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Examining Circumstances Surrounding Fatal Pediatric Heatstroke in the United States

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***Abstract:** Fatal Pediatric Vehicular Heatstroke (PVH) is a preventable tragedy that claims the lives of an average of 38 children each year. The purpose of this article is to explore the relationship between fatal Pediatric Vehicular Heatstroke incidents and various circumstantial factors. Data was collected through customized online searches of electronic media using tools such as Google News and Lexis-Nexus. A set of linear regression analyses were conducted to examine the relationship between fatal PVH and three circumstantial variables: geographic region, time of day, and outside temperature. The finding show that specific U.S. Regions, Time of Day, and Outside Temperature significantly predicted fatal Pediatric Vehicular Heatstroke (PVH). Understanding these relationships can aid in the development of more targeted prevention technologies, legislation, and public education efforts aimed at reducing the risk of fatal PVH within the United States.*

***Keywords:** Pediatric Vehicular Heatstroke, Heatstroke, Non-Traffic-Related, Time of Day, Region, Outside Temperature.*

I. INTRODUCTION

Each year, an average of 38 children die in the United States from Pediatric Vehicular Heatstroke (PVH) after being left in parked vehicles (Null, 2022, [18]). In 2018, the number of fatal PVH cases reached a record high of 51. Pediatric Vehicular Heatstroke refers to the unintended death of a child under 18 due to exposure to extreme heat while inside an enclosed vehicle. Pediatric Heatstroke occurs when a child's internal body temperature reaches approximately 104°F, at which point major organs begin to shut down, leading to death (Alowirdi et al., 2020, [1]). A study funded by the National Highway Traffic Safety Administration reported that between 1998 and July 2022, 919 children in the U.S. died due to PVH. Alarmingly, 100% of these deaths were preventable. Of the 919 fatalities, 486 occurred because a caregiver forgot the child in the car. In fact, 53% of these deaths were a result of this tragic oversight (Null, 2019, [17]). Early recognition of heatstroke symptoms and rapid intervention with cooling and hydration are essential to prevent fatalities. A notable study by Anara Guard and Susan Gallagher (2005, [8]) explored heat-related deaths of young children in vehicles.

Their research, which focused on children aged five years or younger from January 1995 to December 2002, documented 171 cases of fatal pediatric vehicular heatstroke. Of these, 76% involved children unintentionally left in the car by an adult (Guard & Gallagher, 2005, [8]). Despite over two decades passing since their research, PVH remains a persistent issue in the U.S., with an average of 38 deaths per year continuing to occur (Null, 2022, [19]). Our study expands on Guard's work, focusing on factors contributing to PVH fatalities involving children aged 18 or younger between January 1998 and July 2022. While public safety campaigns, legislation, and engineering advancements have successfully reduced pediatric automobile crash deaths (Zonfrillo et al., 2018, [23]), the rate of fatal PVH incidents has remained unchanged. Between 1998 and 2022, all U.S. states, except Alaska, New Hampshire, and Vermont, experienced at least one pediatric vehicular heatstroke death [24] [25]. This study seeks to address key research questions, analyzing variables such as geographic location, time of day, and outdoor temperature in relation to PVH fatalities. The findings will provide insights into the circumstances surrounding these incidents and contribute to efforts to develop prevention technologies, improve legislation, and raise public awareness. This article addresses key research questions focused on the variables surrounding fatal Pediatric Vehicular Heatstroke (PVH) incidents, including geographic and circumstantial factors. It examines the relationships between the number of fatal PVH incidents and factors such as region, time of day, and outside temperature. By providing recent data on PVH fatalities and the circumstances surrounding these incidents, this study adds to the existing body of knowledge. It also identifies potential relationships between these variables. The insights gained from this data and the associated hypothesized relationships can support the development of more specialized prevention technologies, tailored legislation, and targeted public education campaigns to reduce the risk of fatal pediatric vehicular heatstroke. The article's chronological structure is an introduction, a review of relevant literature, a section on design and methodology, and a discussion and conclusions section.

