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The effects of increased temperatures (Heat waves) on Cardiovascular health among adults in Atlanta

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An abstract of
a thesis submitted to the Faculty of the
Rollins School of Public Health of Emory University
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Abstract

The effects of increased temperatures (Heat waves) on Cardiovascular health among adults in Atlanta

By Wandave Tizhe

Background: In the coming years, average temperatures will increase as climate change continues. These temperature changes can have a direct effect on human health, including in people with cardiovascular diseases; numerous studies in the United States have reported a link between high ambient temperatures and increased emergency department (ED) visits due to cardiovascular diseases. In this study, we assessed the association between summer temperature (May and September, 2016-2018) and hypertension using ED data for adults in Atlanta Georgia.

Methods: We examined the association between ambient temperature and daily ED visits for hypertensive diagnoses among adults who visited four of Emory University's hospitals. We also explored the impact of having a history of hypertension. We analyzed the data using a time-stratified case-crossover study design, with conditional logistic regression, at up to three days of lag. The case-crossover study design controls for time trends and individual-level confounders, as each individual serves as their own control. We estimated odds ratios (ORs) and 95% confidence intervals (CI) for maximum temperature changes for each degree celsius. We also investigated potential non-linearity in the temperature-morbidity relationship, by evaluating the association within each temperature quartile.

Results: During the 3 year study period from 2016 – 2018, there were 220,210 adult ED visits. Of these, 33,565 (15.2%) were patients with a previous history of hypertension. The reason for the visit was hypertension in twelve percent of cases. Those who presented with hypertension and had a hypertensive history were 15,159 (6.8%) of total visits. About a quarter of all visits were in the elderly. We observed significant ($p<0.05$) associations between heat and all ED visits at lags 0, 1 and 2 days. We observed no significant associations with visits for hypertensions or in visits where the cases had a history of hypertension. There was no evidence of non-linearity.

Conclusion: We found that that increased temperatures increased the rate of visits to the ED but not for hypertensive visits in particular or visits in patients with a history of hypertension.

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INTRODUCTION

The Earth is warming due to elevated concentrations of greenhouse gases, and will continue to warm in the future (Holli Riebeek et al, 2010). The decadal global land and ocean surface average temperature for 2011–2020 was the warmest decade on record, with a surface temperature of +0.82°C (+1.48°F) above the 20th-century average (NOAA., State of climate 2021). In the USA, like many other places, heatwaves have become more frequent and intense, and cold waves have become less frequent (Kristiane Huber et al, 2017). Annual average U.S temperatures are projected to increase by 2.5°F and 8°F by the end of this century, depending primarily on the level of future emissions of greenhouse gases, under the RCP2.6 and RCP 8.5 scenarios respectively. (John Walsh, et al., 2014). These temperature changes will have direct effects on human health and the environment (Balbus et al).

Climate change has increased the frequency and the intensity of high temperatures, which are currently the leading cause of weather-related deaths in the United States (Greg Fischer et al 2021). For example, one study reported that extreme heat accounted for about 31% of all weather-related deaths from 2006 to 2010 (Balbus, J et al., 2016). Numerous study results in the United States have shown a link between high ambient temperatures and increased mortality, including for cardiovascular diseases (Medina-Ramón, M., & Schwartz, J. 2017). For example, a large study of 43 cities in the United States estimated that the daily mortality rate during heatwave days was 3.7% higher on average than non–heatwave days during 1987–2005 (Anderson GB, Bell ML 2011). A 2017 meta-analysis reported that the risk of cardiovascular mortality, specifically, increased by 1.3% per degree rise in temperature (RR, 1.013; 95% CI [1.011–1.015]) (Moghadamnia MT, et al 2017).

In addition to mortality, exposure to hot outdoor temperatures is also associated with severe morbidities, including emergency department (ED) visits and/or hospital admissions (Harikrishna, H et al 2020). This has been reported for many specific causes, including cardiovascular disease (Harikrishna .H., et al 2020, Astrom DO et al 2011,).Another study showed that heatwaves appeared to be associated with cardiovascular and respiratory morbidities (RE: 0.999, 95%CI: 0.996, 1.002, p-value = 0.61 for cardiovascular morbidity; RE: 1.043, 95%CI: 0.995, 1.093; p-value = 0.08 for respiratory morbidity) (Cheng J et al, 2019). Studies also indicate that the strengths of associations between temperature and ED visits varies by age; the elderly and children have been identified as two particularly susceptible populations (Schifano P, et al 2009, Astrom et al 2011).

