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Threat of paediatric hyperthermia in an enclosed vehicle: a year-round study

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ABSTRACT

Objective To describe temperature change throughout the workday in an enclosed vehicle in Austin, Texas across the calendar year while accounting for heat index.

Methods In this observational study, vehicular temperature was measured 1 day per month during 2012 in Austin, Texas. Data were recorded at 5-min intervals via an EL-USB-1-PRO digital temperature sensor from 8:00 to 16:00. Selected days were primarily cloud-free (with 'clear' or 'few clouds') with a predicted ambient temperature high within ±20°F of the 30-year normal high. Referent temperature and 30-year normal data were collected via the nearest National Weather Service (NWS) weather station. The NWS heat index and corresponding hazard levels were used as a guideline for this study.

Results Per NWS guidelines, the enclosed vehicle temperature rose to 'danger' levels of ≥105°F (41°C) in all months except January and December and to 'extreme caution' levels of ≥90°F (32°C) in every month of the year. In June, the vehicle rose to ≥105°F (41°C) by 9:25. The hottest vehicular temperature achieved was 137°F (58°C). In 9 months of the year, the vehicle reached ≥90°F (32°C) by noon. We also found that an ambient temperature as low as 68°F was associated with vehicular temperatures ≥105°F (41°C).

Conclusions Infants and children in states that experience mild winter temperatures face the threat of vehicular hyperthermia disability and death across the calendar year. Prevention efforts that focus on awareness of a childhood heat vulnerability, parental perception of susceptibility to forgetting a child in a vehicle and universal availability of vehicular safety devices may reduce paediatric vehicular hyperthermia death.

INTRODUCTION

In the USA, 384 children died due to hyperthermia between 2003 and 2012 while unattended in an enclosed vehicle.[1] Paediatric vehicular hyperthermia persists as a highly preventable form of heat-related death. The majority of vehicular hyperthermia deaths occurred during warmer months and in southwestern and southern states—with 17% in Texas alone.[1 2] Hyperthermia sets in when the body's natural ability to dissipate heat becomes ineffective. As the core body temperature rises above 104°F (40°C), delirium, convulsions, coma and ultimately, death can occur.[3] For survivors, neuropsychological deficits can be severe and permanent.[4] Infants and children are at increased hyperthermia risk because they produce more heat (due to a higher metabolic rate and greater surface area-to-body mass ratio) yet have lower blood volume to dissipate heat and they sweat less than adults do.[5–7] A child's ability to thermoregulate in a hot environment is impacted by their acclimatisation level, metabolic rate, level of hydration and manner of dress.[3 5] In a hot, enclosed vehicle, an infant or small child belted into a car seat would likely be unable to remove clothing layers, open a car window or move out of the direct rays of the sun thereby decreasing their ability to thermoregulate and increasing their risk of hyperthermia.

Factors that impact heating within a vehicle include ambient air temperature, angle of the sun, ventilation, cloud cover and shading.[7] An enclosed vehicle may pose additional threat due to increased humidity (brought about by a child's evaporated sweat and respiration) which in turn reduces effectiveness of evaporative and perspiration-related cooling.[8] While no universal ambient or vehicular temperature threshold exists for heat-related illness, the National Weather Service (NWS) issues advisories for daytime heat index at or exceeding 105°F (41°C).[9] The heat index guide was created by the NWS as a part of their heat/health watch warning system to convey levels of threat of heat-related illness to the public. While these NWS hazard guidelines were designed to convey threat of ambient not vehicular temperatures, they represent ranges that the public can easily understand. The NWS also advises 'caution' of heat illness at lower heat indices: fatigue and heat cramps at ~80–89°F (~27–32°C) and 'extreme caution' of heat exhaustion and possible heat stroke at ~90–104°F (~32–40°C).[10 11]

In addition, temperatures inside enclosed vehicles can rise quickly to dangerous levels at ambient temperatures much milder than 105°F (41°C). Ambient temperatures as mild as 72°F (22°C) can result in a 40°F (22°C) increase inside an enclosed vehicle within 1 h.[12] Of the 384 paediatric vehicular hyperthermia deaths in the USA since 2003, almost a third (120 cases) occurred at ambient temperatures of 80–89°F (~27–32°C) and another 8% (31 cases) at ≤79°F (≤26°C). The lowest ambient temperature recorded in a vehicular hyperthermia death due to solar heating of the vehicle was 57°F (14°C).[1]

