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Heat waves and fatal traffic crashes in the continental United States

Connor Y.H. Wu[a,*], Benjamin F. Zaitchik[b], Julia M. Gohlke[c]

[a] Department of Social Sciences, College of Arts and Sciences, Troy University, Troy, AL, 36082, USA
[b] Department of Earth and Planetary Sciences, Zanvyl Krieger School of Arts & Sciences, Johns Hopkins University, Baltimore, MD, 21218, USA
[c] Department of Population Health Sciences, Virginia-Maryland College of Veterinary Medicine, Virginia Tech, Blacksburg, VA, 24061, USA

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ABSTRACT

Background: A better understanding of how heat waves affect fatal traffic crashes will be useful to promote awareness of drivers' vulnerability during an extreme heat event.

Objective and Methods: We applied a time-stratified case-crossover design to examine associations between heat waves and fatal traffic crashes during May-September of 2001–2011 in the continental United States (US). Heat waves, defined as the daily mean temperature > 95% threshold for ≥2 consecutive days, were derived using gridded 12.5 km^2 air temperatures from Phase 2 of the North American Land Data Assimilation System (NLDAS-2). Dates and locations of fatal traffic crash records were acquired from the National Highway Traffic Safety Administration (NHTSA).

Results: Results show a significant positive association between fatal traffic crashes and heat waves with a 3.4% (95% CI: 0.9, 5.9%) increase in fatal traffic crashes on heat wave days versus non-heat wave days. The association was more positive for 56–65 years old drivers [8.2% (0.3, 16.7%)] and driving on rural roadways [6.1% (2.8, 9.6%)]. Moreover, a positive association was only present when the heat wave days were characterized by no precipitation [10.9% (7.3%, 14.6%)] and medium or high solar radiation [24.6% (19.9%, 29.5%) and 19.9% (15.6%, 24.4%), respectively].

Conclusions: These findings are relevant for developing targeted interventions for these driver groups and driving situations to efficiently reduce the negative effects of heat waves on fatal traffic crashes.

1. Introduction

Temperature plays an important role in the occurrence of traffic crashes (Daanen et al., 2003; Malyshkina et al., 2009; Bergel-Hayat et al., 2013; Basagaña et al., 2015; Liu et al., 2017). The effect of heat waves on fatal traffic crashes is less known compared with other meteorological factors, such as precipitation, snow, wind, fog, and hail. Previous research showed that working in heat waves diminishes human capability to carry out both physical and mental tasks (Ramsey, 1995; Kerslake, 2011), increases accident risk (Ramsey et al., 1983) and leads to heat-related illnesses (e.g., heat exhaustion or stroke), if prolonged (Kilbourne, 1997). Driver performance was reported to deteriorate in hot environments. For instance, drivers become irritable and drowsy (McDonald, 1984) and tend to miss signals (Wyon et al., 1996), drift out of their lane and make large steering adjustments (Mackie and O'hanlon, 1977) in the heat. High temperatures also increase the likelihood of vehicle breakdowns (e.g., flat tires) and make roadways soften or buckle, which may lead to collisions (Vajda et al., 2014).

Many previous studies have demonstrated the negative effects of high temperatures on traffic crashes (Nofal and Saeed, 1997; Brijs et al., 2008; Malyshkina et al., 2009; Basagaña et al., 2011; Bergel-Hayat et al., 2013; Basagaña et al., 2015; Liu et al., 2017). For instance, a relevant study conducted in Indiana, US found that summer weeks with high temperatures were at high-risk in terms of crashes (Malyshkina et al., 2009). An epidemiologic study found that a 1 °C increase in average temperature resulted in a 1%–2% increase in the number of motor vehicle injuries in France and the Netherlands (Bergel-Hayat et al., 2013). A study in Spain used daily data to find that the estimated risk of crashes significantly increased by 2.9% on heat wave days (Basagaña et al., 2015). Liu et al. (2017) found increased odds of motor vehicle collisions associated with extreme heat events during summer months in Maryland, US. For other meteorological factors that might relate to traffic crashes, such as bright sunlight, extreme storms, or haze, few previous studies examined how they affect the association between fatal traffic crashes and the extreme heat event. Moreover, how heat waves may differently affect female or male drivers, drivers at different ages, and with different body mass indices (BMI), as well as driving on different days of the week, time of the day, and on different

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[*] Corresponding author.
E-mail address: yuhaowu@troy.edu (C.Y.H. Wu).

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types of roadways with varying speed limits is less studied. One relevant study related to driver age is Liu et al. (2017), who compared three age groups (i.e., 15–19, 20–64, and > = 65 years old) of drivers in motor vehicle collisions involving a single vehicle in different seasons and found the number of collisions in each of these age groups was similar across the four seasons.

Many previous studies focused on how absolute temperatures would lead to traffic crashes (Nofal and Saeed, 1997; Brijs et al., 2008; Malyshkina et al., 2009; Bergel-Hayat et al., 2013). However, acclimation is an important determinant of human activities associated with heat exposure. For instance, people who live in a warmer climate will be able to sustain higher temperatures versus those who live in a colder climate. Therefore, for a nationwide study with diverse climates in the study area, it may be more meaningful to define periods of unusual warmth (i.e., "heat waves") based on deviation from average local conditions rather than absolute temperature thresholds. Heat waves have many different quantitative definitions. When comparing different definitions of heat waves, previous studies have found that relative, mean daily temperature-based heat wave definitions are a simple metric and predictive of mortality and preterm birth (Anderson and Bell, 2009, 2011, Kent et al., 2014). Thus, the present study uses mean daily temperature- > 95th percentile for ≥ 2 consecutive days to define heat wave days (we also present mean daily temperature > 90th, 98th, and 99th percentile for ≥ 2 consecutive days and show their relevant results in Supplemental Materials). Some previous studies focused on heat waves or extreme heat events assigned traffic crashes with the temperature data from the nearest weather stations or the weather stations within a specific area (e.g., Zip code, county, or climatic region) (Basagaña et al., 2011, 2015; Liu et al., 2017). However, the density and spatial distribution of weather stations, as well as the geometric shape and size of the specific areas, might result in exposure measurement error at the locations of traffic crashes. To minimize this error, this study used address-level data (i.e., traffic crashes' locations) and gridded temperature data (with resolution 12.5 km^2) to evaluate whether the traffic crashes occurred in a location experiencing a heat wave.