Associations between heat and cardiovascular disease are also supported by plausible biological mechanisms. For example, one theory is that high temperatures can increase the occurrence of heart attacks and strokes in susceptible patients because of increased blood viscosity (Baaghideh M, Mayvaneh F, et al 2017). Other proposed mechanisms between heat and cardiovascular outcomes include increased surface blood circulation and sweating, which may lead to increased cardiac workload, dehydration and salt depletion, hemoconcentration, elevated blood viscosity, and the risk of thrombosis (Bouchama, A. and J.P. Knochel, 2012). Moreover, heat stress was suggested to induce the release of interleukins modulating local and systemic acute inflammatory responses (Bouchama, A. and J.P. Knochel, 2012). These inflammatory responses can result in heart failure by increasing damage to heart tissue and inflammation (Wilker EH, et al, 2012).

The elderly population may be at a higher risk for physiological and behavioral reasons, such as existing cardiovascular diseases, impaired kidney function, and living alone with limited social support (Kovats RS, Kristie LE. 2017). Individuals who are confined to bed and unable to care for themselves may be at high risk of death during heat waves, possibly due to their limited access to emergency care (Hajat S, Armstrong, et al, 2006, Knowlton K, et al, 2009). Children may be vulnerable in part because their renal systems are stressed by a series of thermoregulatory adjustments under excessive heat (Xu Z et al 2012) as well as their activity patterns (Vanos JK, 2015).

When put together, these results suggest that more heat-related cardiovascular mortality may be expected in the future with climate change (Chen, B., et al., 2021). This is a particular concern because of the high disease burden from cardiovascular disease worldwide, including in the United States (Ponjoan, A. et al 2017).

To prevent temperature-related morbidity, it is important to protect vulnerable populations. In addition to children and the elderly, another potentially vulnerable population is people with a history of cardiovascular disease. In this study, our objective was to estimate warm-season associations between increased temperatures (heat) and daily ED visits for hypertension in Atlanta, Georgia. Atlanta is located in the southeastern United States, which tends to experience more intense heat and humidity than rest of the United States (Bonan, G.B. 2017). Atlanta has also experienced rates of increase in heatwave frequency and duration that are higher than the national averages from 1961 to 2010 (Habeeb, D., et al, 2015)

This study aimed to answer the following two research questions (1) Does increased temperature prompt ED visits for hypertension in Atlanta?, and (2) does a history of hypertension make people more vulnerable to ambient temperature? To answer these questions, we used a time-stratified case-crossover study design, a statistical technique well suited to examining short-term exposures with the acute outcome.

Our findings can play an important role in supporting local emergency preparedness, performing detailed risk assessment, and protecting public health (Ebi KL, et al 2015, Frumkin H et al 2008). For example, identification of heat metrics most associated with adverse health outcomes may result in more effective local warning systems.

METHODS

As mentioned above, we conducted a case-crossover study on the association between ambient temperature and ED visits for hypertension in Atlanta, GA, USA.

Study area

Atlanta is the capital of Georgia and its most populous city. With an estimated 6 million people in the metropolitan area in 2020, it is also the 37th most populous city in the United States, with 51% black, 38% white, 4% Asian, and other groups comprising 2.3%The median age of 33.5 (Census.gov). The climate of Atlanta and its metropolitan area is humid subtropical according to the Köppen classification, with four seasons including hot, humid summers and cool winters that are occasionally cold by the standards of the southern United States. (climaterealityproject.org) Summers are long and consistently hot and humid.

Health dataset

Data on ED visits comes from the Emory Clinical Data Warehouse dataset from the Emory University School of Medicine Emergency Department, and includes individual-level patient records from four of Emory's hospitals. We collected CDW data on all ED visits for three consecutive summers between 2016 and 2018. We restricted our analysis to the warm season of May 1st to September 30th to focus on the effects of high temperatures. We included any ED visit if the patient was an adult (18 or older) and lived in Atlanta. We looked at all ED visits and those diagnosed with the ICD 10 code for hypertension (I10).

