Life-threatening motor vehicle crashes in bright sunlight

Donald A. Redelmeier, MD, FRCPC, MS(HSR), FACPa,b,c,d,e,∗, Sheharyar Raza, HBSc∗,b

Abstract

Bright sunlight may create visual illusions that lead to driver error, including fallible distance judgment from aerial perspective. We tested whether the risk of a life-threatening motor vehicle crash was increased when driving in bright sunlight.

This longitudinal, case-only, paired-comparison analysis evaluated patients hospitalized because of a motor vehicle crash between January 1, 1995 and December 31, 2014. The relative risk of a crash associated with bright sunlight was estimated by evaluating the prevailing weather at the time and place of the crash compared with the weather at the same hour and location on control days a week earlier and a week later.

The majority of patients (n = 6962) were injured during daylight hours and bright sunlight was the most common weather condition at the time and place of the crash. The risk of a life-threatening crash was 16% higher during bright sunlight than normal weather (95% confidence interval: 9–24, P < 0.001). The increased risk was accentuated in the early afternoon, disappeared at night, extended to patients with different characteristics, involved crashes with diverse features, not apparent with cloudy weather, and contributed to about 5000 additional patient-days in hospital. The increased risk extended to patients with high crash severity as indicated by ambulance involvement, surgical procedures, length of hospital stay, intensive care unit admission, and patient mortality. The increased risk was not easily attributed to differences in alcohol consumption, driving distances, or anomalies of adverse weather.

Bright sunlight is associated with an increased risk of a life-threatening motor vehicle crash. An awareness of this risk might inform driver education, trauma staffing, and safety warnings to prevent a life-threatening motor vehicle crash.

Level of evidence: Epidemiologic Study; level III.

Abbreviations: None.

Keywords: driver error, optical illusion, traffic accident, trauma, weather effects

1. Introduction

Life-threatening motor vehicle crashes are a common cause of death and disability for patients at all ages. The worldwide total exceeds 3000 fatalities per day, the economic costs amount to 2% of the Gross Domestic Product in most countries, and a person’s lifetime risk of a life-threatening crash is about 57% in the United States.[1–4] Motor vehicle crashes are the ninth leading cause of death worldwide and anticipated to become the seventh by year 2030.[P,6] The health care demands are extensive and include patients with airway obstruction, tension pneumothorax, cardiac tamponade, intracranial hemorrhage, spinal cord compression,
abdominal organ damage, orthopedic fractures, or long-term complications. Almost all life-threatening motor vehicle crashes can be avoided by a small change in individual behavior.

We hypothesized that the risk of a life-threatening motor vehicle crash might be partially predictable due to a common perceptual error. Safe driving relies on vision (with lesser contributions from auditory, tactile, and vestibular feedback). Visual illusions, however, predispose healthy people to recurrent mistakes when judging size, position, and motion. Judgment about distance, in particular, rely heavily on aerial perspective (also called the Rayleigh effect or atmospheric scattering) where clear bright objects appear close and dim faded objects appear distant. Visual artists, for example, use aerial perspective to render depth to otherwise flat images (such as the Leonardo da Vinci painting of the Mona Lisa). Aerial perspective, however, is a source of visual error in judging the distances and speeds of far objects in natural settings.

Bright sunlight is a natural factor in aerial perspective because it increases the contrast, resolution, and luminosity of surrounding landscapes. As a consequence, distant terrain can seem unduly close and travel velocity may feel deceptively slow for drivers traveling in bright sunlight. The faulty impression could then lead drivers to compensate by accelerating faster (particularly for individuals on uncongested roads with seemingly easy driving conditions). Without a conscious effort to recheck the vehicle speedometer, therefore, a driver might inadvertently increase their risk of a life-threatening motor vehicle crash when traveling in bright sunlight.

In this study, we analyzed patients at Canada’s largest trauma hospital to test whether the risk of a life-threatening crash was increased when driving in bright sunlight.

2. Methods

2.1. Patient selection

We identified consecutive patients admitted to Canada’s largest trauma hospital (Sunnybrook Health Sciences Centre) because this center treats patients from crashes throughout Canada’s most populous and diverse region. The enrollment interval spanned from January 1, 1995, to December 31, 2014, yielding a comprehensive sample for the 2 most recent decades available. We selected patients with a life-threatening motor vehicle crash (defined as resulting in hospitalization) with a known crash date (and retaining cases with an inexact crash hour). Injured pedestrians were included as were those on bicycles, motorcycles, or miscellaneous vehicles. The study was conducted with research ethics board approval and a waiver for direct patient consent.