Over the past 30 years in Austin, Texas, ambient temperatures as high as 80–90°F (~27–32°C) degrees have been recorded in every month of the calendar year.[13] Infants and small children residing in southern and southwestern states may be at risk of vehicular hyperthermia death throughout the year—even during milder winter months. Prior US studies of vehicular air temperature in an enclosed vehicle have primarily been conducted during warmer months.[12 14–16] Several prior studies achieved extreme vehicular temperatures >170°F

(>77°C) due to placement of temperature sensors in direct contact with the sun's rays or on the seat of the vehicle.[15–17] One year-round study in Switzerland achieved extremely high vehicular temperatures <192°F (<89°C) with exposure to direct solar irradiation inside several vehicles.[18] However, to the authors' knowledge, no studies have examined year-round vehicular air temperatures for threat of hyperthermia death to infants and small children left unattended in enclosed vehicles in areas with warmer winters. Furthermore, we have attempted to place the threat of heat-illness in an easily understood context. Given that over half (50.5%) of heat-related vehicular fatalities in the USA occurred when children were simply forgotten inside the vehicle by their caregiver (often on the way to work), we attempted to recreate a typical workday scenario.[2 12] This study sought to provide a realistic description of temperature change from early morning through the afternoon in an enclosed vehicle in Austin, Texas across the calendar year while accounting for ambient temperature.

MATERIALS AND METHODS

Study design

In this observational study, temperature was measured inside an enclosed vehicle 1 day per month from 18 January to 20 December 2012 in Austin, Texas. Days were selected for data collection if they were: (1) primarily cloud-free (defined as 'clear'=0–1/8 cloud cover or 'few'=1/8–2/8 cloud cover), and (2) the NWS predicted ambient high temperature was within 20°F (11.1°C) of the average normal high temperature per the NWS 30-year normal dataset.[19] Referent temperature data used to determine day selection were collected via the nearest urban NWS Automated Surface Observing weather station (Camp Mabry).[13] Ambient temperature data for selected days were also collected from the Camp Mabry weather station.[20] We chose to use the NWS heat/health watch warning system hazard categories as a guideline for this study. As mentioned above, the NWS advises extreme caution for heat exhaustion at 90–104°F and danger of possible heat stroke at ≥105°F (41°C) (see figure 1).

Data collection

Temperature was recorded on selected days with an EL-USB-1-PRO (Lascar Electronics) high temperature digital data logger from 8:00 to 16:00. The EL-USB-1-PRO has a resolution of 0.2°F (0.1°C), a range of −40°F to +257°F (−40°C to +125°C) and an accuracy of ±0.4°F (±0.2°C). The vehicle, a white station wagon with grey interior and non-tinted windows, was parked in full sun (non-shaded) in the same area and east-facing orientation of an asphalt parking lot on each data collection day. The sensor was set to record the temperature at 5-min intervals and hung above the centre rear seat at approximately 6 inches from the ceiling to simulate where a child's head would be located if in a child passenger safety seat. Use of a light coloured vehicle and placement of the temperature logger out of direct sunlight were intended to obtain conservative air temperature readings. Care was taken to equalise vehicular and ambient temperatures by allowing vehicle doors and windows to remain open for 10 min prior to initiation of data collection. Windows remained closed during data collection to limit air ventilation and to maximise interior vehicular heating.

Statistical analysis

All recorded temperature data were imported from the EL-USB-1-PRO data logger to an Excel spreadsheet where all statistical analysis was conducted. Data were analysed descriptively for maximum temperature, rate of temperature rise, mean and SD. Data were also graphed in order to assess visual significance of temperature patterns.

RESULTS

Daytime high temperatures in the enclosed vehicle

As expected, the highest vehicular temperatures were collected in summer months (figure 2). The highest vehicular temperature was collected in June (137°F/58°C). The vehicle reached 105°F (41°C), the temperature at which the NWS issues a heat advisory in the danger category, in 10 of the 12 months (excluding December and January). Finally, in all 12 months of the year, the vehicle attained a temperature of ≥90°F (≥32°C) at which the NWS recommends extreme caution for heat exhaustion and possible heatstroke.

Highest vehicular, ambient and 30-year normal temperatures

The high vehicular temperature exceeded the high ambient temperature in every month of the calendar year by an average of 36°F (20°C) (SD: ±6.4; range: 19.4–45.6°F) (figure 3). The highest ambient temperature ranged from 66°F to 106°F (19°C to 41°C). Ambient temperatures as low as 68°F (20°C) were associated with vehicular temperatures ≥105°F (41°C) in the NWS danger category. The high ambient temperature exceeded the 30-year normal temperature high in every month except November.

