


Original Research

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Tropical Storms and Hurricanes in New Orleans Lead to Increased Rates of Violent Injury

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Abstract

Objective: The effects of named weather storms on the rates of penetrating trauma is poorly understood with only case reports of single events currently guiding public health policy. This study examines whether tropical storms and hurricanes contribute to trauma services and volume.

Methods: This was a cross-sectional review of tropical storms/hurricanes affecting New Orleans, Louisiana, during hurricane seasons (June 1–November 30) from 2010–2021, and their association with the rate of penetrating trauma. Authors sought to determine how penetrating trauma rates changed during hurricane seasons and associate them with demographic variables.

Results: There were 5531 penetrating injuries, with 412 (7.4%) occurring during landfall and 554 (10.0%) in the aftermath. Black/African Americans were the most affected. There was an increase in the rate of penetrating events during landfall (3.4 events/day) and aftermath (3.5 events/day) compared to the baseline (2.8 events/day) ($P < 0.001$). Using multivariate analysis, wind speed was positively related to firearm injury, whereas the rainfall total was inversely related to firearm violence rates during landfall and aftermath periods. Self-harm was positively related to distance from the trauma center.

Conclusions: Cities at risk for named weather storms may face increasing gun violence in the landfall and aftermath periods. Black/African Americans are most affected, worsening existing disparities. Self-harm may also increase following these weather events.

A significant amount of research and time has been devoted to determining the economic costs of extreme weather events, with the annual cost of hurricanes in 2021 alone totaling US \$145 billion.¹ However, little is known regarding the effects of extreme weather on trauma services and volume. Prior studies have shown that higher temperatures lead to increased rates of emergency room visits and are associated with increased trauma volume.^{2–5} However, whether tropical storms and hurricanes contribute to trauma volume remains unclear with various studies showing differing results.^{2–5}

Penetrating trauma, which is an injury during which the skin and its underlying tissues are violated by a sharp/piercing object, is rising significantly throughout the United States. Firearms, one example of an object that can cause penetrating trauma, are being used in a greater percentage of homicides and injuries. In 2021, the Centers for Disease Control and Prevention reported that 80% of homicides and 55% of suicides were committed with a firearm.⁶ In addition to individual firearm events, mass shooting events are also significantly on the rise with an exponential increase from 269 reported events in 2014 to 611 in 2020 and to 649 in 2022.⁷ Overall, trauma centers across the nation are experiencing greater rates of penetrating trauma than ever.⁸ There is a host of research looking into ways to curb these tragic events.

Penetrating trauma in the United States disproportionately affects Black/African Americans.⁹ Furthermore, recovery from catastrophic storms also is fraught with differences depending on one's local government and community. How these two public health problems intersect during and after major storms is not fully understood. What is not known is the impact of extreme weather, particularly hurricanes or tropical storms, on violent, penetrating trauma. Previous research demonstrated that the overall rate of gun violence transiently rose after Hurricane Katrina.^{10,11} With a number of climate scientists, including the National Aeronautics and Space Administration, predicting a greater number of Categories 4 and 5 storms, there is a need to understand the impact of these storms on rates of violent penetrating trauma.¹² This study aimed to better elucidate the relationship between named tropical storms and hurricanes and their impact on the incidence of penetrating trauma in a metropolitan city that is under constant threat of major storms. Study authors hypothesized that named hurricanes and tropical

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storms would impact the rates of penetrating trauma, specifically injuries from firearms, knives, and other sharp objects, in New Orleans, Louisiana, during the study period.

Methods

This was a cross-sectional, retrospective, study that reviewed data from all penetrating trauma patients who presented to the only level 1 trauma center in southeastern Louisiana during the Atlantic hurricane season per the National Weather Service (June 1 to November 30) between the years 2010 and 2021.¹ June 1 to November 30 was selected as this is the defined period of a hurricane season per the National Weather Service.¹ As the trauma registry is devoid of identifiers, it was exempt from institutional review board approval. The trauma registry (a database of all trauma admissions) at University Medical Center, the facility at which data were collected, is maintained by the hospital registrar who uses International Classification of Diseases (ICD) codes and search terms to update the trauma presentations and admissions.