2.2. Clinical characteristics

We obtained baseline characteristics for each patient from hospital records using a standardized method validated in past research and masked to study hypothesis. Information on date, time, and location of the crash was based on paramedic reports when available (hospital records otherwise). Similarly, chart review provided data on patient age, sex, alcohol involvement, comorbidity, Injury Severity Score, Glasgow Coma Scale, and vital signs (after paramedic resuscitation). Further clinical details included surgical procedures, intensive care unit admission, total length of stay, and hospital mortality. The available data lacked information on impact speed, direction of travel, vehicle condition, past infractions, visual acuity, road conditions, or vehicle mileage.

2.3. Crash circumstances

The patient’s crash location was available in differing formats (geographic coordinates, street intersection, postal code), drawn from a diverse geographic area (1 million square kilometers), and converted to exact geocodes of the crash site. Patients with missing or inexact crash locations were coded explicitly, retained for analysis, and also subjected to sensitivity testing. Geographic proximity to the trauma center was based on straight-line (Euclidean) distance for patients with known crash locations and the median distance for patients with missing or inexact crash locations. Crash time was recorded to the nearest hour because archived weather data lacked greater precision (imprecise weather reports tend to slant subsequent analyses to the null).

2.4. Bright sunlight

Hourly weather data were obtained from the official National Climate Data and Information Archive, as validated in past research. We selected the airport weather station closest to the crash for patients with exact crash locations and the most central airport weather station for those with inexact crash locations so that no patient was excluded (cases with inexact locations also subjected to subgroup analyses). We focused on bright sunlight conditions, defined as clear daylight with clouds in less than half of the dome of the sky (in accord with the official classification). All other sky conditions were defined as not sunny, with nighttime retained for secondary analysis (set as 7:00 PM to 7:00 AM without data on exact sunset and sunrise). Additional attributes for tracer analysis included alternative weather conditions and ambient barometric pressure.

2.5. Comparison circumstances

We identified 2 control observations for each crash based on the same day a week earlier and a week later. A crash at noon on Tuesday July 19, 2011, for example, was compared with the same location at noon on Tuesday July 12, 2011, and at noon on Tuesday July 26, 2011. In contrast to past publications (Appendix §1, http://links.lww.com/MD/B480), this approach corrected for seasonal, daily, and hourly trends; avoided ecologic bias; controlled for road design; and minimized multiple potential confounders, including driver education, personality, genetics, vehicle technology, and safety campaigns. The prevailing weather at the same location and hour for crashes and controls was extracted in a blinded manner, with specific attention to missing weather data that were replaced by the immediately preceding hour so all comparisons were 100% complete (Appendix §2, http://links.lww.com/MD/B480).

2.6. Matched design

The weather is a feature of surrounding circumstances and not a patient characteristic. Our study, therefore, examined the circumstances of the crash and focused on each location at 3 moments. The specific moments were the crash hour and the same hour on the 2 controls (days that were presumably crash-free, as repeated events are rare for identical locations on separate days). The null hypothesis, therefore, would mean that the weather is unrelated to the probability of a crash at each location. The aerial perspective illusion, in contrast, would mean that bright sunlight is more common during crash circumstances than control circumstances at each location. This case-only paired-comparison design avoids
confounding from different patients and the symmetric bidirectional sampling of control times adjusts for exposure trends.[38-60]}

### 2.7. Statistical analysis

Our pre-specified primary analysis compared the presence of bright sunlight during the crash with the presence of bright sunlight on the 2 control days at the same location and hour (Appendix §3, http://links.lww.com/MD/B480). The relative risk of a crash associated with bright sunlight was calculated using conditional logistic regression (similar to McNemar test and accounting for the 1:2 matched design).[61] Secondary analyses evaluated nighttime crashes to check for a lack of an observed association where no association was anticipated. Stratified analyses accounted for individual patient and crash characteristics. Time intervals were precise to the hour and identical for all comparisons. All estimates were calculated using exact 95% confidence intervals and considered each case as a separate event.