Temperature rise in the enclosed vehicle

In the warmest months, May to August, the vehicular temperature rose most quickly in the 1st hour of data collection (between 8:00 and 9:00) by an average of 17°F (9.5°C), (SD: ±6.9 range: 10.2–20.8°F) (figure 4). In June, the hottest month in our sample, the maximum 1-hour heating was 24.7°F (13.7°C), (from 74.6°F to 99.3°F/23.7°C to 37.4°C),) between 8:00 and 9:00. On that day, vehicle temperature exceeded the NWS extreme caution category (≥90°F/≥32°C) by 8:35 and the danger category (105°F/41°C) as early as 9:25. Vehicular temperatures in May–August rose to the NWS extreme caution category (≥90°F/≥32°C) by 9:00 each selected day.

When averaged across all months of the year, the vehicular temperature rose the most in the 2nd hour (between 9:00 and 10:00) by an average of 10.9°F (6.1°C) (SD: ±4.1 range: 3.3–15.8°F). However, in the warmest months (May–August), 27% of total heating occurred in the 1st hour of the day while 18% of total heating occurred in the 2nd hour. From September to April, only 12% of heating occurred during the 1st hour and 20% occurred in the 2nd hour.

In 9 months of the year, including several cooler months (February, April, October and November), the vehicle rose to the NWS extreme caution category (≥90°F/≥32°C) before noon. Across all months, the vehicular temperature rose to the NWS caution category (≥80°F/≥27°C) by noon. The hottest ambient temperatures for warmer months were recorded between 14:30–16:00.

DISCUSSION

We aimed to describe daytime vehicular temperatures across the calendar year in Austin, Texas while accounting for ambient temperature. In our study, the enclosed vehicle temperature rose to 'danger' levels (≥105°F/≥41°C) in all months except January and December and to 'extreme caution' levels (≥90°F/≥32°C) in every month of the year. In June, the vehicle rose to ≥105°F (≥105°F/≥41°C) by 9:25. The hottest vehicular temperature achieved was 137°F (58°C). In 9 months of the year, the vehicle reached ≥90°F

Relative Humidity (%) \ Temperature (°F)*	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110
40	80	81	83	85	88	91	94	97	101	105	109	114	119	124	130	136
45	80	82	84	87	89	93	96	100	104	109	114	119	124	130	137	
50	81	83	85	88	91	95	99	103	108	113	118	124	131	137		
55	81	84	86	89	93	97	101	106	112	117	124	130	137			
60	82	84	88	91	95	100	105	110	116	123	129	137				
65	82	85	89	93	98	103	108	114	121	128	136					
70	83	86	90	95	100	105	112	119	126	134						
75	84	88	92	97	103	109	116	124	132							
80	84	89	94	100	106	113	121	129								
85	85	90	96	102	110	117	126	135								
90	86	91	98	105	113	122	131									
95	86	93	100	108	117	127										
100	87	95	103	112	121	132										

Heat Index	Category	Hazard of Heat Disorder
~80 - 89°F	Caution	Possible fatigue with prolonged exposure
~90 - 104°F	Extreme Caution	Heat exhaustion possible with long exposure
~105 - 125°F	Danger	Heat stroke possible and heat exhaustion likely
~≥126°F	Extreme Danger	High risk of heat stroke

* Formula to convert Fahrenheit to Celsius: (°F - 32) x 5/9 = °C

Figure 1 Heat index chart (Adapted from the National Oceanic and Atmospheric Adminstration (NOAA's) National Weather Service Heat/Health Watch Warning System chart).

(≥32°C) by noon. We also found that an ambient temperature as low as 68°F (in November) was associated with vehicular temperatures in excess of 105°F (41°C).

The implications of these findings are twofold. First, a child can be forgotten by a distracted caregiver in any month of the year. While the majority of hyperthermia deaths occur outside of winter months, a child left unintentionally in a car on the morning of 22 February 2012 would have experienced 108°F (42°C) before lunchtime.[2] While vehicular temperatures may not rise as quickly in winter months, they still achieve deadly levels. Second, small children in winter would likely be dressed more warmly than in summer months. As such, temperatures ≥90°F (≥32°C) could be dangerous or potentially fatal to an infant or small child, layered for cooler weather, and left unattended for several hours (or an entire day) without access to fluids or ventilation.

