociologists tend to discuss it as a community-level phenomenon. For example, Wilson (Wilson, 1987) argues that isolation, in a community context, is key to understanding urban neighborhood disadvantage. He asserts that racial segregation and concentrated poverty contribute to a lack of social resources and opportunities for residents of disadvantaged neighborhoods. Consequentially, individuals residing in these isolated neighborhoods tend to experience reduced life chances, including lower educational and occupational attainment and worse health. More recent scholarship has shown that social cohesion and collective efficacy within a community are strongly associated with community outcomes, such as violent crime (Sampson et al., 1997).

While isolation has been broadly explored as an individual and community-level phenomenon, less research has engaged with it in relation to weather, despite that being a self-evident factor. Some research has shown social isolation is worse when the weather is colder (Clarke et al., 2015), but this association has not been well-studied with neighborhoods, race, and socioeconomic status. While many studies have shown that poor and non-White Americans are more socially isolated (Tigges et al., 1998), it is unclear how weather may uniquely impact their isolation.

Climate change necessitates more research on the nexus between weather conditions and social outcomes. Given extreme winter events,

E-mail address: vachuska@wisc.edu.

https://doi.org/10.1016/j.pmedr.2023.102541
Received 27 July 2023; Received in revised form 4 December 2023; Accepted 6 December 2023
Available online 9 December 2023

in recent years, climate scientists have increasingly explored whether climate change can cause extreme cold weather. Some research suggests that climate change alters the stratospheric polar vortex, a band of winds circulating in the stratosphere. Scientists believe the melting of the ice caps can induce upward atmospheric wave energy flux, which can result in severely cold winter weather in the Northern Hemisphere (Cohen et al., 2021).

A large body of research suggests that cold weather can negatively impact mental health. In particular, cold is often associated with feelings of isolation, depression, and anxiety (Molin et al., 1996). Cold weather can also negatively impact the amount of time individuals spend outdoors, which may further amplify isolation and mental illness (Hartig et al., 2007). Moreover, prolonged exposure to cold climates is associated with a heightened risk of Seasonal Affective Disorder. Research suggests that a key mechanism for moderating these impacts is staying socially connected and physically active throughout winter (Seasonal, 2015; Kvam et al., 2016). Individuals who manage to do so report fewer negative mental health symptoms throughout the winter (Rohan et al., 2003; Wirz-Justice et al., 1996).

Beyond combatting social isolation, spending time outside has numerous health benefits (Schaefer et al., 2014). Natural light exposure benefits the body's circadian rhythm and has been shown to improve sleep patterns (Burns et al., 2021). Spending time outdoors is also associated with lower levels of stress (Kondo et al., 2018). Physical activity can also improve cardiorespiratory health and increase muscular strength (Harada et al., 2017). Physical activity has been shown to mediate a key association between outdoor time and mental health (Bélanger et al., 2019). While cold weather somewhat prohibits spending substantial amounts of time outside, spending at least some time outside and finding ways to stay active are crucial to maintaining good physical health throughout the year, especially in the winter.

While the benefits of being socially involved and spending time outside are clear, huge disparities persist in the United States. Studies show that impoverished and non-White individuals are significantly more likely to suffer from social isolation and physical inactivity (Tigges et al., 1998; Hawes et al., 2019). Neighborhoods have been called a key driver of these disparities, though the mechanisms are not perfectly understood. Some research suggests that social isolation is exacerbated in impoverished non-White communities because of reduced social cohesion and collective efficacy, and heightened residential instability (Forrest and Kearns, 2001; Cradock et al., 2009). Other research suggests that fewer institutional resources leave residents with fewer opportunities to stay engaged or connect with others (Tigges et al., 1998). Broadly, feeling unsafe outdoors is strongly associated with physical inactivity and staying indoors excessively. Disadvantaged communities also generally have limited access to green spaces or other appropriate places to engage in physical activity, further exacerbating health disparities (Bennett et al., 2007). While the exact mechanisms are not perfectly understood, research has documented substantial disparities along neighborhood lines in terms of social isolation and physical activity (Tigges et al., 1998).