II. LITERATURE REVIEW

A. Fatal Pediatric Vehicular Heatstroke Studies

Pediatric vehicular heatstroke has been a concern in the United States for decades, with studies examining heat stress in vehicles and related deaths dating back to 1981. Research has identified leaving children unattended in hot vehicles as the leading cause of non-traffic-related child fatalities (Kids and Cars, 2022, [10]).

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A 2018 study by Zonfrillo, Ramsay, Fennell, and Andreasen found that incidents involving children left in hot vehicles accounted for 26% of all non-traffic-related injuries and 21% of all non-traffic-related fatalities among children (Zonfrillo et al., 2018, [23]). Additional research by King et al. (1981, [11]) demonstrated how quickly car temperatures rise, showing that the interior of a car can reach 152.6°F within just 15 minutes, even if the outside temperature is only 96.8°F. In such conditions, infants can lose fluid rapidly through sweat, potentially leading to dehydration of up to 8% of their body weight in four hours. Thermal regulation in children differs significantly from adults, with studies indicating that the core body temperature of infants is typically 0.69°F higher than that of adults (Garcia-Souto & Dabnichki, 2016, [7]). When a child's body temperature reaches 104°F, organ failure can occur, and death may follow at 107°F (National Highway Traffic Safety Administration, 2022, [14]). Research has shown that the rate at which a car's interior heats up is not significantly impacted by the outside temperature (McLaren et al., 2005, [13]). Even leaving a window cracked does little to reduce the rate of temperature rise, as car windows trap heat similarly to greenhouse windows (Loy, 2022, [12]). McLaren et al., (2005, [13]) found that regardless of outside conditions, a vehicle's internal temperature can reach dangerous levels within five minutes of turning off the air conditioning.

B. Public Prevention Education

Studies suggest that increasing public awareness and education could help reduce PVH fatalities. In response to the persistent nature of these deaths, the National Safety Council (NSC), a leading U.S. safety advocacy group, launched a free online course for parents and caregivers. This course educates participants on the dangers of vehicular heatstroke and offers strategies for preventing these tragedies (National Safety Council, 2022, [15]). The National Highway Traffic Safety Administration (NHTSA) has also initiated public education campaigns, including the "Where's Baby? Look Before You Lock" initiative launched in 2022. This $3 million campaign encourages drivers to never leave children unattended in vehicles and to always lock their cars when unoccupied. The campaign's website, www.WheresBaby.com, provides statistics, educational videos, and prevention tools. Notably, over 88% of children who have died from vehicular heatstroke were under the age of three (National Highway Traffic Safety Administration, n.d., [16]).

C. Government Policies and Legislation

Several government policies and laws aim to prevent pediatric deaths related to vehicles, including PVH incidents. For example, the Hot Cars Act of 2019 (H.R. 3593) and its companion bill S. 1601, introduced in the 116th Congress, require all new passenger vehicles weighing less than 10,000 pounds (roughly half the weight of a school bus) to be furnished with child safety alert systems. These systems provide visual and auditory reminders for drivers to check the back seat after turning off the vehicle's engine. Some legislation also suggests requiring systems to detect the presence of any occupant in a vehicle, even if they entered independently (Congress, 2019, [4]). It is important to note that H.R. 3593 – 116th Congress includes a proposal to require systems that can detect the presence of any occupant who enters a vehicle independently, even when the vehicle is unoccupied.

D. Prevention Product Engineering

Efforts to develop products that prevent fatal Pediatric Vehicular Heatstroke (PVH) are currently underway across the United States. These innovations, known as Rear Seat Reminder Technologies (RSRT), come in four types: 1) pressure-based systems, 2) child-restraint-based systems, 3) vehicle-based systems, and 4) sensor-based systems. However, an evaluation by the National Highway Traffic Safety Administration (NHTSA) found that aftermarket RSRTs were unreliable and challenging for consumers to install (Arbogast et al., 2012, [2]). Additionally, many of these technologies faced synchronization and connectivity issues, hampered their effectiveness (Rudd et al., 2015, [22]). As a result of NHTSA's findings, several companies withdrew their products from the market to focus on conducting more in-depth research (Glenn et al., 2019, [9]).