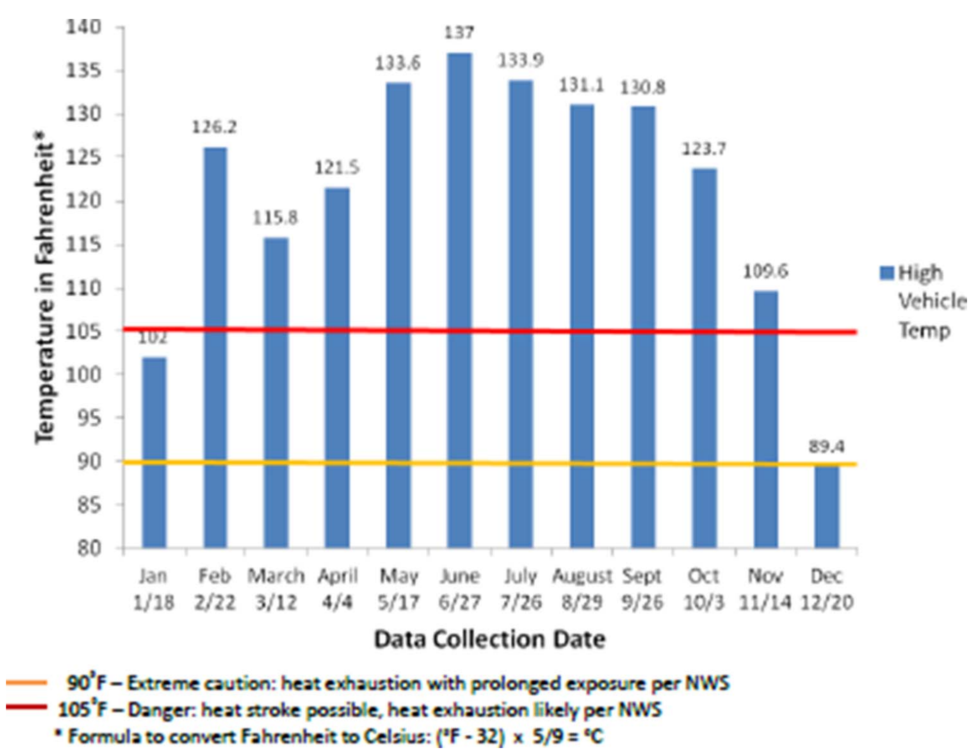

Figure 2 Highest daytime temperature in an enclosed vehicle in central Texas during 2012.

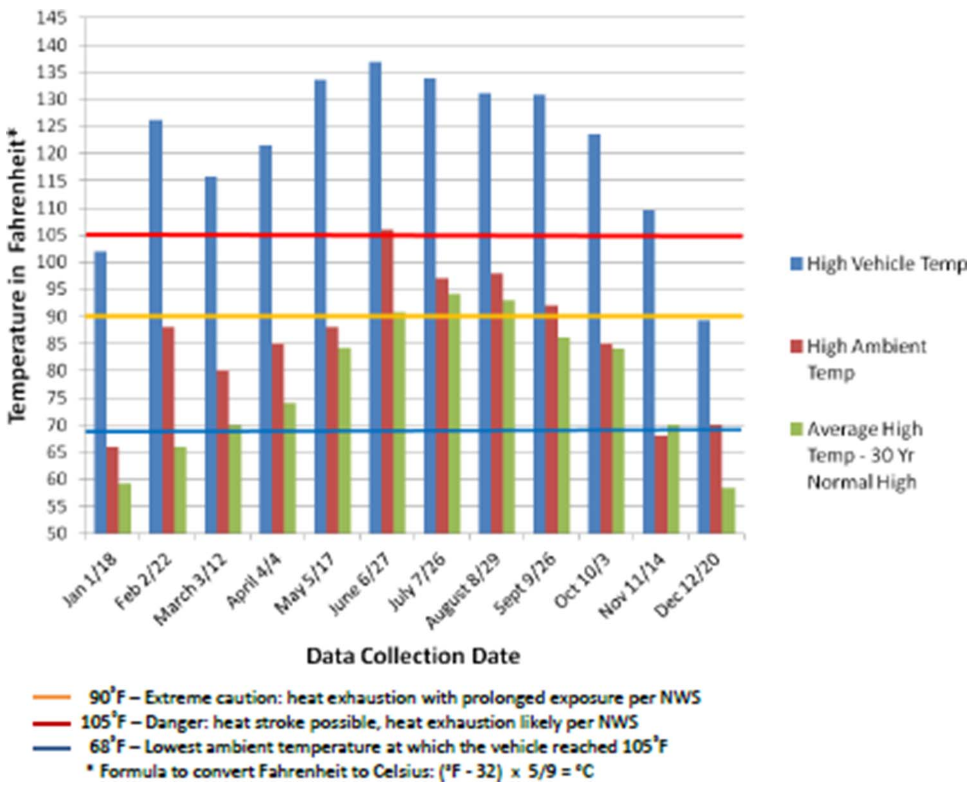

Figure 3 Highest vehicular, ambient and 30 year normal temperatures on data collection days in central Texas during 2012.