In this paper, I use neighborhoods to explore the impact of temperature on activity, with a keen focus on racial and socioeconomic disparities. As past research has suggested associations between temperature and activity and race/socioeconomic status and activity, I seek to examine how the three variables interact. I focus on cold weather, rather than hot weather, as the health implications around isolation in the winter are fundamentally different than those in the summer (Denissen et al., 2008). Furthermore, some literature suggests that due to seasonal factors, summertime has much greater levels of activity and mobility (Chan and Ryan, 2009; Hawelka et al., 2014). Using pre-pandemic cell phone mobility data from a nationally-representative sample of 45 million mobile devices, I measure the relationship between daily temperature and the fraction of residents who spend the entire day at home. On a typical day in a typical neighborhood, I find that around 30 % of residents spend the entire day at home. While I find that, on average, more isolation occurs in poor Black and Hispanic neighborhoods, I also find that these disparities are especially worse on the coldest days. From the warmest to the coldest days of the year, I estimate that the growth in disparities between all-Black/Hispanic and all-White neighborhoods can be close to 10 percentage points in parts of the country. I conclude by arguing for more research at the nexus of race, weather, and isolation.

2. Data

For this project, I used three sources. First, I obtain mobility data from SafeGraph, a United States firm specializing in mobility and traffic data. SafeGraph aggregates anonymized, repeatedly measured location data from a nationally representative sample of 45 million smartphone devices that Veraset provides. I specifically rely on SafeGraph's "Social Distance Metrics" dataset, which provides daily information on individuals' activity levels for every day in 2019. SafeGraph determines the home location for a device as the device's common nighttime (6:00 pm to 7:00 am) location estimated over the prior 6-week period. Then, for each census block group and each day in 2019, SafeGraph reports how many devices spent the entire day at home based on how many devices did not ping outside their estimated home location during that day.

Readers should bear in mind potential limitations of SafeGraph data when interpreting these results. While some evidence suggests the SafeGraph data is based on a generally representative sample of Americans, other literature has highlighted potential concerns. Noi and colleagues (Noi et al., 2022) observed some inconsistencies in mobility findings derived from Safegraph compared to other sources. To be included in the SafeGraph sample, individuals need a smartphone, which slightly biases the sample as not all Americans have smartphones. Nonetheless, data derived from SafeGraph's mobility patterns generally correlate strongly with data obtained from independent sources. At the county level, spatial analyses of the SafeGraph device panel suggest the SafeGraph sample is highly nationally representative, and only minor sampling biases exist. Li and colleagues (Li et al., 2023) found that in 2019, the sampling bias in terms of age, race and educational attainment, was minor. I encourage readers to interpret the findings of this paper with potential limitations, in terms of sample representativeness, in mind. Future research should replicate these analyses with other data sources.

This project's second data source is the National Oceanic and Atmospheric Administration's 2019 Global Daily Summaries dataset. The Global Daily Summaries dataset provides daily weather information for a large number of locations around the world. The dataset includes a wide variety of daily measurements of meteorological data, including average daily temperature. The data is quality controlled to ensure accuracy and has been relied upon heavily in past meteorological research (Menne et al., 2012). The weather stations utilized are fairly well-distributed across the United States, ensuring that almost the entire country is close to at least one station.

I subset the set of stations with Average Daily Temperature available for 2019. I then link census block groups to the nearest station based on their population centroid. In line with past approaches, I drop census block groups where the nearest station was more than 100 miles away (Adeyeye et al., 2019). Additionally, to eliminate extreme or inaccurate values, I remove all observations where the daily average was less than −40 °C or more than 30 °C. While 30 °C is not unrealistically warm, I exclude such observations because there is reason to believe people spend more time inside on days when heat is excessive. If this is the case, high temperatures may affect the linearity of the temperature-activity relationship, thereby biasing the results. 30 °C has been used in past research as a cutoff for identifying hot days with "extreme temperatures" (Hawelka et al., 2014; Noi et al., 2022).