The objectives of this study are to examine: 1) whether fatal traffic crashes occur at a greater frequency during heat waves at the national level; and 2) whether the associations are different when the analysis is stratified by drivers' gender, age, BMI, as well as day of the week, time of day, speed limit, rural/urban roadways and other meteorological factors (i.e., solar radiation and precipitation).

2. Materials and methods

2.1. Fatal traffic crash records

We obtained the records (N = 261,125) of drivers who were involved in fatal traffic crashes in the continental US for the warm months (May-September) of 2001–2011, from the Fatality Analysis Reporting System (FARS) provided by NHTSA. These fatal traffic crash-related records are non-identifiable, publicly available and only used for research purposes. Each record includes driver demographic information (i.e., gender, age group, height, and weight), the crash date, roadway function class, and the crash location. We selected those records with the valid longitude and latitude information, thus 248,809 records (approximately 95.3% of total records) were considered in subsequent analyses.

2.2. Heat wave indices (HIs)

There is not a universally accepted definition of a heat wave (Smith et al., 2013). This study defined the HI as the daily mean temperature higher than 95% percentile for ≥ 2 consecutive days, because this relatively simple metric has shown to be predictive of mortality and preterm birth in previous studies (Anderson and Bell, 2009, 2011, Kent et al., 2014). We also applied an additional three daily mean temperature-based HIs, using 90%, 98%, and 99% percentile thresholds, in Supplemental Materials – Table S1. Percentile-based HIs (90th, 95th, 98th, and 99th) were determined by ranking all daily temperatures in the warm season (May 1 to September 30) from 2001 to 2011. The temperature data used to calculate HI, and the solar radiation and precipitation data, is 12.5 km gridded data from NLDAS-2 (Cosgrove et al., 2003; Smith et al., 2013). In the present study, this metric was refined to use longitude and latitude information reported on the fatal traffic crash record. The first step was to match the fatal traffic crashes with longitude and latitude information to NLDAS-2 grid cells, and then we determined whether the NLDAS-2 grid cells with the crash dates were on a heat wave day defined by HIs.

2.3. Rurality, weekdays, age, BMI, speed limits, and day/night-times

The analysis was stratified by drivers' demographic factors (i.e., gender, age and BMI), as well as crash-related factors (i.e., rural/urban roadways, weekdays/weekends, speed limits, and day/night time of involved fatal traffic crashes), respectively. In terms of BMI, the data included the weight and height for each fatal crash-involved driver, so that we were able to use BMI (which is used to screen for weight categories that may lead to health problems and calculated by weight in kilograms divided by the square of height in meters). Then, BMI was grouped into three categories: 1) Underweight and normal weight < 24.9 kg/m^2; 2) Overweight – 25.0 to 29.9 kg/m^2; and 3) Obese - ≥ 30 kg/m^2 following CDC's standard weight status categories for adults (Center for Disease Control and Prevention, 2015). For rurality, the traffic crash data from FARS includes the information on the roadway function class, which indicates if the road or highway where the traffic crashes occurred, is considered rural or urban. The roadway function classes at the rural level include: 1) rural-principal arterial-interstate; 2) rural principal arterial-other; 3) rural minor arterial; 4) rural major collector; 5) rural minor collector; 6) rural local road or street; and 7) unknown rural roadway. The urban level had a similar set of seven road types. We mapped the fatal traffic crashes on rural and urban roadways to visualize their spatial pattern (Fig. 1). We grouped the speed limits at the crash locations for three categories: 1) < 30 miles per hour (m/h), which are usually community roads; 2) ≥ 30 and < 55 m/h, which are avenues and boulevards at the town/county/city level; and 3) ≥ 55 m/h, which are highways. For day/night-time, we defined 7 a.m. to 6 p.m. (or 7–18) as the daytime period and other time slots (i.e., before 7 a.m. and after 6 p.m.) as the nighttime period.

2.4. Study design and statistical analysis

Chi-square test was used to examine the difference in drivers' demographic factors (i.e., gender, age and BMI) and other crash-relevant factors (i.e., rural/urban roadways, weekdays/weekends, speed limits, and day/night time of involved fatal traffic crashes) between heat wave days and non-heat wave days. A p-value of ≤ 0.05 is the level of significance set for all statistical tests.

We adopted a time-stratified case-crossover design, which is a statistical method ideally suited to examine short-term exposure with acute outcomes (Basu et al., 2005; Janes et al., 2005a; Crouse et al., 2012). In the case-crossover design, each driver serves as his or her own control; therefore, known and unknown time-invariant confounders, such as BMI, seasonality, and overlap bias, are inherently adjusted by study design (Maclure, 1991). The time-stratified control selection method in this design is frequently used in environmental health studies (Basu et al., 2005; Janes et al., 2005b, a, Crouse et al., 2012; Tong et al., 2012). Moreover, in this time-stratified sampling design, all days that are on the same day of the week and within the same month as the case day are selected as control periods. Similar to a matched case-control design, the case-crossover design uses the case and matched time-stratified control period as the stratum in conditional logistic regression

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