III. RESEARCH DESIGN AND METHODS

This study uses a set of linear regression models to examine the relationship between fatal pediatric vehicular heatstroke in the U.S. from January 1998 to July 2022 and three factors: the U.S. geographical region, outside temperature, and time of day. Linear regression helps explain how an independent variable (e.g., region) influences a dependent variable (fatal PVH). The study includes three models, each focusing on one of the independent variables.

Model 1 uses Fatal PVH as the dependent variable and Region as the independent variable. The independent variable Region represents one of five geographical locations in which the PVH death occurred. This study follows the common United States grouping of five regions according to their geographic position on the continent: Northeast, Southwest, West, Southeast, and Midwest.

Model 2 uses Fatal PVH as the dependent variable and time of day as the independent variable. The independent variable, Time-of-day, represents a specific chronological part of a 24-hour day in which the PVH death occurred. The research follows the time intervals outlined as follows: a) Morning: 5 am – 12 pm, b) Afternoon: 12:01 pm – 5 pm, c) Evening: 5:01 pm – 9 pm, and d) Night: 9:01 pm – 4:59 am.

Model 3 used Fatal PVH as the independent variable and Outside Temperature as the independent variable. Outside temperature represents the temperature outside of the vehicle during the time of the incident as a measure of Fahrenheit.

A. Data Sources

i. Dependent Variable

Data for the dependent variable, fatal PVH, was collected through customized online news searches using platforms like Google News and Lexis-Nexus. This data was then transcribed and analyzed. Fatal PVH refers to the death of a child under the age of 14 due to hyperthermia while inside a vehicle.

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The data spans from January 1998 to June 2022, with fatal PVH values ranging from 1 to 19, representing the number of PVH deaths associated with specific variables in each model.

ii. Independent Variables

Data for the independent variables, region, outside temperature, and time of day, was gathered through customized online news searches using tools like Google News and Lexis-Nexus. This data was then transcribed and analyzed. The independent variable region refers to the location of the PVH death, with the United States divided into five regions: Northeast, Southwest, West, Southeast, and Midwest. PVH deaths were categorized based on their occurrence in one of these regions. The independent variable outside temperature represents the local environmental temperature, measured in Fahrenheit, with values ranging from 13°F to 115°F. The independent variable, time of day, refers to the specific timeframe within 24 hours when the PVH death occurred, divided into four timeframes: a) morning, b) afternoon, c) evening, and d) night.

B. Assumptions

i. Normality

The assumption of normality was assessed by plotting the quantiles of the model residuals against the quantiles of a Chi-square distribution, also called a Q-Q scatterplot (DeCarlo, 1997, [5]). For the assumption of normality to be met, the quantiles of the residuals must not strongly deviate from the theoretical quantiles. Strong deviations could indicate that the parameter estimates are unreliable. Figure 1, Figure 2, and Figure 3 present a Q-Q scatterplot of each model's residuals.