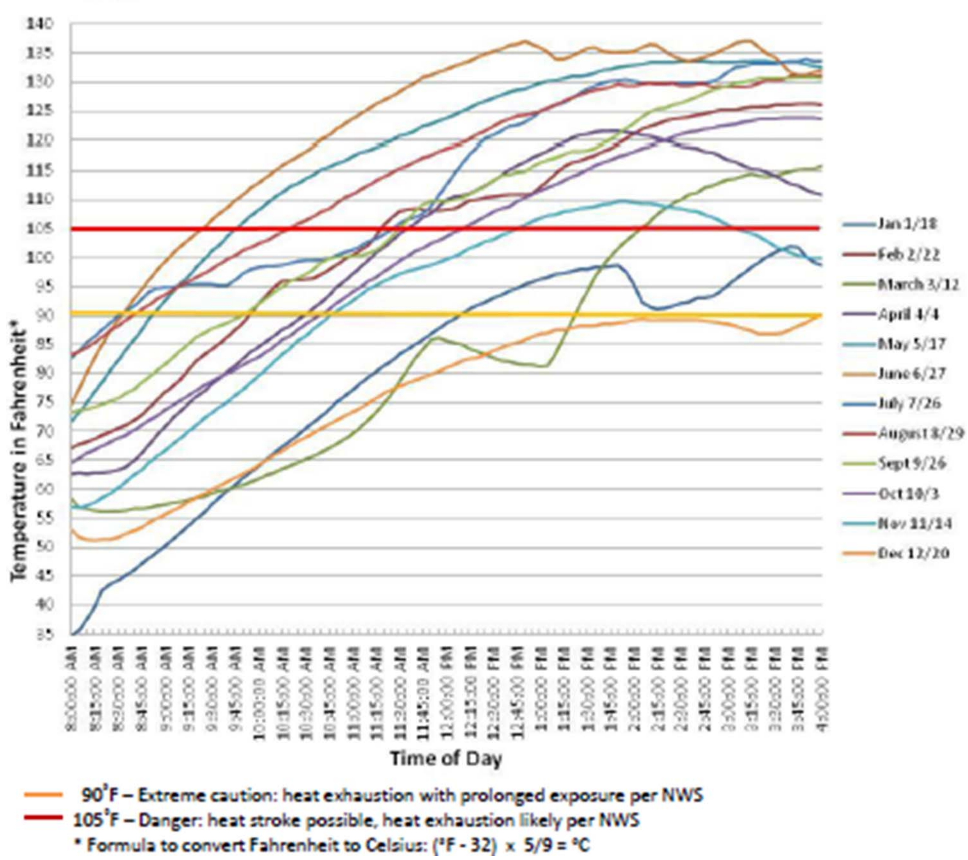

Figure 4 Daytime temperature rise in an enclosed vehicle in central Texas during 2012.

It remains unclear how long it takes for infants and small children enclosed in a vehicle to experience the phases of heat illness at lower ambient temperatures. Heat-related illness is comprised of three stages: heat stress (mild), heat exhaustion (mild to moderate) and heat stroke (severe to life threatening).[3] Some hyperthermia deaths due to solar heating have occurred at relatively low ambient temperatures (eg, 57°F/14°C, 60°F/16°C, 66°F/19°C, 67°F/19°C), however, the vehicular temperatures associated with those deaths is unknown.[1] Climate researchers have created models to project maximum vehicle temperatures and human heat balance of a small child inside an enclosed vehicle.[8 21 22] These models may be useful to medical examiners in estimating time of death and to child safety advocates in educating about the risks of leaving children unattended in vehicles. Such models could be deployed to examine risk to children at less extreme but still dangerous temperatures on the lower end of the spectrum. Accounting for additional clothing insulation in cooler months could add an interesting dimension to future modelling work.

