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Heat Stress From Enclosed Vehicles: Moderate Ambient Temperatures Cause Significant Temperature Rise in Enclosed Vehicles

Catherine McLaren, MD*; Jan Null, CCM‡; and James Quinn, MD*

ABSTRACT. Objective. Each year, children die from heat stroke after being left unattended in motor vehicles. In 2003, the total was 42, up from a national average of 29 for the past 5 years. Previous studies found that on days when ambient temperatures exceeded 86°F, the internal temperatures of the vehicle quickly reached 134 to 154°F. We were interested to know whether similarly high temperatures occurred on clear sunny days with more moderate temperatures. The objective of this study was to evaluate the degree of temperature rise and rate of rise in similar and lower ambient temperatures. In addition, we evaluated the effect of having windows “cracked” open.

Methods. In this observational study, temperature rise was measured continuously over a 60-minute period in a dark sedan on 16 different clear sunny days with ambient temperatures ranging from 72 to 96°F. On 2 of these days, additional measurements were made with the windows opened 1.5 inches. Analysis of variance was used to compare how quickly the internal vehicle temperature rose and to compare temperature rise when windows were cracked open 1.5 inches.

Results. Regardless of the outside ambient temperature, the rate of temperature rise inside the vehicle was not significantly different. The average mean increase was 3.2°F per 5-minute interval, with 80% of the temperature rise occurring during the first 30 minutes. The final temperature of the vehicle depended on the starting ambient temperature, but even at the coolest ambient temperature, internal temperatures reached 117°F. On average, there was an ~40°F increase in internal temperature for ambient temperatures spanning 72 to 96°F. Cracking windows open did not decrease the rate of temperature rise in the vehicle (closed: 3.4°F per 5 minutes; opened: 3.1°F per 5 minutes or the final maximum internal temperature.

Conclusions. Even at relatively cool ambient temperatures, the temperature rise in enclosed vehicles is significant on clear, sunny days and puts infants at risk for hyperthermia. Vehicles heat up rapidly, with the majority of the temperature rise occurring within the first 15 to 30 minutes. Leaving the windows opened slightly does not significantly slow the heating process or decrease the maximum temperature attained. Increased public awareness and parental education of heat rise in motor vehicles may reduce the incidence of hyperthermia death and improve child passenger safety. Pediatrics 2005;116:e109–e112. URL: www.pediatrics.org/cgi/doi/10.1542/peds.2004-2368.

ABBREVIATION. CI, confidence interval.

Every year, children die from heat stroke after being left unattended in a vehicle. From 1998 to 2002, the average number was 29 children per year (Fig 1). In 2003, this number increased to 42 (Fig 2) and was 35 in 2004. In addition to death, it is estimated that annually hundreds of children experience varying degrees of heat illness from being left in cars. This danger exists despite public education efforts and lobbying for laws against leaving children unattended in vehicles. In a survey performed by Roberts and Roberts, approximately one quarter of interviewed women who had infants or toddlers admitted to leaving their children unattended in cars.

Previous studies have examined the internal environment of motor vehicles. King et al found that in an ambient temperature of 36.8°C (98.2°F), 75% of the maximum temperature rise occurred within 5 minutes of closing the doors and maximized within 15 minutes to 51 to 67°C (124–153°F). Opening the windows 20 cm (~8 inches) had minimal effect on the temperature rise and maximum temperature attained. Roberts and Roberts had similar findings. Most studies examined temperature rise on days with ambient temperatures >90°F, except for the study of Robert and Roberts, in which the ambient temperature was 83°F. These studies show that, not surprising, significant heat rise occurs on hot days.

We hypothesized, however, that even on cooler days, the risk for heat illness is significant inside a vehicle. This study was designed to quantify the amount and the rate of heating inside vehicles over a broader range of ambient temperatures. We also sought to determine whether “cracked” windows made any difference on the heating of vehicles, because in a survey, fewer than one third of mothers would leave the windows half open because of theft concerns.

METHODS

Study Design

This was an observational study in which we measured the interior vehicle temperature on 16 different cloud-free days between May 16 and August 8, 2002, in Fremont, California. Abi-
ent temperatures ranged from 72 to 96°F. The vehicle was parked in full sun, oriented 45 degrees to the sun’s rays to minimize direct sunlight through the windshield. Internal vehicle temperature was measured continuously from time 0 to 1 hour. Temperature was recorded at time 0 and every 5 minutes for 1 hour. The vehicle was a dark-blue 2000 Honda Accord with medium-gray interior and without tinted windows. Recordings were made with closed windows on 16 different days. On 2 of these days, recordings were made first with the windows closed. Then the doors were opened to return the vehicle to ambient temperature, and a second hour of measurements was made with the windows cracked 1.5 inches. It was ensured that no significant change in ambient temperature occurred during these 2 hours.