The third data source is the American Community Survey's 2015–2019 5-year estimates. I operationalize census block groups'

Table 1
Summary Statistics on Census Block Groups in the United States in 2019.

Variable	Mean	Sd	Min	25th %	75th %	Max
Temp.	14	10.113	−39.6	6.7	22.5	29.9
Prop. Home	0.3	0.102	0.002	0.234	0.37	0.963
RND	0	0.925	−2.624	−0.642	0.585	4.773
Prop. Black	0.1	0.224	0	0	0.14	1
Prop. Hispanic	0.2	0.223	0	0.014	0.204	1
Prop. Other	0.1	0.121	0	0.011	0.102	1

N = 75,851,034.

racial composition based on three variables: proportion non-Hispanic Black, proportion Hispanic (of any race), and proportion non-Hispanic Other,[1] with proportion non-Hispanic White as the omitted reference category. Additionally, following past research, I operationalize a neighborhood's socioeconomic status by its residential disadvantage score. Residential disadvantage is calculated as the factor from a principal factor analysis of seven variables: percentages of poverty, unemployment, single-headed households, public assistance receipt, adults without a high school diploma, adults with a bachelor's degree or higher, and workers who are managers or professionals (Levy et al., 2020; Wodtke et al., 2011; Levy et al., 2022;8(7):eabl3825.). This study relied only on geographically aggregated, non-individual level data from publicly available sources, and does not constitute human subjects research by the University of Wisconsin-Madison's definition.

Table 1 presents summary statistics on the panel dataset. The mean temperature across all days and census block groups is 14 ℃, or 57.2 °F. On a typical day in an average census block group, approximately 30 % of residents spend the entire day at home.

3. Methods

The main method employed in this analysis is two-way fixed effects linear probability models predicting the fraction of residents of a census block group *i* on day *j* who spend the entire day at home. I include fixed effects for unique combinations of day and weather station, and census block group *i*. These fixed effects control for general variation in time spent at home on different days of the year, in different areas of the country, and in different census block groups. My preferred model can be written formally as follows:

$$p_{ij} = \beta_1 * TEMP_{ij} * BLACK_i + \beta_2 * TEMP_{ij} * HISP_i + \beta_3 * TEMP_{ij} * OTHER_i + \beta_4 * TEMP_{ij} * RND_i + \Delta_{xj} + \nabla_i + \epsilon$$

where p_{ij} represents the fraction of residents that spend the entire day at home in neighborhood *i* on day *j*, $BLACK_i$ represents the proportion of residents of neighborhood *i* that are non-Hispanic Black, $HISP_i$ represents the proportion of residents of neighborhood *i* that are Hispanic of any race, $OTHER_i$ represents the proportion of residents of neighborhood *i* that are non-Hispanic other, RND_i represents the residential disadvantage score of neighborhood *i*, and Δ_{xj} represents day-area fixed effects for neighborhoods where the nearest weather station is *x* and the day is *j*, ∇_i represents fixed effects for neighborhood *i*, ϵ represents an error term with the usually-assumed statistical properties. All models are estimated using the *fixest* package in R (Berge et al., 2021).

