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Inverse correlation between daily outdoor temperature and blood pressure in six US cities

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This study aims to evaluate the relationship between mean outdoor temperature and mean daily blood pressure (BP) and heart rate (HR) among six, large, geographically and climatically diverse US cities. We collected BP and HR data from Higi stations, located in a wide range of neighborhood grocery stores and retail pharmacies, from six US cities (Houston, Los Angeles, Miami, Boise, Chicago, and New York City). Outdoor daily temperature data were collected from the National Centers for Environmental Information's database. Pearson's correlation was used to assess the linear relationship between mean daily outdoor temperature and mean daily BP and HR for each city from May 2016 through April 2017. A total of 2 140 626 BP and HR readings were recorded in the six study cities. Mean outdoor temperature was inversely correlated with both mean daily average systolic ($r=-0.69$, $P<0.0001$) and diastolic ($r=-0.71$; $P<0.0001$) BPs, but not HR ($r<0.0001$, $P=0.48$). We also found that temperature change had a larger impact on BP in equatorial climates such as Miami compared with colder and more temperature variable cities like Chicago and Boise. Previous studies have found that BP varies seasonally, but few have looked at the impact of daily temperature on both BP and HR changes. Our study is one of the largest and most climatically diverse populations ever looking at this relationship. Our results suggest that temperature, and perhaps geography, should play a role in tailoring individualized evaluation and treatment for hypertensive diseases. *Blood Press Monit* 23:148–152

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Introduction

High blood pressure (BP) is a well established risk factor for cardiovascular and chronic kidney diseases, and its prevalence is increasing globally [1]. Although most of what is known about BP is based on measurements taken in the artificial setting of a doctor's office or equivalent, it is known that multiple factors contribute to substantial variability in BP readings. This variability is clinically important and can not only impact treatment decisions but also clinical outcomes [2]. A more complete understanding of factors that influence variations in BP could have important implications for improving patient management.

Cold weather may impact BP by causing vasoconstriction, whereas warm temperature causes the opposite effect, vasodilation [3]. Previous studies have found a seasonal fluctuation in BP with higher measurements typically found in the winter and lower measurements in the summer [4]. However, few studies have examined the association of short-term fluctuations in temperature with BP [5,6] and HR [6] and none have compared the association in geographically and climatologically diverse locations.

Materials and methods

Higi SH, LLC (*http://www.higi.com*) provides users with free health screening measurements, including BP, HR, weight, and BMI, at food, drug, and club retail locations across the USA. Users also have the option to create a profile and login at the station so they can longitudinally track and visualize their readings through Higi's website or online app. Higi stations are Food and Drug Administration 510k cleared and go through a rigorous quality assurance process. There are currently 11 574 stations that have taken over 122 million BP readings since 2012.

We collected cross-sectional de-identified and aggregated Higi data from six cities with high Higi use in the USA from May 2016 through April 2017. We chose three cities with relatively warm climates (Houston, Los Angeles, and Miami) and three cities with cooler climates (Boise, Chicago, and New York City). The majority (89%) of Higi measurements are taken between time 7 am CST and 9 pm CST. Daily mean outdoor temperature was collected from the National Centers for

Environmental Information and calculated as the average of hourly readings from 9 am to 5 pm [7].

Pearson's correlation was used to evaluate the linear association of daily mean temperature and daily average BP and HR for all cities combined and each city on its own. We also selected several weeks where there were large temperature fluctuations to further show that day-to-day temperature change impacted BP, rather than simply a season of cold versus warm weather.

R version 3.3.3 and Tableau desktop (version 10.1; Tableau Software, Seattle, Washington, USA) were used for analyses and data visualization.

Results

Across all six cities, there were a total of 416 stations that collected 2 140 626 BP and HR readings during the study period, of which ~ 20% also measured BMI. This population of measurements had an average daily age of 53 ± 17.9 years and an average daily BMI of 28.00 ± 5.93 kg/m^2 and was composed of 61% males. The average daily systolic BPs measured 128.29 ± 19.30 mmHg and average daily diastolic BPs measured 79.93 ± 12.06 mmHg. In the study regions the average daily mean temperature varied from − 18 to 34°C.

Our study found inverse correlations between daily average temperature and daily average systolic ($R^2 = 0.48$, $r = -0.69$, $P < 0.0001$) and diastolic ($R^2 = 0.51$, $r = -0.71$; $P < 0.0001$) BPs in the six cities included in our study. The regression equations for BP are: systolic BP = 135.57 − (0.194 × temperature); diastolic BP = 81.56 − (0.095 × temperature) (Fig. 1). This corresponds to 1.9 mmHg increase in systolic BP and a 1.0 mmHg increase in diastolic BP for every 10°C increase in temperature.