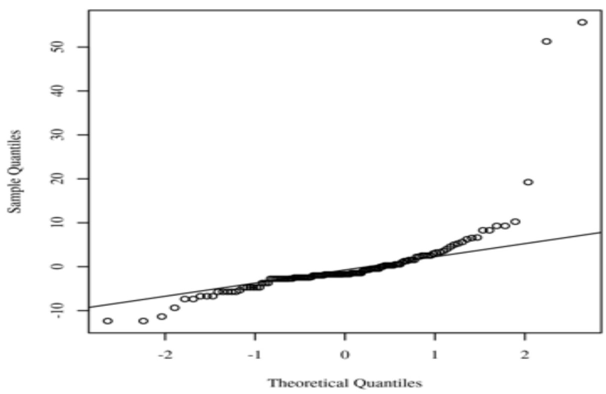

Fig. 1: Model 1 Residuals

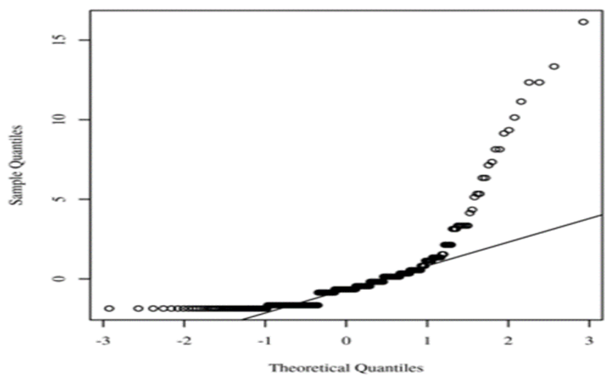

Fig. 2: Model 2 Residuals

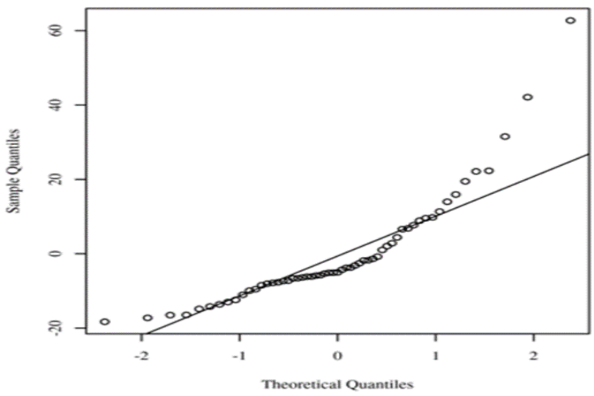

Fig. 3: Model 3 Residuals

ii. Homoscedasticity

Homoscedasticity was evaluated by plotting the residuals against the predicted values (Bates et al., 2014, [3]; Field, 2017, [6]; Osborne & Walters, 2002, [20]). The assumption of homoscedasticity is met if the points appear randomly distributed with a mean of zero and no apparent curvature. Figure 4, Figure 5, and Figure 6 present a scatterplot of predicted values and model residuals for each Model, respectively.