We defined each ED visit as a case; thus, a patient could be in the dataset more than once if the person experienced multiple visits to the ED over the study period. Relevant data elements included the date of the visit, patient age, prior medical history and diagnosis (reason for visit). We were also able to extract data on whether the patient had a self-reported history of hypertension.

Temperature dataset

We obtained daily observations of minimum and maximum temperature during the summer season May to September 2016-2018 from the Atlanta Hartsfield international airport station for the 3-year study period of 2016 through 2018. The daily temperatures were merged with the ED data by date.

Statistical Analysis

We analyzed the data using a time-stratified case-crossover study design, with conditional logistic regression. The approach is a modification of the matched case-control study, where each case serves as his or her own control so that known and unknown time-invariant confounders are inherently adjusted for by design. We compared the temperature on the day of the ED visit (case) with up to four control periods on the same day of the week within the same month and year to control for time trends and day of the week.

In previous studies of apparent temperature and mortality (Kovats RS, Kristie LE, 2016) and hospital visits (Moghadamnia MT, 2017), acute effects of same-day temperature were found to have the best model fit. Thus, our a priori focus for this analysis was the effect of same-day temperature (lag0). We did, however, examine other single-day lags up to three days before the ER visit on lag days 0,1, 2 and 3

Using R studio, conditional logistic regression models were used to obtain estimates of odds ratios (ORs) and 95% confidence intervals (CIs) associated with a 1 degree increase in temperature (^{O}C). In our main analyses we assumed a linear effect, but also explored non-linearity by estimating effects for each temperature quartile.

We had an approved Emory IRB for studying environmental exposures and acute morbidity and we listed the CDW data as the data source for this study.

Results

During the 3 year study period from 2016 – 2018, there were 220,210 adult ED visits. Of these, 33,565 (15.2%) were patients with a previous history of hypertension (Table 1). The cause for the visit was hypertension in twelve percent of the visits. Those who presented with hypertension and had a hypertensive history were 15,159 (6.8%) of total visits. About a quarter of all visits were in the elderly.

Gender-based presentation to the ED were similar, Females had 50.3% with males 49.7% of the total visits for hypertension with 128,817 and 93227 respectively. These levels increase a bit when compared to those who presented with hypertension comorbidity with females having 55% and males 45% (33,011 and 27,658 respectively).

Table 1. Descriptive statistics of emergency department visits (HTN=hypertension).

ED visits	Total number	Total %	% Male
All visits	220210	100%	42%
HTN visits	26,454	12%	49.7%
Visits with HTN history	33,565	15.20%	45.87%
HTN visits with HTN history	15,159	6.80%	49.6%
All Visits > 65 years	53,124	24.12%	42.2%
HTN visits >65 years	13,004	5.90%	46.8%
All visits >65 years	16,816	7.60%	43%

with history			
Visits >65 years with H TN and a history of HTN	7,983	3.60%	46.5%

Over the three-summer study period, the median daily maximum temperature was 31.7^{O}C with an interquartile range of 13^{o}C, a minimum of 13^{O}C and a maximum of 38^{O}C. June was the hottest month and May was the coolest month. A temperature time-series can be found in Figure 1.