To further explore whether the temperature-related changes were related to intravascular status, we evaluated the relationship between external temperature and HR. Unlike BP, we found no overall correlation between daily average temperature and daily average HR ($R^2 < 0.0001$, $r < 0.0001$, $P = 0.48$) (Fig. 1). There were a few days with very limited measurements because of holidays (Miami during Christmas), which resulted in outliers in our results.

When we further examined the association between average daily temperature and average daily BP in each individual city, we generally saw higher associations in the warm and less temperature variable cities compared with the colder and more temperature variable cities. Miami had significantly higher associations between temperature and BP than any other city (Table 1). We also saw larger day-to-day BP flucations in relation to temperature change in Miami than in Chicago (Fig. 2).

Discussion

Multiple studies have assessed how the seasonality of BP is associated with seasonal outdoor temperature changes, with higher BP seen during winter or colder months or weeks [8–10]. In addition, increased rates of cardiovascular diseases and mortality are associated with environmental changes such as temperature [11,12]. It is estimated that for every 20 mmHg increase in systolic BP, individuals 40–69 years old are at a two-fold higher risk for stroke death [13]. However, few have looked at how short-term or day-to-day fluctuations impact BP [4–6] and very few have examined the association with HR averages in a large population [6].

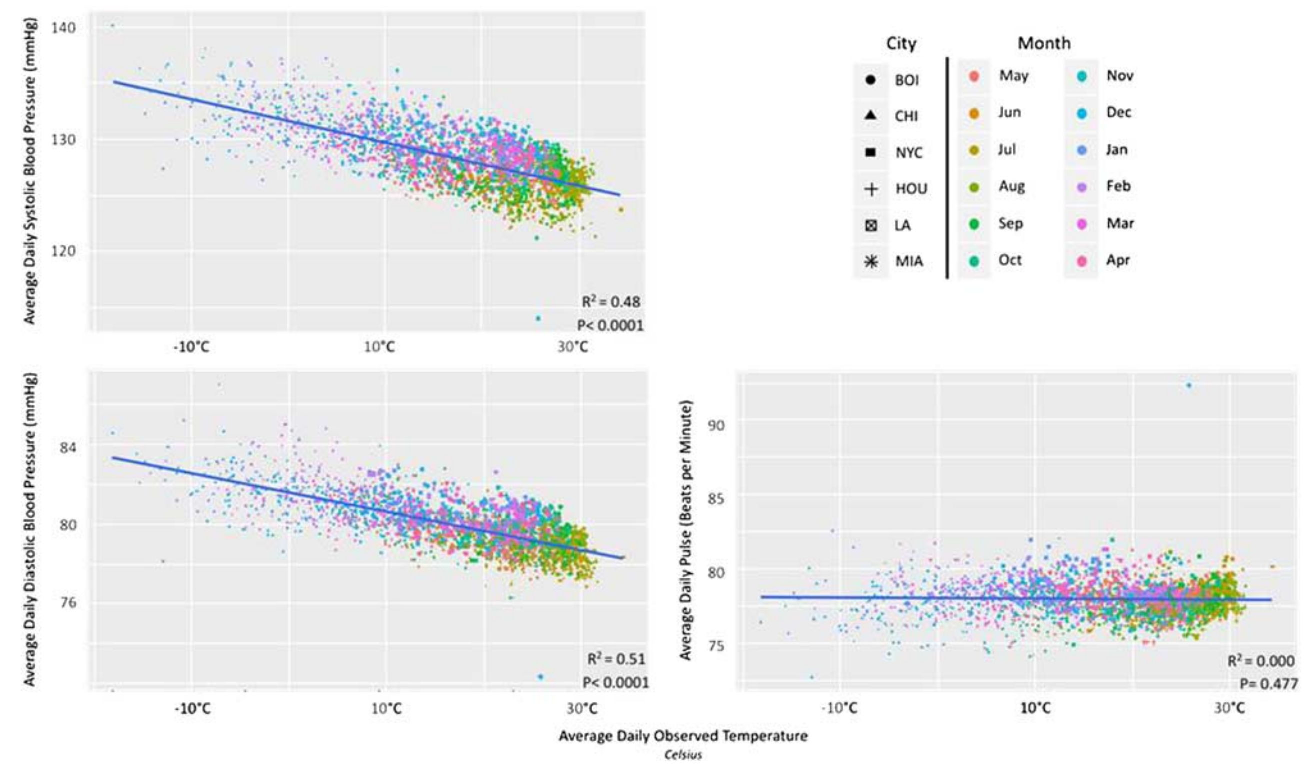
The Kailuan cohort study, which studied 47 000 Chinese participants, found that both HR and BP had a nonlinear relationship with 3-day moving averages of daily mean temperature [6]. Another study, looking at over 100 000 Dutch participants, found a significant nonlinear association between the mean daily temperature and BP [5]. Unlike these previous studies, ours saw a linear relationship with systolic BP and no relationship with HR. We also did not see peaks in HR or BP at the higher temperatures. Our study used daily city population averages instead of 3-day moving averages which may explain some of the differences; however, it is likely that daily averages are correlated with 3-day moving averages.