Further analyses explored alternative interpretations for a potential association between bright sunlight and life-threatening crashes. We distinguished morning from afternoon hours, reasoning that fatigue-related crashes are more common later in the day.[62] We distinguished weekends and summer months, reasoning that increased driving from variable travel tends to predominate on weekends and the summer.[63,64] We distinguished different adverse weather conditions (rain, snow, fog) reasoning that an association linked to bright sunlight might be an artifact from adverse weather on some comparison days (Appendix §4, http://links.lww.com/MD/B480).

### 3. Results

A total of 11,539 patients were injured during the study from 11,095 separate life-threatening motor vehicle crashes. The majority of cases occurred during the daytime and exact crash locations were documented for over half (Table 1). The typical patient in a life-threatening daytime crash was a middle-aged man who was the driver and had no medical comorbidity or alcohol detected. Daytime crashes were no less severe than those injured in nighttime crashes as indicated by the frequency of abnormal vital signs, decreased Glasgow Coma Scale scores, or decreased Injury Severity Scale scores. As expected, patients injured in daytime crashes were less likely than those injured in nighttime crashes to have alcohol detected.

Bright sunlight was present in about one-third of daytime crashes and similarly frequent regardless of whether the crash location was exact or inexact. In total (Appendix §3, http://links.lww.com/MD/B480); bright sunlight was present for 2487 crashes, 2264 controls before the crash, and 2254 controls after the crash (including 312 for all three days together). The primary analysis indicated that bright sunlight was associated with a 16% increased risk of a life-threatening motor vehicle crash (95% confidence interval: 9–24, \(P < 0.001\)). The observed increase in risk was apparent throughout the morning or afternoon and not limited to dusk or dawn (Fig. 1). In contrast, a clear sky at night was associated with no significant increased or decreased risk of a life-threatening motor vehicle crash.

The increase in crash risk associated with bright sunlight extended to patients with different characteristics. The increased

### Table 1

**Patient characteristics.**

|                | Daytime crash | Nighttime crash |
|----------------|---------------|-----------------|
| **Patients included** | (n = 6962)     | (n = 4577)      |
| Age, y          |               |                 |
| <25             | 1267 (18)     | 1436 (31)       |
| 25–44           | 2260 (32)     | 1812 (40)       |
| 45–64           | 2029 (29)     | 964 (21)        |
| ≥65             | 1406 (20)     | 365 (8)         |
| Sex             |               |                 |
| Male            | 4364 (63)     | 3269 (71)       |
| Female          | 2508 (37)     | 1308 (29)       |
| Position        |               |                 |
| Driver          | 4109 (59)     | 2502 (55)       |
| Passenger       | 753 (11)      | 588 (13)        |
| Pedestrian      | 1343 (19)     | 904 (20)        |
| Miscellaneous   | 757 (11)      | 583 (13)        |
| Crash location  |               |                 |
| Exact           | 4018 (58)     | 2726 (60)       |
| Inexact         | 2944 (42)     | 1815 (40)       |
| Protective device inactive | 3328 (48) | 2545 (56) |
| Alcohol detected | 763 (11)     | 1588 (35)       |
| Medical comorbidity | 2443 (35) | 1416 (31)       |
| Abnormal vital signs | 1271 (18) | 929 (20) |
| Decreased Glasgow Coma Score | 1300 (19) | 963 (21) |
| Injury severity score | <15 | 2215 (32) |
| <15             | 1451 (32)     |                 |
| 15–24           | 1955 (29)     | 1270 (28)       |
| 25–34           | 1449 (21)     | 967 (21)        |
| ≥35             | 1303 (19)     | 889 (19)        |

Data are count (percentage) of each column.

1. Bicyclists and other vulnerable road users.
2. Sex: male or female.
3. Seatbelts or helmets when indicated.
4. Hypertension (BP >140 mm Hg), tachycardia (HR >120 bpm), or tachypnea (RR >25).
5. Decreased consciousness (value <15).