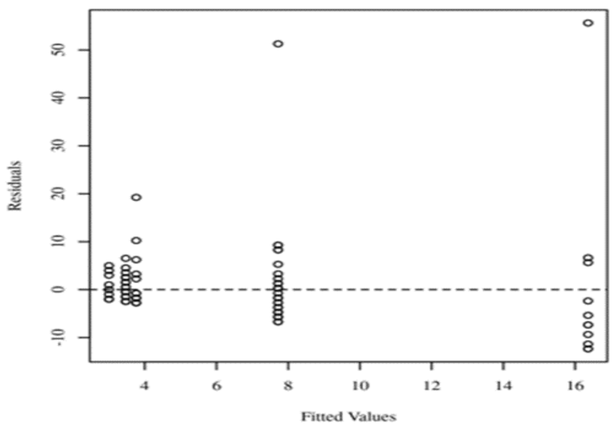

Fig. 4: Model 1 Predicted Values and Residuals

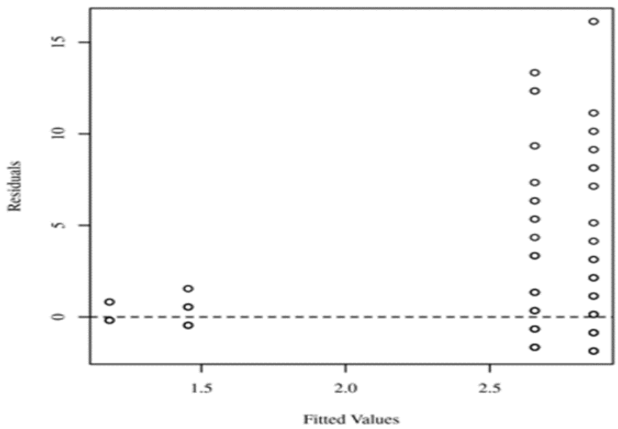

Fig. 5: Model 2 Predicted Values and Residuals

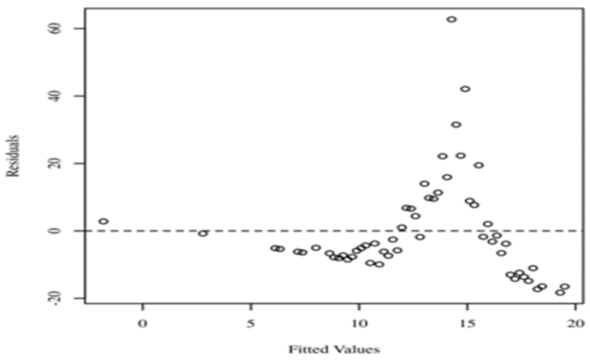

Fig. 6: Model 3 Predicted Values and Residuals

iii.Multicollinearity

Since there was only one predictor variable, multicollinearity does not apply, and Variance Inflation Factors were not calculated.

iv.Outliers

To identify influential points, Studentized residuals were calculated, and the absolute values were plotted against the observation numbers (Field, 2017, [6]; Pituch & Stevens, 2015, [21]). Studentized residuals are calculated by dividing the model residuals by the estimated residual standard deviation. In Model 1, an observation with a Studentized residual greater than 3.16 in absolute value, the 0.999 quantile of a t distribution with 119 degrees of freedom, was considered to have a significant influence on the results of the model. Figure 7 presents the Studentized residuals plot of the observations in Model 1. These observation numbers are specified next to each point with a Studentized residual greater than 3.16.

In Model 2, an observation with a Studentized residual greater than 3.12 in absolute value, the 0.999 quantile of a t distribution with 290 degrees of freedom, was considered to have a significant influence on the results of the model. Figure 8 presents the Studentized residuals plot of the observations in Model 2. These observation numbers are specified next to each point with a Studentized residual greater than 3.12.

In model 3, an observation with a Studentized residual greater than 3.24 in absolute value, the 0.999 quantile of a t distribution with 56 degrees of freedom, was considered to have a significant influence on the results of the model. Figure 9 presents the Studentized residuals plot of the observations in Model 3. These observation numbers are specified next to each point with a Studentized residual greater than 3.24.