It is hypothesized that outdoor temperature can impact HR through automatic nervous system responses. The Kailuan cohort study found a nonlinear association between HR and 3-day moving average temperature, with higher HR measurements at very high temperatures and an inverse association between 0 and 20°C [6]. Another small study among 53 women found an association between outdoor temperature and HR variability, but not HR [14]. Like this second study, we did not see any overall association between HR and daily temperature.

One study in China found that most of the association between BP and cold temperatures disappeared when they looked at individuals who had access to central indoor heat [9]. Participants in our study entered a climate controlled environment when they went to measure their BP/HR at the Higi location; however, we still saw an association with BP. It is possible that HR is faster to respond to a more temperate environment compared with BP. Therefore, although HR may be impacted by temperature, it was not captured by the Higi stations.

The overall strength of our linear relationship between temperature and BP was very similar to previous studies [5,12]. However, when we examined the association in each city, we found that Miami had a significantly higher association between BP and temperature than all other cities in our study. Miami also showed a significant positive relationship between average daily temperature and average daily HR, whereas this was not seen in any of the other cities. Miami has a tropical climate and experiences very little temperature variance throughout the year compared with most other parts of the USA (Table 1). Our results coincide with a previous study that found that populations

Fig. 1



Relationship between average daily temperature and average daily systolic and diastolic blood pressure and heart rate in six US cities from May 2016 to April 2017. BOI, Boise; CHI, Chicago; HOU, Houston; LA, Los Angeles; MIA, Miami; NYC, New York City.

Table 1 Association between mean daily temperature (°C) and mean daily blood pressure and heart rate measurements across warm and cold cities, May 2016 through April 2017

	Temperature (mean ± SD)	Temperature range	Systolic blood pressure	Diastolic blood pressure	Heart rate
Warm					
Miami	25.62 ± 3.07	14.35–30.50	−0.41 (−0.45 to −0.36)	−0.18 (−0.11 to −0.09)	0.10 (0.07–0.14)
Houston	22.76 ± 5.82	−0.90 to 31.50	−0.28 (−0.30 to −0.26)	−0.13 (−0.21 to −0.16)	0.01 (−0.01 to 0.03)
Los Angeles	17.62 ± 5.50	5.81–34.34	−0.30 (−0.33 to −0.28)	−0.14 (−0.15 to −0.13)	−0.04 (−0.06 to −0.02)
Cold					
New York City	14.26 ± 9.29	−7.00 to 31.73	−0.29 (−0.30 to −0.28)	−0.13 (−0.14 to −0.13)	−0.02 (−0.03 to −0.01)
Chicago	12.03 ± 10.61	−18.10 to 29.20	−0.23 (−0.24 to −0.21)	−0.10 (−0.11 to −0.09)	−0.00 (−0.01 to 0.01)
Boise	8.61 ± 9.02	−14.70 to 25.20	−0.23 (−0.25 to −0.21)	−0.10 (−0.11 to −0.08)	0.01 (−0.01 to 0.02)