Named tropical storms and hurricanes that resulted in rain and/or wind damage in the New Orleans, Louisiana, metropolitan area during this study period were identified through the National Weather Service. Wind speeds and rainfall totals were obtained from the National Weather Service. Landfall was defined as 2 days prior through 7 days after the eye of the storm made landfall. The storm recovery period was defined as the 2-week period following landfall. The remainder of the Atlantic hurricane season between June 1 and November 30 was used as the control.

The primary outcome was the rate of penetrating violence (any trauma activation that resulted in violation of the skin with a firearm or sharp object, such as a knife, spear, and stick) during these time periods. Secondary outcomes included the specific rates of firearm violence, knife violence, and self-harm with a penetrating object. To examine the relationship between firearm violence specifically and the various factors related to tropical storms and hurricanes, linear regression was performed. Using the Shapiro-Wilk test, the normality of residuals was confirmed. The correlation between predictor variables was evaluated. The overall fit of the linear regression model was calculated with an R^2 (coefficient of determination) and the statistical significance was interpreted by using a 2-sided test with a level of $P < 0.05$. In these analyses, firearm violence was treated as a dependent variable. The model covariates considered were distance from the trauma center, wind speed, and rainfall total. Distance as determined by zip code was analyzed. Statistical analysis was completed using R Studio (using programming language R).

Results

There were 5531 penetrating injuries, as identified by their ICD codes, seen at the trauma center (University Medical Center, New Orleans, Louisiana) from June 1 to November 30 during the years from 2010–2021. Thirteen named storms impacting the New Orleans metropolitan area were identified during the study period. There were no mandatory evacuations for the city of New Orleans during any of the named storms that would have impacted population levels significantly. The overwhelming number of patients were male (84.8% control, 88.1% landfall, 84.6% aftermath, $P = 0.23$) and identified as African American/Black (77.4% control, 76.4% landfall, 78.7% aftermath, $P = 0.92$). There was no difference in the average age between any of the groups ($P = 0.99$) (Table 1).

Table 1. Demographics

Time period	Control	Landfall	Aftermath	P value
Age (years)	32.73	32.38	32.48	0.99
Female, %	15.23	16.46	11.92	0.23
Black, %	77.4	76.4	78.7	0.92
Mean ISS	10.8	10.2	11.1	0.44

ISS = injury severity score, ranges 0-75 with more severe injuries represented as higher numbers.

There were 412 injuries (7.4%) that occurred during landfall and 554 (10.0%) occurred in the aftermath period (Table 2). There was an increase in the rate of penetrating trauma events in the landfall (3.4 ± 2.4 events/day) and aftermath groups (3.5 ± 2.4 events/day) compared to other days (2.8 ± 1.8 events/day) during the hurricane season ($P < 0.001$) (see Table 2). There was a significant increase in knife-related incidents in the landfall (0.28 ± 0.53 events/day) and aftermath groups (0.36 ± 0.59 events/day) when compared to the control (0.14 ± 0.39 events/day) group ($P < 0.001$). Frequency of firearm-related injuries increased in the landfall and aftermath groups compared to baseline (2.27 ± 1.92 vs 2.22 ± 1.78 vs 1.62 ± 1.50 incidents/day, $P < 0.001$). Frequency of penetrating self-harm injuries also increased in the aftermath group (0.14 ± 0.38 events/day) compared to baseline (0.07 ± 0.27 events/day; $P = 0.004$) but was not different in the landfall group when comparing to baseline hurricane season (0.09 ± 0.33 events/day; $P = 0.22$).

Firearm Injury

Variables associated with firearm injury during landfall and aftermath periods were examined by linear regression and are detailed in Table 3. Associated factors included wind speed ($\beta = 5.10$, OR 164, 95% CI: 4.18 to 6.02, $P < 0.001$) and rainfall total ($\beta = -4.70$, OR 0.01, 95% CI: -8.92 to -0.48, $P = 0.04$) (see Table 3). The final model had an R^2 of 0.92.

Self-Harm

When examining self-harm using multivariate analysis, increasing distance from storm landfall ($\beta = 0.96$, OR 2.61, 95% CI: -2.55 to -0.35, $P < 0.01$) was significant in predicting penetrating self-harm rates during landfall and aftermath periods (Table 4). Wind speed ($\beta = 0.29$, OR 1.34, 95% CI: -0.15 to 0.73, $P = 0.22$) and rainfall total ($\beta = -0.14$, OR 0.87, 95% CI: -0.01 to 0.01, $P = 0.58$) were not associated with self-harm during landfall and aftermath periods (see Table 4). The final model had an R^2 of 0.62.