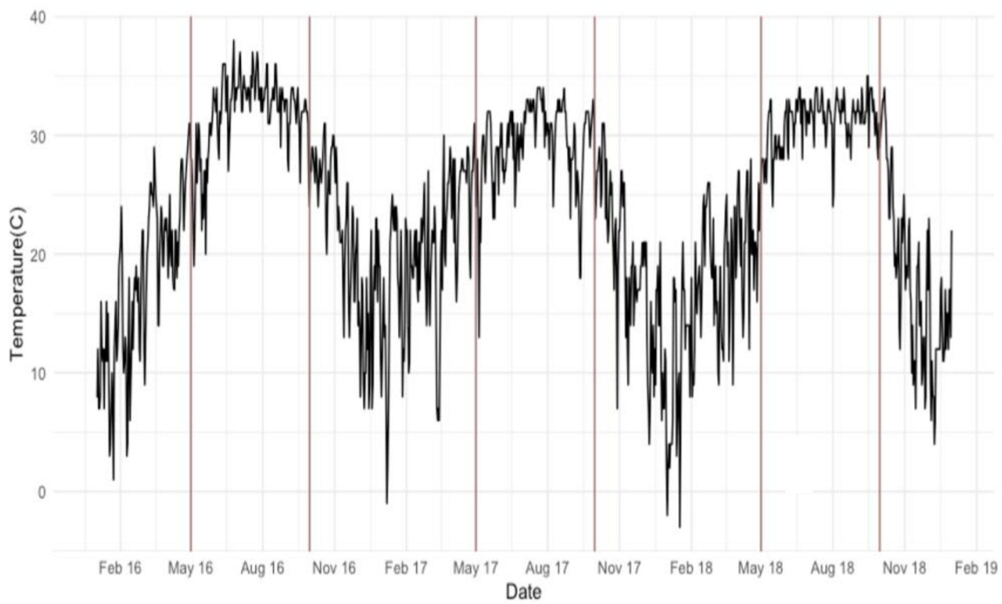

Figure 1. Temperature time series; Study is period between May and September 2016-2018 shown within the highlighted lines

Figure 2. shows the odds ratios for the association between temperature and ED visits for each outcome for each lag. We observed no significant associations except for all visits with lag 0, lag 1, and lag 2."

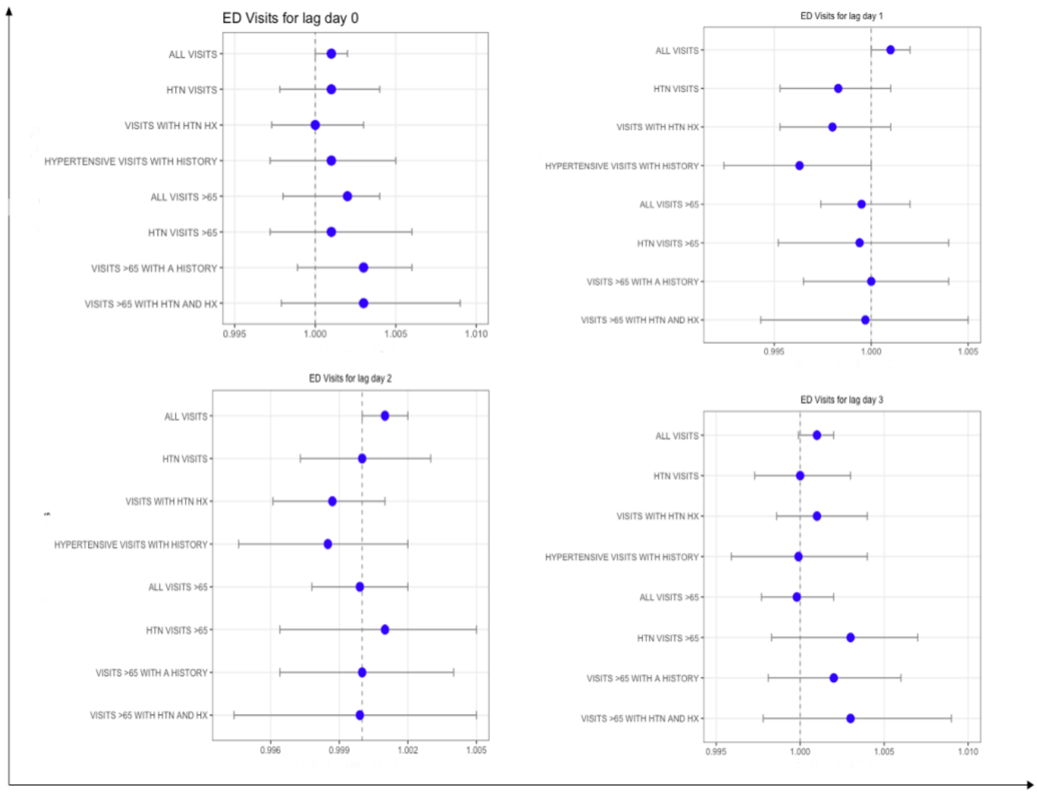

Figure 2. Odds ratios for the association between temperature and ED visits for various outcomes on each lag days

To analyze the potential non-linearity in the temperature-morbidity relationship, we evaluated the association for each temperature quartile (Figure 3). There were no statistically significant associations observed.