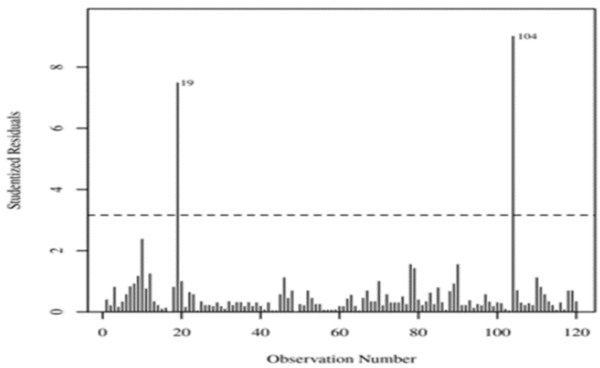

Fig. 7: Model 1 Studentized Residuals

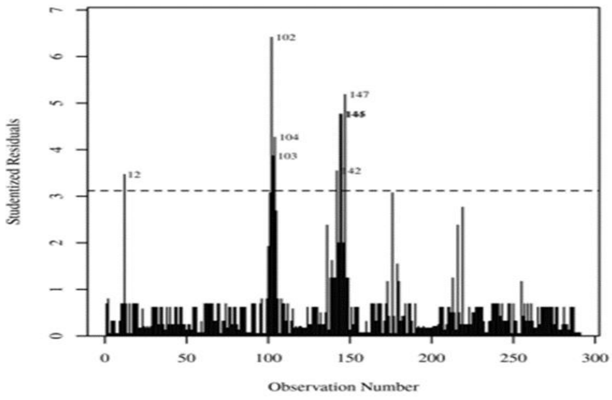

Fig. 8: Model 2 Studentized Residuals

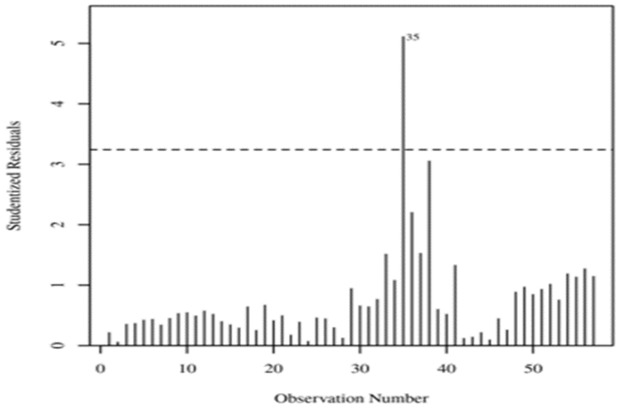

Fig. 9: Model 3 Studentized Residuals

IV. RESULTS

E. Model 1

The results of the linear regression model were significant, F(4,115) = 6.12, p < .001, R2 = .18, indicating that approximately 17.55% of the variance in Fatal PVH is explainable by Region. The Southwest category of Region significantly predicted Fatal PVH, B = 8.65, t(115) = 3.00, p = .003. Based on this sample, this suggests that moving from the Southeast to Southwest category of Region will increase the mean value of Fatal PVH by 8.65 units on average. The West category of Region did not significantly predict Fatal PVH, B = -3.96, t(115) = -1.83, p = .070. Based on this sample, this suggests that moving from the Southeast to West category of Region does not have a significant effect on the mean of Fatal PVH. The Northeast category of Region did not significantly predict Fatal PVH, B = -4.72, t(115) = -1.75, p = .084. Based on this sample, this suggests that moving from the Southeast to Northeast category of Region does not have a significant effect on the mean of Fatal PVH. The Midwest category of Region significantly predicted Fatal PVH, B = -4.25, t(115) = -2.11, p = .037. Based on this sample, this suggests that moving from the Southeast to Midwest category of Region will decrease the mean value of Fatal PVH by 4.25 units on average. Table 1 summarizes the results of the regression model.

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Table 1. Model 1

Variable	*B*	*SE*	95.00% CI	β	*t*	*p*
(Intercept)	7.72	1.35	[5.04, 10.40]	0.00	5.71	< .001
RegionSouthwest	8.65	2.88	[2.94, 14.35]	0.35	3.00	.003
RegionWest	-3.96	2.16	[-8.24, 0.33]	-0.16	-1.83	.070
RegionNortheast	-4.72	2.70	[-10.07, 0.64]	-0.19	-1.75	.084
RegionMidwest	-4.25	2.01	[-8.24, -0.26]	-0.17	-2.11	.037

Note. Results: $F(4,115) = 6.12$, $p < .001$, $R^2 = .18$
Unstandardized Regression Equation: Fatal_PVH = 7.72 + 8.65*RegionSouthwest - 3.96*RegionWest - 4.72*RegionNortheast - 4.25*RegionMidwest