Discussion

With extreme weather, including tropical storms and hurricanes, on the rise in intensity and severity throughout a significant portion of the Gulf South, there is a need to understand how tropical storms and hurricanes may impact frequency and presentation of penetrating trauma to hospitals in cities at risk for major storms. In this novel study, investigators sought to examine the impact of tropical storms and hurricanes on the presentation of penetrating trauma to our facility. Study authors found that there was an increase in the rate of penetrating trauma during the landfall and aftermath periods, including self-harm during the aftermath period.

Table 2. Penetrating violence

Time period	Control	Landfall	Aftermath	P value (control vs landfall)	P value (landfall vs aftermath)
Injuries (% of total)	4565 (82.6%)	412 (7.4%)	554 (10.0%)		
Events per day (mean ± SD)	2.8 ± 1.8	3.4 ± 2.4	3.5 ± 2.4	< 0.001	< 0.001
Knife-related events per day (mean ± SD)	0.14 ± 0.39	0.28 ± 0.53	0.36 ± 0.59	< 0.01	< 0.001
Firearm-related events per day (mean ± SD)	1.62 ± 1.5	2.27 ± 1.92	2.22 ± 1.78	< 0.001	< 0.001
Self-harm related incidents per day (mean ± SD)	0.07 ± 0.27	0.09 ± 0.33	0.14 ± 0.38	0.22	< 0.001

Total 5531 penetrating events analyzed.

Table 3. Factors independently associated with firearm injury

Independent factors	Standardized β	OR	95% Confidence interval		P value
			Lower limit	Upper limit	
Wind speed	5.10	164	4.18	6.02	< 0.001
Rainfall total	-4.70	0.01	-8.92	-0.48	0.04

Excluding self-harm. Mean-centered linear regression analysis was applied using best subsets regression. R² = 0.92.

Table 4. Factors independently associated with self-harm

Independent factors	Standardized β	OR	95% Confidence interval		P value
			Lower limit	Upper limit	
Rainfall total	-0.14	0.87	-0.01	0.01	0.58
Distance	0.96	2.61	0.48	1.44	< 0.01
Wind speed	0.29	1.34	-0.15	0.73	0.22

Mean-centered linear regression analysis was applied using best subsets regression. R² = 0.62. Distance as measure from University Medical Center, New Orleans, Louisiana.

Data as presented above show that the overall number of patients presenting to this urban, level 1, academic trauma center in New Orleans, Louisiana, on a daily basis for penetrating trauma increases during both the initial time of landfall and the aftermath periods. This increase held true across both gun and knife-related traumas. Interestingly, data showed that firearm injuries are associated with wind speeds, suggesting that more severe storms are associated with greater gun violence. First, wind speed is a challenging datapoint to accurately estimate as it is dependent on sustained wind speeds. While maximum wind speeds were obtainable through online services such as the National Weather Service from the local airport, they were variable across the city of New Orleans throughout the neighborhoods. Why higher maximum wind speeds lead to increased firearm violence could not be determined from this study but may be related to the more desperate social conditions that exist in a city after being hit by a major storm. Unstable housing, lack of transportation, and food insecurity are common after major storms in New Orleans and likely play a role in firearm violence.^{13,14} This finding is likely multifactorial and needs further investigation.

Furthermore, this study showed that firearm injuries appear to decrease with higher rainfall totals. For example, during Hurricane Ida, the majority of the violence reported in the media were related

to non-penetrating violent looting and carjacking, but the city received over 10 inches of rain, which is significantly more than others, likely driving down the penetrating trauma rates.¹⁵ One potential explanation for this finding is that New Orleans is prone to street flooding with heavy rains, which may limit transportation and mobility in the metropolitan area.¹⁶ This may lead to fewer penetrating injuries in periods of heavy rainfall. These data, along with findings on windspeed, have important staffing implications for trauma centers that may move to essential personnel-only staffing model when preparing for major storms and hurricanes.