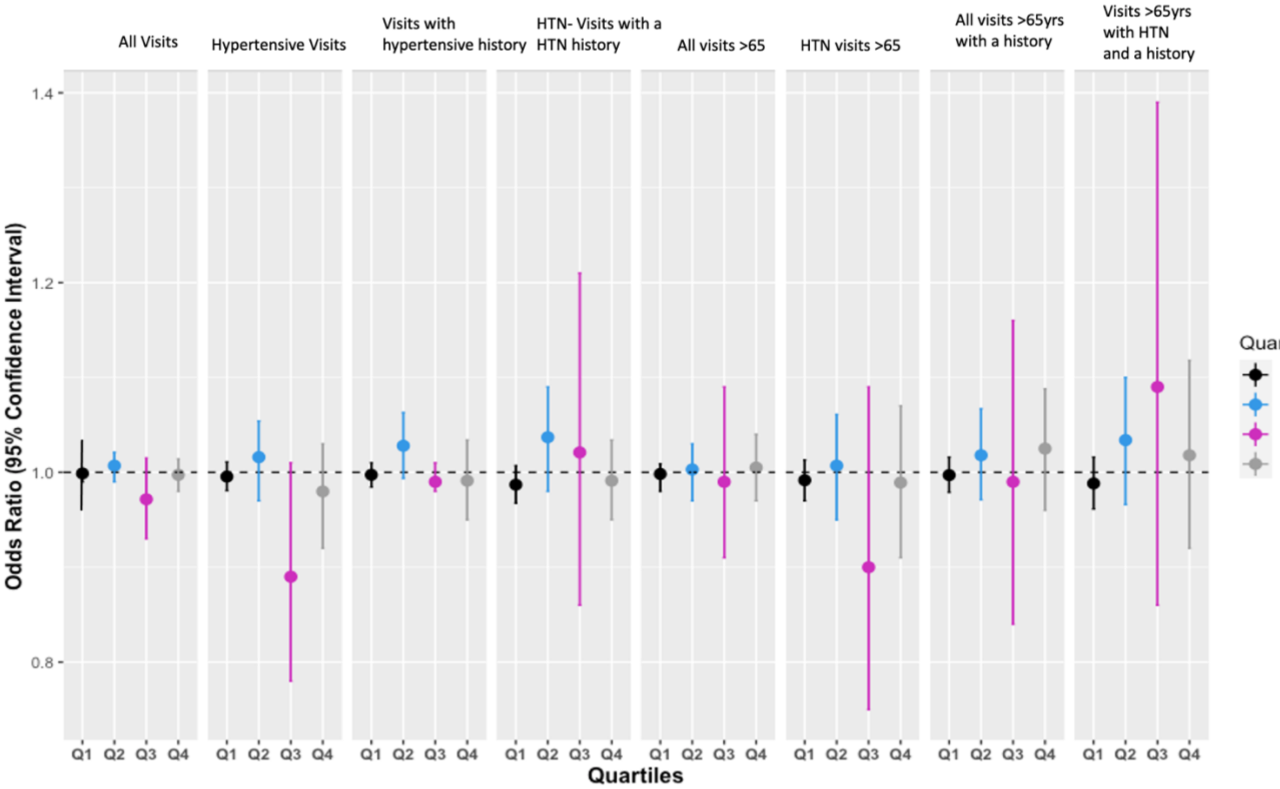

Figure 3. Associations by temperature quartile at lag day 0.

Discussion

We found a statistically significant result for all ED visits and daily ambient temperature in Atlanta during the 2016-2018 warm seasons at lag days 0,1, and 2.We did not find any significant associations with hypertension, history of hypertension, hypertensive visits with a history of hypertension, all visits greater than 65, hypertensive visits greater than 65, hypertensive history among patients greater than 65, and visits withhypertension and history in patients greater than 65 years. This was also true when we explored temperature quartiles.