Broadly, the intuition for this main model rests in the idea that regional variations exist in levels of isolation and activity that are likely due to unmeasurable attributes. In addition, stark variation between days exists in how much time residents spend at home. Activity is higher on holidays and certain days of the week (Adeyeye et al., 2019). Finally, the intuition for the census block group fixed effects is to isolate the effect of temperature, fully conditional on neighborhood attributes. By controlling on the mean level of activity in a neighborhood, I can isolate whether or not certain types of neighborhoods are subject to disproportionate changes in isolation based on the changing temperature. While, for ease of interpretation, I estimate these and a sequence of other models as linear probability models, these results can also be replicated with logit models. Replication with logit models is included in the supplementary material. I additionally replicate the main models with controls for proportion of residents age 65 or older and proportion of residents with a disability,[2] since age and disability status are likely to be important factors in mobility. These models can be found in the supplementary material. I additionally include region-specific models replicating the main results across each region of the United States in the supplementary material.

4. Results

Table 2 presents the main results of the analysis. Model 1 presents simple results regarding the average relative association between neighborhood racial composition and the fraction of residents that spent all day completely at home on a typical day. Model 1 includes day-area fixed effects to control for both interregional and intertemporal variation in activity. These results suggest on an average day, a neighborhood that is 100 % Black would expect to have 13.33 percentage points more residents spend the entire day at home compared to a nearby 100 % White neighborhood. I observe a similar disparity for proportion Hispanic. The effect of proportion Other is smaller but still positive. All three of these results are highly significant ($p < 0.001$).

Model 2 removes the day-area fixed effects and adds an interaction between temperature and the racial composition variable to present a broader descriptive portrait of the interaction between temperature, neighborhood racial composition, and spending the whole day at home. The intercept, 0.3004, can be interpreted as the fraction of residents in a 100 % White neighborhood that would spend the entire day at home on a day when the temperature is 0 ℃. The temperature coefficient, −0.0017, indicates that for every 1 ℃ the temperature increases, the percentage of residents that spend all day at home declines by 0.17 percentage points. While this increment appears small, it would imply that a 50-degree shift (−20 ℃ (−4 °F) to 30 ℃ (86 °F), which is a realistic winter to summer shift in the Northern United States, is associated with 8.5 percentage points fewer residents spending the whole day at home.

The Black, Hispanic, and Other coefficients in Model 2 are similar to those in Model 1 but slightly attenuated. The racial composition and temperature interaction terms highlight the heterogenous effects of temperature on activity. The coefficients for all three interactions are negative and highly significant ($p < 0.001$), indicating that disproportionality fewer people spend time at home as the weather warms. Inversely, this also implies that disproportionately more people spend time at home when the weather is colder. This is in addition to not only general inequalities in spending the whole day at home but also the general association between temperature and activity for all neighborhoods (e.g., the "Temp." coefficient).

Model 3 looks at the heterogenous effect of temperature in terms of neighborhood socioeconomic status, as measured by Residential Neighborhood Disadvantage (RND). These results reveal that RND is positively associated with the likelihood of spending the entire day at home and also that temperature has disproportionate returns in more disadvantaged neighborhoods. Model 4 turns back to racial composition and includes both day-area fixed effects and census block group fixed effects. The results align with the Model 2 results, but the coefficients are substantially larger. For example, these results indicate that a 100 % Black neighborhood experiences an additional eight percentage points decline in the percentage of people spending all day at home with a 50-degree increase in the temperature relative to a 100 % White

[1] Other refers to any racial group other than Black or White.

[2] Imputed from census tract statistics.

Table 2
Linear Probability Models Predicting the Fraction of Residents Spending the Entire Day at Home across the United States in 2019.