Interestingly, rates of self-harm penetrating traumas only increased in the storm aftermath (2 weeks after landfall) period but not during the landfall period. A previous study examining the relationship of Hurricane Katrina that devastated New Orleans showed that while mental illness rates increased (mild, moderate, and severe), suicidal ideation actually decreased, thought to be secondary to a greater strength in community.¹⁷ However, there is evidence in the literature showing that mental health does worsen specifically after times of flooding and climate change, and this may explain the increased injuries by self-harm that were observed in the present study.^{17,18} Linear regression showed that a greater distance away (as measured by zip code) from the hospital was associated with self-harm by penetrating mechanism. While the etiology of this finding could not be determined by this analysis, it is likely that those living in more rural portions of Louisiana were also devastated by these storms and are more at risk for death by suicide. Additionally, there is evidence in the literature that baseline suicide rates are higher in rural areas, particularly among men, who make up the majority of the trauma population.¹⁹ With regard to weather-related mental health effects, Grineski et al. have shown a “post-traumatic stress” effect on mental health after a winter storm in Texas that is exacerbated in persons who are Black/African American (OR 6.6), Hispanic (OR 3.5), or another non-white race (OR 4.2).²⁰ This disparity in mental health is likely further exacerbated during times of extreme stress, such as those of a named storm system.

In much the same way that the US firearm violence epidemic disproportionately afflicts Black/African Americans, Hurricane Katrina (2005) showed us that disparities also exist along racial lines in the country's response to hurricanes. Data from this study further show that black/African Americans are more likely to be patients of trauma during all phases of storms and, specifically, more likely to present to the emergency department as patients with penetrating trauma. This observation will only worsen the existing disparities observed in health care among Black/African American communities. Exposure to extreme heat or cold has been shown to result in worsening outcomes, including overall mortality, respiratory, cardiovascular, mental health, and heat-related diseases.^{21,22} Sharpe et al., in their retrospective study examining years 1999–2018, showed that while non-Hispanic white people were more likely affected by natural hazards or extreme weather, the mortality rate among black/African American people was 1.87 times higher as compared to white populations affected.²² As the majority of those presenting to our trauma center with penetrating injury over this 11-year period were Black/African American, it is clear that existing disparities are worsened during and after named storms. There is a need to address the structural factors that lead to these glaring and discouraging disparities in the trauma population.

Limitations

Notable limitations include that this was a cross-sectional analysis, thus limiting its generalizability. As the electronic medical records system at University Medical Center in New Orleans was initiated in 2010, the study authors were unable to collect and analyze data from years preceding 2010. Furthermore, as a nature of the storms themselves, wind speeds and rainfall totals are not perfect markers and varied even within the city of New Orleans itself. Additionally, the study could not account for changes that COVID-19 may have had on the data set, although study authors suspect that the impacts of COVID-19 on data were minimized due to performance of an 11-year analysis.

Conclusions

In this study of our urban, level 1, academic trauma center, penetrating trauma rates with both firearms and knives increased during the time around a tropical storm/hurricane as well as during the aftermath period. Self-harm penetrating injuries increased in the aftermath period only. Firearm violence during and in the period immediately after named storms disproportionately affects Black/African Americans. Study authors conclude that datapoints to the need for the development of concerted efforts to build resilience and develop injury prevention strategies focused on prehospital and hospital preparedness around the time of tropical storm/hurricane landfall and afterward during recovery periods to minimize the rate of injury and potentially save lives.

Data availability statement. Research data supporting this publication are a combination of publicly available from the National Weather Service, Centers for Disease Control and Prevention, and data from our institution's trauma registry.

Author contribution. MG and ST contributed to conceptualization; MG, CG, and ST assisted with the formal statistical analysis; MG, CG, AC, JF, KT, JC, DT, PM, JD, and ST all assisted with project design, methodology, data curation, and either writing of the original draft or editing of the manuscript.

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Competing interests. The authors declare that they have no affiliations with or involvement in any organization or entity with any financial interest in the subject matter or materials discussed in this manuscript.