The finding of a significant association with all-age all-cause ED visits has been reported in a number of other studies (Dong et al, 2016; Mengxuan et al,2019; Basu et al,2012; kenney et al,2014; Zheng S, et al,2016; Mai Li et al,2016; Huang J, et al, 2014). However, it was surprising that we did not find an association with all visits over age 65, which has also been commonly reported (Fuhrmann CM, et al., 2011; Phung, D et al., 2016; Dadbakhsh M et al., 2012). Most other studies have also shown a positive statistically significant relationship between elderly hypertensive visits on hot days especially during the summer (Zheng S et al.,2016; Mai Li et al.,2016; Huang J et al.,2014; Kim YM et al.,2016 Kenny L.P et al.2010)In terms of hypertension specifically, the literature is mixed. (Basu et al., 2012; Kim S.E. et al., 2019; Lin S et al., 2009) found no association or a negative association between temperature and ED visits for hypertension, as did (Winquist A., et al. 2016) in a study in Atlanta using different data from ours. Other studies, however, have observed positive associations (Phung D et al., 2016 McNaughton et al., 2013; Candace D et al. 2012)

When we analyzed the ED visits for patients with a prior history of hypertension we found a non-statistically significant result for this association (OR: 1.00, p-value: 0.97, C.I: 0.99 – 1.003), similar to a study by Basu et al. 2012;(Basu et al on the effects of ambient temperatures on emergency room visits in 2012.) That study did find associations when with other cardiovascular diseases, which, along with our findings, may suggest that observed cardiovascular effects are being driven by diseases other than hypertension.

The lack of an association – or of a possible protective association – may have mechanistic support. As suggested by Winquist, A et al .,2016;   They studied warm season temperatures and emergency department visits in Atlanta. For example, studies have reported an inverse linear relationship between increasing temperature and increased blood pressure (Chen et al., 2013; Chen et al., 2015; Lanzinger et al., 2014; Q. Wang et al., 2017; S. Wang et al., 2017). This may only be true in warmer seasons (Hozawa et al., 2011). However, Madaniyazi et al. found a V-shaped relationship between daily temperature and blood pressure (Madaniyazi et al., 2016).

Our lack of association could also be because we only looked at outdoor temperatures. Many studies have reported statistically significant associations between indoor temperatures and ED visits for cardiovascular events. (Jung CC et al., 2020) compared indoor temperatures on cardiovascular disease related emergency department visits, where they found significant results for increased indoor temperature and hypertensive visits to the ED. This is similar to studies by (Zhao et al., 2019; Saeki K et al., 2014; Kim S et al., 2019; Glen P Kenney et al., 2014; BW Waugh et al.,2021).

Our study area is an urban setting with a generally warm climate and mild winters, with an air conditioning prevalence of over 94% (U.S. Department of Commerce, 2011). This could be responsible for the largely non-significant results we observed, if local populations are adapted to heat. Studies carried out by Arbuthnot et al on the changes in population susceptibility to heat and cold over time showed that the presence of air conditioning and other adaptive measures reduced the burdens of heat among these populations. In 2010 Ostro et al discovered that increased air conditioning could lead to a decreased association between temperature and hospital admissions. Other studies by (Anderson GB et al., 2015; Hatvani-Kovacs G, et al. 2016; Waugh et al., 2021) also reported similar findings.

Studies that compared heat waves and morbidity showed a stastistically significant association between heat waves and cardiovascular events (Winquist et al.,2016; Hajat et al., 2015; Sun et al.,2014)

Several studies have shown some reduced association between increased temperatures and hypertensive visits (Bai L et al.,2016 Ponjoan A et al.,2017; Hu J et al.,2014; Janke et al., 2013) in the southern part of the united states compared to the northern states, (Wang Y et al.,2017; Anderson and Bell., 2009; Saha et al., 2015), for reasons related to the population's ability to adapt to high temperatures from different adaptive measures, either increased compliance with medication, proper control of the disease, planting of trees, Air conditioning use or more cooling centers.