Limitations of this study should be considered when interpreting these findings. As temperatures were only collected 1 day per calendar month, our sample may underestimate vehicular temperatures in January and December. According to the NWS, 18 days in December 2012 and 14 days in January 2012 exceeded 68°F (20°C) yet were not captured in our findings. An additional consideration is that given the lack of a universal temperature threshold for hyperthermia risk, the NWS heat/health watch warning system hazard guidelines were used to contextualise the threat of heat illness for this study. These guidelines were not necessarily designed for the enclosed vehicular environment. Given a young child's reduced thermoregulatory capability and higher metabolic rate combined with the humidified environment of an enclosed vehicle with a child trapped inside, guidelines that are more conservative may be appropriate.[3 5]

These findings align with prior research whereby relatively low ambient temperatures were associated with dangerous vehicular temperatures.[13] Our findings underscore the need for increased awareness and vigilance on the part of parents and caregivers with regard to leaving children unattended in vehicles at any time of year. However, given that in over half of vehicular hyperthermia deaths, children are reportedly forgotten, prevention methods should be geared towards helping distracted parents remember to check the backseat before exiting their vehicle.[1] To prevent this potentially fatal mistake, interventionists have suggested mnemonic tips such as placing a handbag, briefcase, phone or other essential item on the floorboard below the car seat to ensure caregivers notice the infant or small child.[23] One programme asks parents and daycare providers to pledge to notify one another if an infant or small child does not arrive at daycare.[24] A smart phone application, Baby Reminder, can be programmed to remind caregivers to pick up or drop off a child as expected.[25] Use of available occupant presence-sensing vehicular devices that can be placed on an existing car seat to alert caregivers that a child has been left in the car has also been recommended.[23 24 26 27] However, an evaluation commissioned by the US Department of Transportation found that reminder technologies have yet to deliver consistent, reliable results.[28] Finally, a convertible car seat equipped with a sensor and alarm system to notify parents if the infant or child is left unattended was scheduled to be available as of summer 2013.[29]

Unfortunately, child safety advocates raise concerns that parents may underestimate their own risk of unknowingly forgetting a child in a vehicle and therefore do not perceive a need for safety devices or mnemonic aids (J Fennell, KidsAndCars.org and K Reeves Cavaliero, Ray Ray's Pledge, personal communication, May 2013). Study of parental risk perception with regards to paediatric vehicular hyperthermia and preventive devices is warranted. Further, development of weight-sensing alarm solutions that are built in to the vehicle at manufacturing, and thus widely available to the public, may be preferable.

For parents that knowingly and intentionally leave their children unattended, public education on the risk of ever leaving a child in a car is imperative. With regards to legal deterrents, only 20 US states (including Texas) currently have specific laws regarding leaving children unattended in vehicles.[1] Many southern and southwestern states have yet to pass such laws including Arkansas, Mississippi, Alabama, Georgia, North Carolina, South Carolina, Virginia, West Virginia, New Mexico and Arizona. Such laws could be expanded across all 50 states.

In conclusion, infants and children in Texas and other states that experience mild winter temperatures face the threat of vehicular hyperthermia and death across the calendar year. Efforts to educate and aid caregivers to eliminate this highly preventable cause of death in infants and young children should be expanded and made widely available to the public. Further study is needed to understand (and potentially modify) parental risk perception with regards to susceptibility of forgetting their child in a hot car.

What is already known on this subject

- Vehicular hyperthermia remains a highly preventable form of disability and death among infants and small children.
- Despite increased awareness on this topic, since 2003 an average of 38 infants and children have died of vehicular hyperthermia each year in the USA. Over 50% of these children are forgotten in the vehicle by their caregiver.
- Ambient temperatures as mild as 72°F (22°C) can result in a 40°F (22°C) increase inside an enclosed vehicle within 1 h. Vehicular temperatures can reach dangerous levels even on relatively cool days.

What this study adds

- This is the first study to examine vehicular air temperature across the calendar year in one location of southern USA during a typical workday.
- Children can be forgotten in a vehicle in any month of the year. Infants and small children face the threat of hyperthermia disability and death throughout the year in regions of the country with milder winters.
- Further study is needed to examine parental risk perception regarding forgetting their child in a vehicle.

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Competing interests None.

Provenance and peer review Not commissioned; externally peer reviewed.

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Do rugby helmets work?

Caroline Finch believes there is no evidence that helmets used in rugby and Australian football stop concussions or severe head injuries. She thinks American hard-shell helmets are more effective because of the shell and the padding. *Editor's comment*: Her points seem reasonable, but the report provides neither epidemiologic nor lab evidence in support (noted by IBP).