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Intercept		0.3004 ***	0.3304 ***			
		(0.0000)	(0.0000)			
Temp.		−0.0017 ***	−0.0018 ***			
		(0.0000)	(0.0000)			
Prop. Black	0.1333 ***	0.1103 ***				
	(0.0003)	(0.0001)				
Prop. Hispanic	0.1334 ***	0.1240 ***				
	(0.0003)	(0.0001)				
Prop. Other	0.0434 ***	0.0131 ***				
	(0.0003)	(0.0002)				
RND			0.0404 ***			
			(0.0000)			
Temp. X Prop. Black		−0.0008 ***		−0.0016 ***		−0.0008 ***
		(0.0000)		(0.0000)		(0.0000)
Temp. X Prop. Hispanic		−0.0019 ***		−0.0018 ***		−0.0008 ***
		(0.0000)		(0.0000)		(0.0000)
Temp. X Prop. Other		−0.0004 ***		−0.0006 ***		−0.0004 ***
		(0.0000)		(0.0000)		(0.0000)
Temp. X RND			−0.0004 ***		−0.0005 ***	−0.0004 ***
			(0.0000)		(0.0000)	(0.0000)
Day-Area Fixed Effects	X			X	X	X
CBG Fixed Effects				X	X	X
N	75,851,034	75,851,034	75,851,034	75,851,034	75,851,034	75,851,034
AIC	−162433069.1405	−140244804.9686	−141742027.2294	−194267696.7310	−194313128.4150	−194343544.2935
BIC	−153136981.7493	−140244675.8143	−141741962.6522	−181517104.3325	−181562568.3051	−181592935.7507
Adj. R2	0.3389	0.1075	0.1250	0.5667	0.5670	0.5671

*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$.

neighborhood.

Model 5 is similar to Model 4 but looks at residential disadvantage, not racial composition. These results reveal a similar finding to Model 3, but with a slightly larger coefficient. They indicate that a one standard deviation increase in residential disadvantage is associated with an additional 2.5 percentage points decline in residents spending the entire day at home per 50-degree increase in temperature. Finally, Model 6 represents the aforementioned preferred models. The results of this model mostly align with the results of Models 4 and 5 but highlight how both racial composition and socioeconomic status have independent heterogeneity in association with the effect of temperature on activity.

Fig. 1 visualizes these findings. Based on Model 4, this figure depicts the predicted difference in disparities between an all-White and an all-Black neighborhood between the warmest and coldest days of the year. The units of analysis are county-level, with the 2019 minimum and maximum temperatures for the county imputed based on the averages of all census block groups in the county. As shown, there is substantial variation in nationwide predicted change. In the upper Midwest, the disparities between an all-White and an all-Black neighborhood in terms of the proportion of residents that spend all day at home grow by nearly ten percentage points from the warmest to the coldest day. In contrast, the change is less than four percentage points in much of Florida and California. This figure would appear nearly the same if examining change in Hispanic-White disparities instead, given the similar coefficients in Model 4. Region-specific models are presented in the supplementary material. While the directions and significance of coefficients are consistent across regions, the magnitude varies slightly, with the effect of neighborhood racial composition and disadvantage weaker in the Western United States.