Strength and limitations

This is one of the few studies that evaluated acute exposures of heat and hypertension among adults in Atlanta using Emergency department data. This data provides information on early acute cardiovascular events on presentation. Our case-crossover study design controlled for confounders that may have been present during the study period by using each individual as both cases and controls. Hence age, sex, race, or ethnicity were controlled for. However we did not control for Air pollution and humidity like other studies, this could also have affected the strength of the association between heat and increased temperature. We also didn’t control for holidays, time trends and participation periods which was all done in the (Winquist et al., 2016; Chen T et al., 2017) studies that showed significant associations.

Disease severity could be a possible confounder, studies have shown that most patients with existing cardiovascular diseases don’t present with hypertension but other diagnosis like a stroke, myocardiac infarction and other internal causes (Winquist A et al.,2016; Basu et al.,2012 Zheng S et al.,2016 Mai Li et al., 2016;Chen T et al., 2017).

Because heat as a cause of Hypertension has not been fully explored as the primary cause of elevated blood pressure there could have been some under-reporting of hypertensive visits, or possible it could have been mis diagnosed, as a handful of medical practitioners don’t immediately correlate the association between heat and hypertensive visits. A report, Medical alert; Climate change is harming our health in Wisconsin, by Jonathan pats in October 2020 reported that medical practitioners in the state underreported the effects of heat on chronic diseases including cardiovascular events like hypertension.

Another reason could be because we only had a subset of Atlanta hospitals (Emory University Hospital) which is not a complete representation of all ED hospital visits for cardiovascular events in Atlanta.

Georgia is one of the slowest-warming states in the US over the years Atlanta have developed a green sustainable environment, most green spaces reduce the detrimental effects of increased temperatures on human health. (climaterealityproject.org) This could be another reason why we didn't have a statistically significant relationship in our study.

Most people living in Atlanta have adapted to the weather as their physiology have fully adjusted to the humid hot summers and not show a significant effect on their cardiovascular health. Studies have shown that colder states have shown more heat related ED visits compared to warmer states(Medical alert; Climate change is harming our health in Wisconsin, by Jonathan pats in October 2020; Medina-Ramon et al., 2007; Gasparrini et al, 2015; Curriero et al., 2002; Ponjoan A et al., 2017).Also most people are more likely to be indoors fully air conditioned rather than go out during an extremely hot day We also didn't incorporate out door workers, athletes ,military personnel's and people without air conditioning who are the most vulnerable to outdoor temperatures (EPA). Despite not finding a significant relationship among the older adults for hypertensive visits we didn't look at people on medications that could make them vulnerable to increased temperatures.(Layyton JB et al., 2020) studied the effect of heat adaptation and medication use on heat related hospitalization for chronic diseases.

The Period of the study was relatively short compared to most studies that found statistically significant results between heat and hypertension were over significantly longer periods of time greater than 10-15 years of study. That showed a greater relationship between heat and cardiovascular diseases. (Mengxuan et al.,2019; McNaughton et al.,2013; Candace D et al., 2013; Gronlund CJ et al., 2014).

We also compared hot days to hypertension which is a broad cardiovascular event that many people over the years have learned to control through physical exercise, environmental sustainability and medications.

Conclusion

We observed no significant association between increased temperature and hypertensive visits to the ED, including in patients with a history of hypertension. However, we did find a statistically significant association for all visits to the ED for all causes, which shows that increased temperatures increased the rate of visits to the ED but not for hypertensive visits, Future studies could help establish public health preparedness and interventions to reduce the adverse health effects of high temperatures especially among vulnerable populations all across Atlanta being affected by increasing temperatures. Identifying the mechanism by which this happens can be pivotal in reducing the global burden of cardiovascular diseases in the US which is the leading cause of death in the US.

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Abbreviation

1. CDW- Clinical Data Warehouse
2. C-Celsius
3. CI– Confidence intervals
4. ED- Emergency Department
5. F- Fahrenheit
6. HX- History
7. HTN- hypertension
8. ICD- International Classification of Disease
9. OR- Odds Ratio
10. Q- Quartiles