References

1. **Hurricane Costs.** National Oceanic and Atmospheric Administration Office for Coastal Management. Published June 2, 2022. Accessed February 15, 2023. <https://coast.noaa.gov/states/fast-facts/hurricane-costs.html#:~:text=Of%20the%20310%20billion%2Ddollar,6%2C697%20between%201980%20aan%202021>
2. **Rising WR, O'Daniel JA, Roberts CS.** Correlating weather and trauma admissions at a Level I trauma center. *J Trauma.* 2006;60(5):1096-1100.
3. **Ho VP, Towe CW, Chan J, Barie PS.** How's the weather? Relationship between weather and trauma admissions at a Level I trauma center. *World J Surg.* 2015;39(4):939.
4. **Kim SH, Sul YH, Kim JS.** Effect of weather variables on the incidence of trauma: a retrospective study at a single tertiary hospital center for 4 years. *Medicine (Baltimore).* 2019;100(43):e27623.
5. **Ali AM, Willett K.** What is the effect of the weather on trauma workload? A systematic review of the literature. *Injury.* 2015;46(6):945-953.
6. **Firearm Deaths Grow, Disparities Widen.** Centers for Disease Control and Prevention. Published October 5, 2022. Accessed November 12, 2022. <https://www.cdc.gov/media/releases/2022/s0510-vs-firearm-deathrates.html>
7. **Charts and Maps.** Gun Violence Archive. Accessed October 30, 2022. <https://www.gunviolencearchive.org/charts-and-maps>
8. **Mokhtari AK, Maurer LR, Dezube M.** Adding to the story, did penetrating trauma really increase? Changes in trauma patterns during the COVID-19 pandemic: a multi-institutional, multi-region investigation. *Injury.* 2022;53(6):1979-1986.
9. **Black Homicide Victimization in the United States.** Violence Policy Center. Published January 6, 2022. Accessed October 22, 2022. <https://vpc.org/studies/blackhomicide20.pdf>
10. **Bailey RK, Barker CH, Grover A.** Structural barriers associated with the intersection of traumatic stress and gun violence: a case example of New Orleans. *Healthcare (Basel).* 2021;9(12):1645.
11. **Kessler RC, Galea S, Jones RT, Parker HA;** Hurricane Katrina Community Advisory Group. Mental illness and suicidality after Hurricane Katrina. *Bull World Health Organ.* 2006;84(12):930-939.
12. **A Force of Nature: Hurricanes in a Changing Climate.** The National Aeronautics and Space Administration. Published January 6, 2022. Accessed February 17, 2023. [https://climate.nasa.gov/news/3184/a-force-of-nature-hurricanes-in-a-changing-climate/#:~:text=This%20change%20is%20likely%20related,Category%204%20or%205\)%20levels](https://climate.nasa.gov/news/3184/a-force-of-nature-hurricanes-in-a-changing-climate/#:~:text=This%20change%20is%20likely%20related,Category%204%20or%205)%20levels)
13. **Kagawa RMC, Riley ED.** Gun violence against unsheltered and unstably housed women: a cross-sectional study that highlights links to childhood violence. *Inj Epidemiol.* 2021;8(1):52.
14. **Ali A, Broome J, Tatum D.** The association between food insecurity and gun violence in a major metropolitan city. *J Trauma Acute Care Surg.* 2022;93(1):91-97.
15. **More Than 40 People Arrested in New Orleans for Looting After Hurricane Ida Court Records Show.** NOLA.com. Published February 9, 2021. Accessed February 24, 2023. https://www.nola.com/news/crime_police/more-than-40-people-arrested-in-new-orleans-for-looting-after-hurricane-ida-court-records/article_db2a25da-0c2d-11ec-a2e5-6b9aef1554fd.html
16. **Dixon TH, Amelung F, Ferretti A.** Space geodesy: subsidence and flooding in New Orleans. *Nature.* 2006;441(7093):587-588.
17. **Kim KH, Kabir E, Jahan SA.** A review of the consequences of global climate change on human health. *J Environ Sci Health C Environ Carcinog Ecotoxicol Rev.* 2014;32(3):299-318.
18. **Weinhammer V, Schmid J, Mittermeier I, et al.** Extreme weather events in Europe and their health consequences—a systematic review. *Int J Hyg Environ Health.* 2021;233:113688.

19. **Casant J, Helbich M.** Inequalities of suicide mortality across urban and rural areas: a literature review. *Int J Environ Res Public Health.* 2022; 19(5):2669.
20. **Grineski SE, Collins TW, Chakraborty J.** Cascading disasters and mental health inequities: Winter Storm Uri, COVID-19 and post-traumatic stress in Texas. *Soc Sci Med.* 2022;315:115523.
21. **Berberian AG, Gonzalez DJX, Cushing LJ.** Racial disparities in climate change-related health effects in the United States. *Curr Environ Health Rep.* 2022;9(3)451-464.
22. **Sharpe JD, Wolkin AF.** The epidemiologist and geographic patterns of natural disaster and extreme weather mortality by race and ethnicity, United States, 1999–2018. *Public Health Rep.* 2022;137(6):1118-1125.