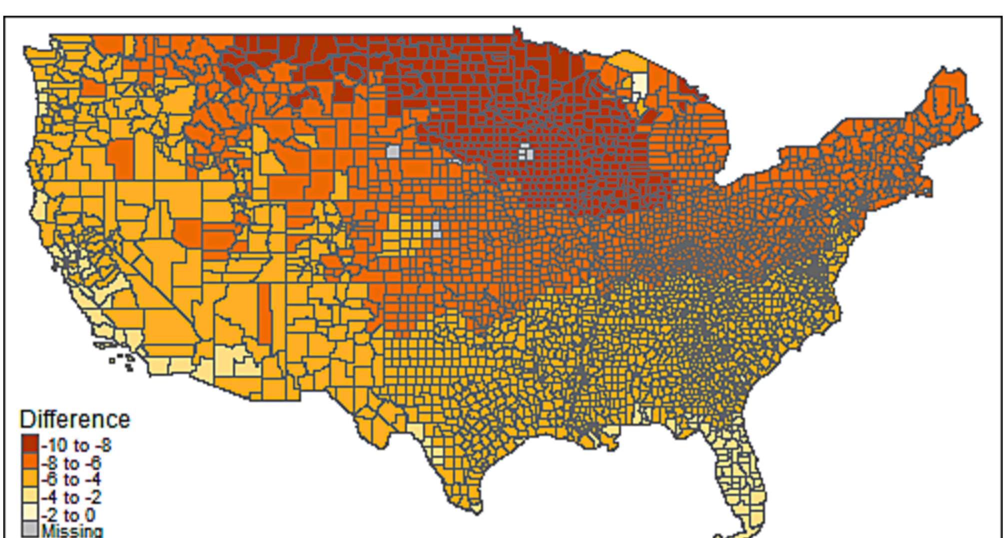

Fig. 1. Expected Change in Black-White Disparity between Coldest and Warmest Day of Year across the United States by County in 2019.

5. Discussion

The study examines the relationship between neighborhood racial composition, temperature, and the percentage of residents who spend the entire day at home. Aligned with past research, I find that residents of poor, non-White neighborhoods are substantially more likely to spend the entire day at home (Tigges et al., 1998). However, I find that this effect is highly reliant on the daily temperature. Moreover, this heterogenous temperature effect can be quite substantial. In some parts of the country, the disparity between an all-Black and all-White neighborhood from the warmest day to the coldest day of the year can be nearly ten percentage points.

This study highlights the persistence of racial and socioeconomic disparities in terms of access to resources and opportunities, as indicated by intense social isolation. In addition, the fact that the effect of neighborhood racial composition on residents staying at home is highly conditional on temperature indicates that temperature is a key factor that must be taken into account when studying social isolation disparities. These findings also suggest that policy interventions designed to address neighborhood disparities must consider the role temperature and season play in shaping neighborhood inequalities. Broadly, this study has considerable implications for public health and well-being, as substantial evidence suggests that those who are socially isolated may also be more vulnerable to the negative health effects associated with staying indoors, such as lack of natural light and inadequate physical activity. Given these past findings, this research would suggest a important pathway through which neighborhoods affect physical and mental health: intensified winter isolation. Ultimately, while past research has documented the greater social isolation poor, non-White Americans face, the effects of that isolation may be worse than past scholarship has hypothesized because of how temporally concentrated it is.

Despite informative findings, interpreting this study's results has several limitations. First, it is entirely unclear what mechanisms explain the observed heterogeneous effects. Additionally, I look at only neighborhood-level associations and cannot account for individual-level factors that may impact isolation, such as employment status or transportation access. Lastly, this analysis was performed on data from before the onset of the pandemic, data which is no longer openly available to academic researchers, so it is unclear if these patterns would still hold today.

In light of these informative results, future research should investigate several related questions. First, future research should take advantage of quasi-experimental, individual-level data or other unique data types to provide a more causally-sound estimate of the impact of neighborhoods on social isolation and examine heterogeneity in who bears the brunt of that effect. Additionally, research should examine the mediating individual-level factors in the association between neighborhood racial composition, temperature, and the percentage of residents who spend the entire day at home, such as employment status and transportation access. More broadly, the neighborhood-level factors in the association, such as access to green space or sense of safety outdoors, should be explored in greater detail. Future research should additionally explore heterogeneity in these results in terms of neighborhood age composition, disability status and region.

Ultimately, this research highlights a key disparity that has substantial health implications. More concerning, as climate change exacerbates extreme weather, this research suggests that these inequalities may only be amplified. Further research must explore these disparities' causes, mechanisms, and health effects. Policies to promote neighborhood equitability in social inclusion and physical activity should also be considered. The findings of this research call attention to the urgent need to address these neighborhood-level disparities, not only to improve public health today, but also to preemptively mitigate the potential exacerbation of these disparities by climate change in the future.

CRediT authorship contribution statement

Karl Vachuska: Conceptualization, Methodology, Data curation, Formal analysis, Investigation, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The author declares that he has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The author does not have permission to share data.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.pmedr.2023.102541.