Data Collection
Ambient temperature was recorded continuously with a Davis Instruments Vantage Pro Sensor Suite. Wireless temperature sensors were placed in the test vehicles in the rear passenger section 15 inches above the seat, in the shade and not in direct contact with any part of the car. The temperature sensors had a resolution of 1°F and accuracy of ±1°F. All recorded data were transmitted to the Vantage Pro base station.

RESULTS
Rate of Temperature Rise Versus Ambient Temperature
Regardless of the ambient temperature, the rate of internal vehicle temperature rise was similar ($P = 1.0$). Figure 3 shows how the slope of the temperature over time was virtually the same for the different ambient temperatures. Eighty percent of the temperature rise occurred during the first 30 minutes ($P < .0001$).

The effect of air conditioning the vehicle before start of measurements was negligible. In preliminary measurements, the vehicle consistently reached ambient temperatures within 5 minutes of the air conditioning’s being turning off and then would heat up at a similar rate to non–air-conditioned cases.

Final Internal Vehicle Temperature Versus Ambient Temperature
The maximum internal temperature was attained at ~60 minutes of exposure in our study. We also found that the final vehicle temperature was dependent on the initial ambient temperature. In addition, an average 41°F (range: 28–49°F) increase from starting ambient temperature occurred for the ambient temperature range of 72 to 96°F.

Comparison of Closed Versus Cracked Open Windows
Figure 4 illustrates a nonsignificant trend to faster heating in the first 20 minutes with the windows closed.
closed 6.25°F per 5 minutes (95% confidence interval [CI]: 1.0–11.5) versus 5.5°F per 5 minutes (95% CI: 1.2–9.8) with the windows cracked open. However, overall, the rate of temperature rise for windows that were cracked open was 3.4°F per 5 minutes (95% CI: 2.4–4.4°F) compared with the rate for closed windows of 3.1°F per 5 minutes (95% CI: 1.4–4.8°F), with the final temperature for both circumstances being identical.

**DISCUSSION**

We demonstrated that on sunny days, even when the ambient temperature is mild or relatively cool, there is rapid and significant heating of the interior of vehicles. On days when the ambient temperature was 72°F, we showed that the internal vehicle temperature can reach 117°F within 60 minutes, with 80% of the temperature rise occurring in the first 30 minutes. In general, after 60 minutes, one can expect an ~40°F increase in internal temperatures for ambient temperatures spanning 72 to 96°F, putting children and pets at significant risk. We also determined that cracking open windows is not effective in decreasing either the rate of heat rise or the maximum temperature attained.

The exact affect of such temperatures on infants is unknown, but from case reports, we know that they can be devastating. We do know that heat illness is a continuum that is divided into 3 phases. The mildest form is heat stress, the physical discomfort and physiologic strain as a result of a hot environment. Next is heat exhaustion, a mild to moderate illness associated with dehydration and a core temperature ranging from 37°C to 40°C. Symptoms of heat exhaustion include intense thirst, weakness, discomfort, anxiety, dizziness, fainting, and headache. Finally, heat stroke is a life-threatening illness characterized by an elevated core body temperature >40°C with central nervous system dysfunction resulting in delirium, convulsions, coma, and death.4

Young children and infants are more susceptible to heat illness than adults for several reasons. Physiologically, toddlers and infants, despite their increased body surface area to mass ratio, seem to have less effective thermoregulation in comparison with adults as proposed by Tsuzuki-Hayakawa and
and children in enclosed vehicles, the risk is clear. Reasons, so although we may never know the rate of children would be difficult to do for obvious ethical spect.2,3,10,11 King et al3 noted 75% of the maximum period, or even cool sunny days as well as the effects of cracking the windows. Laws regarding kids in cars currently exist in 9 states and are proposed in an additional 9,13 Although the problem of nonexertional hyperthermia in children pales in comparison with that of the top 3 causes of unintentional death (motor vehicle accidents, drowning, and burns) heat illness is conceivably easier to prevent if their caregivers are aware of the danger. It is worth considering incorporating this message along with a discussion of the importance of car seats as part of child passenger safety education for caregivers. Legislation efforts may help to raise awareness, but as these events are mostly unintentional, additional public education efforts ultimately are necessary to decrease the incidence of this fatal yet preventable behavior.

REFERENCES

9. Hardy JD. Physiology of temperature regulation. Physiol Rev. 1961;41:521
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