F. Model 2

The results of the linear regression model were significant, F(3,16) = 4.78, p = .015, R2 = .47, indicating that approximately 47.26% of the variance in Fatal PVH is explainable by Time-of-day. The Evening category of Time-of-day, significantly predicted Fatal PVH, B = -55.60, t(16) = -2.59, p = .020. Based on this sample, this suggests that moving from the Afternoon to Evening category of Time-of-day, will decrease the mean value of Fatal PVH by 55.60 units on average. The Morning category of Time-of-day, did not significantly predict Fatal PVH, B = -0.40, t(16) = -0.02, p = .985. Based on this sample, this suggests that moving from the Afternoon to Morning category of Time-of-day, does not have a significant effect on the mean of Fatal PVH. The Night category of Time-of-day, significantly predicted Fatal PVH, B = -59.80, t(16) = -2.78, p = .013. Based on this sample, this suggests that moving from the Afternoon to Night category of Time-of-day, will decrease the mean value of Fatal PVH by 59.80 units on average. Table 2 summarizes the results of the regression model.

Table 2. Model 2

Variable	B	SE	95.00% CI	β	t	p
(Intercept)	2.86	0.25	[2.36, 3.36]	0.00	11.31	< .001
Time_of_DayEvening	-1.41	0.53	[-2.46, -0.35]	-0.21	-2.63	.009
Time_of_DayMorning	-0.20	0.35	[-0.90, 0.49]	-0.03	-0.58	.562
Time_of_DayNight	-1.68	0.63	[-2.91, -0.44]	-0.25	-2.67	.008

Note. Results: F(3,287) = 4.21, p = .006, R2 = .04
Unstandardized Regression Equation: Fatal_PVH = 2.86 - 1.41*Time_of_DayEvening - 0.20*Time_of_DayMorning - 1.68*Time_of_DayNight

G. Model 3

The results of the linear regression model were significant, F(1,55) = 4.47, p = .039, R2 = .08, indicating that approximately 7.51% of the variance in Fatal PVH is explainable by Outside Temperature. Outside Temperature significantly predicted Fatal PVH, B = 0.21, t(55) = 2.11, p = .039. This indicates that on average, a one-unit increase in Outside Temperature will increase the value of Fatal PVH by 0.21 units. Table 1 summarizes the results of the regression model.

Table 3. Model 3

Variable	B	SE	95.00% CI	β	t	p
(Intercept)	-4.53	8.40	[-21.37, 12.30]	0.00	-0.54	.592
Outside_Temperature	0.21	0.10	[0.01, 0.41]	0.27	2.11	.039

Note. Results: F(1,55) = 4.47, p = .039, R2 = .08
Unstandardized Regression Equation: Fatal_PVH = -4.53 + 0.21*Outside_Temperature

V. CONCLUSION AND DISCUSSION

This study employed a series of linear regression analyses to determine whether specific demographic factors significantly predicted fatal Pediatric Vehicular Heatstroke (PVH). The objective was to investigate the impact of geographical region, time of day, and outside temperature on fatal PVH cases. The results of Model 1 showed significance, with the Southwest and Midwest regions accounting for 18% of the variance. Model 2 also yielded significant results, with the evening and nighttime periods explaining 47.26% of the variance. In Model 3, outside temperature significantly explains 7.51% of the variance. Consequently, the null hypothesis for these variables is rejected. However, examining other independent variables found that the West Region, Northeast Region, and morning time did not significantly influence fatal PVH, leading to the acceptance of the null hypothesis for these factors. Although research shows a relationship between PVH and factors such as geographic region, time of day, and outside temperature, further research is required to better understand these relationships and identify potential correlations between the variables. This study offers valuable insights for public health and safety organizations and policymakers in shaping public education campaigns and legislation to prevent fatal pediatric vehicular heatstroke.

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DECLARATION STATEMENT

I must verify the accuracy of the following information as the article's author.

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- **Funding Support:** This article has not been sponsored or funded by any organisation or agency. The independence of this research is a crucial factor in affirming its impartiality, as it has been conducted without any external sway.
- **Ethical Approval and Consent to Participate:** The data provided in this article is exempt from the requirement for ethical approval or participant consent.
- **Data Access Statement and Material Availability:** The adequate resources of this article are publicly accessible.
- **Authors Contributions:** The authorship of this article is contributed solely.

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