References

Adeyeye, T.E., Insaf, T.Z., Al-Hamdan, M.Z., Nayak, S.G., Stuart, N., DiRienzo, S., et al., 2019. Estimating policy-relevant health effects of ambient heat exposures using spatially contiguous reanalysis data. Environ. Health 18 (1), 1–13.
Bélanger, M., Gallant, F., Doré, I., O'Loughlin, J.L., Sylvestre, M.P., Abi Nader, P., et al., 2019. Physical activity mediates the relationship between outdoor time and mental health. Prev. Med. Rep. 16, 101006.
Bennett, G.G., McNeill, L.H., Wolin, K.Y., Duncan, D.T., Puleo, E., Emmons, K.M., 2007. Safe to walk? Neighborhood safety and physical activity among public housing residents. PLoS Med. 4 (10), e306.
Berge L, Krantz S, McDermott G. Package 'fixest.' 2021.
Boss, L., Kang, D.H., Branson, S., 2015. Loneliness and cognitive function in the older adult: a systematic review. Int. Psychogeriatr. 27 (4), 541–553.
Burns, A.C., Saxena, R., Vetter, C., Phillips, A.J., Lane, J.M., Cain, S.W., 2021. Time spent in outdoor light is associated with mood, sleep, and circadian rhythm-related outcomes: a cross-sectional and longitudinal study in over 400,000 UK Biobank participants. J. Affect. Disord. 295, 347–352.
Chan, C.B., Ryan, D.A., 2009. Assessing the effects of weather conditions on physical activity participation using objective measures. Int. J. Environ. Res. Public Health 6 (10), 2639–2654.
Clarke, P.J., Yan, T., Keusch, F., Gallagher, N.A., 2015. The impact of weather on mobility and participation in older US adults. Am. J. Public Health 105 (7), 1489–1494.
Cohen, J., Agel, L., Barlow, M., Garfinkel, C.I., White, I., 2021. Linking Arctic variability and change with extreme winter weather in the United States. Science 373 (6559), 1116–1121.
Cradock, A.L., Kawachi, I., Colditz, G.A., Gortmaker, S.L., Buka, S.L., 2009. Neighborhood social cohesion and youth participation in physical activity in Chicago. Soc. Sci. Med. 68 (3), 427–435.
Denissen, J.J., Butalid, L., Penke, L., Van Aken, M.A., 2008. The effects of weather on daily mood: a multilevel approach. Emotion 8 (5), 662.
Forrest, R., Kearns, A., 2001. Social cohesion, social capital and the neighbourhood. Urban Stud. 38 (12), 2125–2143.
Griffin SC, Williams AB, Ravyts SG, Mladen SN, Rybarczyk BD. Loneliness and sleep: A systematic review and meta-analysis. Health psychology open. 2020;7(1): 2055102920913235.
Harada, K., Lee, S., Lee, S., Bae, S., Harada, K., Suzuki, T., et al., 2017. Objectively-measured outdoor time and physical and psychological function among older adults. Geriatr. Gerontol. Int. 17 (10), 1455–1462.
Hartig, T., Catalano, R., Ong, M., 2007. Cold summer weather, constrained restoration, and the use of antidepressants in Sweden. J. Environ. Psychol. 27 (2), 107–116.
Hawelka, B., Sitko, I., Beinat, E., Sobolevsky, S., Kazakopoulos, P., Ratti, C., 2014. Geo-located Twitter as proxy for global mobility patterns. Cartogr. Geogr. Inf. Sci. 41 (3), 260–271.
Hawes, A.M., Smith, G.S., McGinty, E., Bell, C., Bower, K., LaVeist, T.A., et al., 2019. Disentangling race, poverty, and place in disparities in physical activity. Int. J. Environ. Res. Public Health 16 (7), 1193.
Heuser, C., Howe, J., 2018. The relation between social isolation and increasing suicide rates in the elderly. Quality in Ageing and Older Adults.
Holt-Lunstad, J., Smith, T.B., Layton, J.B., 2010. Social relationships and mortality risk: a meta-analytic review. PLoS Med. 7 (7), e1000316.
Kondo, M.C., Jacoby, S.F., South, E.C., 2018. Does spending time outdoors reduce stress? A review of real-time stress response to outdoor environments. Health Place 51, 136–150.
Kvam, S., Kleppe, C.L., Nordhus, I.H., Hovland, A., 2016. Exercise as a treatment for depression: a meta-analysis. J. Affect. Disord. 202, 67–86.