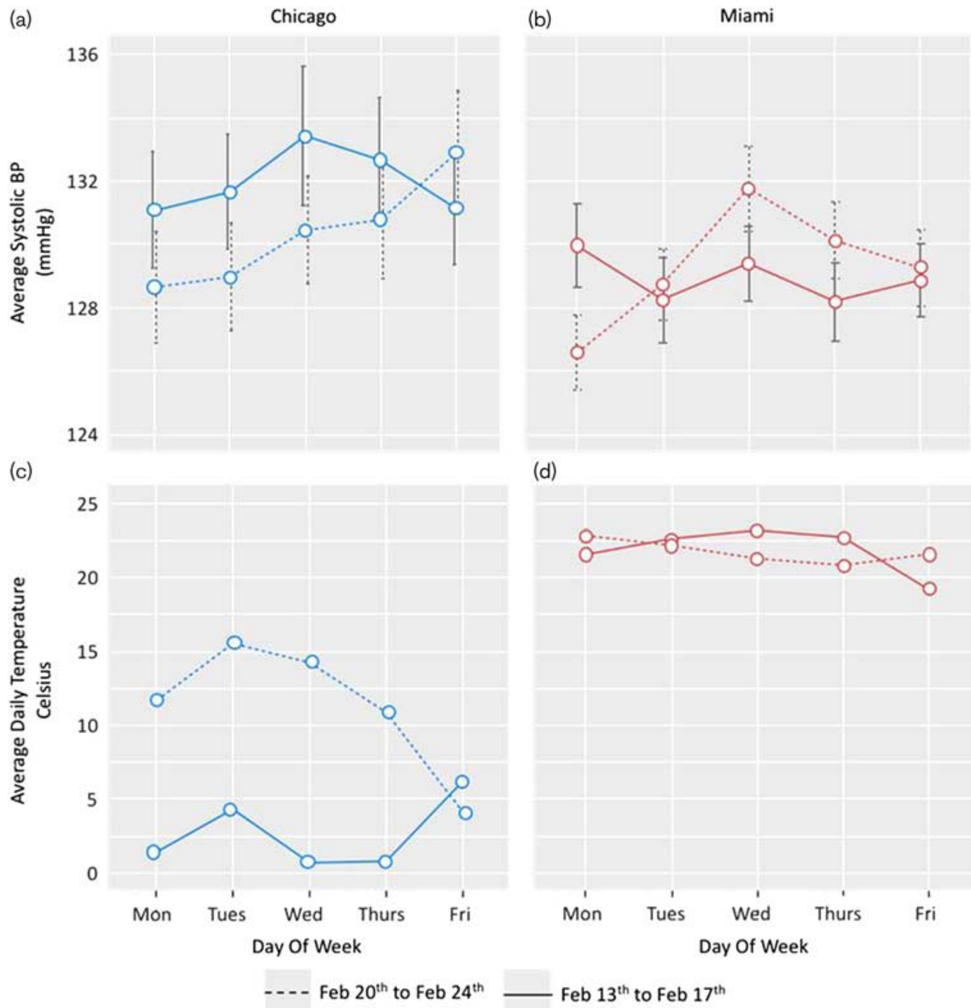
Regression coefficients (95% confidence intervals) per 1°C higher mean daily temperature.

closer to the equator were more sensative to seasonal BP changes [4]. Future prospective studies that control for unique population characteristics and other social determinants of health will be necessary to further evaluate the impact of temperature variance on BP.

One limitation of our study is that we did not have complete data on potential confounding variables such as age and BMI, and did not have any data on comorbidities, and indoor temperature exposure time. However, in the cohort of BP/HR readings that also had BMI, age, and sex (~20%), a multivariate liner regression showed that temperature remained a significant cofactor. People who routinely monitor their BP and weight are likely to have a health reason that motivates them to measure them, and our population was on an average 53 years old, overweight, and had prehypertensive BP readings. Previous studies have found a stronger cold effect on people with low BMIs and a stronger temperature effect on older age groups [6,8,9,15]. Population differences between our study and previous studies in terms of race, BMI, age, indoor environment exposure (use of air conditioners or heat), and temperature adaptation may explain differences in findings.

Another limitation is that our study only used cross-sectional population averages and did not track individuals repeatedly over time. In addition, temperature may vary a lot in a day; therefore, time of measurement or

Fig. 2



Graph showing day-to-day changes in average systolic blood pressure (BP) (a, b) and average daily temperature (c, d) in Chicago and Miami during weekdays over the course of 2 weeks in February 2017. Weekends consistently had lower blood pressure averages and were therefore excluded from this figure.

temperature variability during the day in different cities may bias our results.

Despite these limitations, our study included the largest sample size ever used to evaluate the relationship between daily mean temperature and BP and HR at a population level. Future studies that tract individuals prospectively will enable us to better evaluate the impact of temperature on physiological changes. Prospective studies like this will be increasingly possible with greater access to retail vital monitoring stations. In the future, more frequent measurements will be possible with the development and availability of new digital devices such as home or digitally connected BP monitors or even continuous BP watches.

Improving our understanding of how temperature impacts vitals may play an important role in preventing and controlling hypertensive diseases. It may even help predict the onset of other BP-related diseases, such as pre-eclampsia, which is seen more frequently in colder, winter months [16]. Our study indicates that ~50% of the variation in a population's BP is influenced by daily mean temperature, with the largest impact of temperature seen in the equitorial climate of Miami. Healthcare providers should evaluate BP and HR in terms of environmental conditions or geography and perhaps modify medication dose accordingly. In climates with larger day-to-day fluctuations in temperature, this may even involve individualizing daily medication doses accordingly.

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Conflicts of interest

The authors Neems, Goglia, and Siddiqui work for Higi SH LLC. For the remaining authors there are no conflicts of interest.

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