Levy BL, Vachuska K, Subramanian S, Sampson RJ. Neighborhood socioeconomic inequality based on everyday mobility predicts COVID-19 infection in San Francisco, Seattle, and Wisconsin. Science advances. 2022;8(7):eabl3825.
Levy, B.L., Phillips, N.E., Sampson, R.J., 2020. Triple disadvantage: Neighborhood networks of everyday urban mobility and violence in US Cities. Am. Sociol. Rev. 85 (6), 925–956.
Li Z, Ning H, Jing F, Lessani MN. Understanding the bias of mobile location data across spatial scales and over time: a comprehensive analysis of SafeGraph data in the United States. Available at SSRN 4383333. 2023.
Lim, V.K., 1996. Job insecurity and its outcomes: Moderating effects of work-based and nonwork-based social support. Hum. Relat. 49 (2), 171–194.
Luchetti, M., Lee, J.H., Aschwanden, D., Sesker, A., Strickhouser, J.E., Terracciano, A., et al., 2020. The trajectory of loneliness in response to COVID-19. Am. Psychol. 75 (7), 897.
Menne, M.J., Durre, I., Vose, R.S., Gleason, B.E., Houston, T.G., 2012. An overview of the global historical climatology network-daily database. J. Atmos. Oceanic Tech. 29 (7), 897–910.
Molin, J., Mellerup, E., Bolwig, T., Scheike, T., Dam, H., 1996. The influence of climate on development of winter depression. J. Affect. Disord. 37 (2–3), 151–155.
Noi, E., Rudolph, A., Dodge, S., 2022. Assessing COVID-induced changes in spatiotemporal structure of mobility in the United States in 2020: a multi-source analytical framework. Int. J. Geogr. Inf. Sci. 36 (3), 585–616.
Rohan, K.J., Sigmon, S.T., Dorhofer, D.M., 2003. Cognitive-behavioral factors in seasonal affective disorder. J. Consult. Clin. Psychol. 71 (1), 22.
Sampson, R.J., Raudenbush, S.W., Earls, F., 1997. Neighborhoods and violent crime: a multilevel study of collective efficacy. Science 277 (5328), 918–924.
Schaefer, L., Plotnikoff, R.C., Majumdar, S.R., Mollard, R., Woo, M., Sadman, R., et al., 2014. Outdoor time is associated with physical activity, sedentary time, and cardiorespiratory fitness in youth. J. Pediatr. 165 (3), 516–521.
Melrose S. Seasonal affective disorder: an overview of assessment and treatment approaches. Depression research and treatment. 2015;2015.
Tigges, L.M., Browne, I., Green, G.P., 1998. Social isolation of the urban poor: race, class, and neighborhood effects on social resources. Sociol. Q. 39 (1), 53–77.
Wilson WJ. The Truly Disadvantaged: The Inner City. The Underclass, and Public Policy. 1987;8.
Wirz-Justice, A., Graw, P., Kräuchi, K., Sarrafzadeh, A., English, J., Arendt, J., et al., 1996. 'Natural'light treatment of seasonal affective disorder. J. Affect. Disord. 37 (2–3), 109–120.
Wodtke, G.T., Harding, D.J., Elwert, F., 2011. Neighborhood effects in temporal perspective: the impact of long-term exposure to concentrated disadvantage on high school graduation. Am. Sociol. Rev. 76 (5), 713–736.