### Figure 1

Relative risk of a life-threatening motor vehicle crash associated with bright sunlight according to time of day and accompanied by equivalent nighttime hours of clear sky. X-axis shows time grouped in consecutive 3-hour segments that span full 24-hour interval and center on noon as midpoint. Y-axis shows relative risk of a life-threatening motor vehicle crash calculated by comparing crash days to control days. Horizontal line for null effect. Solid circles indicate estimate and vertical bars indicate 95% confidence intervals. Square brackets for count of total crashes during each time segment. The odds ratio is a valid estimate of relative risk because the baseline risk of a crash is low (<1%) for an average day. The boundary zones separating day and night are imprecise and vary by season. Main findings show an increased risk during daylight hours with no consistent patterns during nighttime.
Table 2
Relative risk of a life-threatening crash in bright sunlight.

| Crashes in bright sunlight | Relative risk | Confidence interval |
|---------------------------|--------------|---------------------|
| All patients              | 2487         | 1.16                | 1.09–1.24          |
| Age, y<25                 | 448          | 1.19                | 1.06–1.34          |
| 25–44                     | 813          | 1.17                | 1.07–1.28          |
| 45–64                     | 715          | 1.13                | 1.03–1.24          |
| ≥65                       | 511          | 1.18                | 1.06–1.32          |
| Sex                       |              |                     |                    |
| Male                      | 1556         | 1.16                | 1.09–1.24          |
| Female                    | 931          | 1.17                | 1.08–1.27          |
| Position                  |              |                     |                    |
| Driver                    | 1448         | 1.11                | 1.04–1.19          |
| Passenger                 | 256          | 1.09                | 0.93–1.27          |
| Pedestrian                | 555          | 1.28                | 1.14–1.44          |
| Miscellaneous             | 278          | 1.34                | 1.16–1.56          |
| Protective device         |              |                     |                    |
| Inactive                  | 1202         | 1.20                | 1.12–1.29          |
| Active                    | 1285         | 1.13                | 1.05–1.21          |
| Alcohol                   |              |                     |                    |
| Detected                  | 231          | 0.94                | 0.80–1.11          |
| Absent                    | 1954         | 1.20                | 1.13–1.27          |
| Unknown                   | 322          | 1.14                | 1.00–1.31          |
| Medical comorbidity       |              |                     |                    |
| Present                   | 857          | 1.18                | 1.08–1.28          |
| Absent                    | 1630         | 1.16                | 1.09–1.23          |
| Vital signs               |              |                     |                    |
| Abnormal                  | 442          | 1.13                | 1.00–1.27          |
| Normal                    | 1859         | 1.17                | 1.11–1.25          |
| Unknown                   | 206          | 1.17                | 0.96–1.40          |
| Glasgow Coma Score        |              |                     |                    |
| Decreased                 | 447          | 1.00                | 0.89–1.13          |
| Normal                    | 1388         | 1.20                | 1.12–1.28          |
| Unknown                   | 652          | 1.22                | 1.10–1.35          |
| Injury Severity Score     |              |                     |                    |
| <15                       | 795          | 1.17                | 1.07–1.28          |
| 15–24                     | 725          | 1.16                | 1.06–1.28          |
| 25–34                     | 506          | 1.13                | 1.01–1.27          |
| ≥35                       | 461          | 1.19                | 1.06–1.34          |

Table 3
Secondary analysis of circumstances.

| Crashes in bright sunlight | Relative risk | Confidence interval |
|---------------------------|--------------|---------------------|
| All patients              | 2487         | 1.16                | 1.09–1.24          |
| Day of the week           |              |                     |                    |
| Weekday                   | 1680         | 1.20                | 1.12–1.27          |
| Weekend                   | 807          | 1.10                | 1.01–1.21          |
| Season of year            |              |                     |                    |
| Spring - summer           | 1632         | 1.17                | 1.10–1.25          |
| Autumn - winter           | 855          | 1.15                | 1.06–1.24          |
| Enrollment era            |              |                     |                    |
| First decade              | 1103         | 1.17                | 1.08–1.26          |
| Second decade             | 1384         | 1.16                | 1.08–1.24          |
| Crash location            |              |                     |                    |
| Exact                     | 1457         | 1.16                | 1.09–1.24          |
| Inexact                   | 1030         | 1.17                | 1.08–1.26          |
| Proximity to trauma center|              |                     |                    |
| <10 miles                 | 824          | 1.14                | 1.04–1.25          |
| ≥10 miles                 | 633          | 1.19                | 1.07–1.32          |
| Inexact                   | 1030         | 1.17                | 1.08–1.26          |
| Ambulance involvement     |              |                     |                    |
| Yes                       | 2357         | 1.16                | 1.10–1.22          |
| No                        | 130          | 1.25                | 1.00–1.57          |
| Surgery performed         |              |                     |                    |
| Yes                       | 1312         | 1.13                | 1.05–1.21          |
| No                        | 1175         | 1.20                | 1.12–1.30          |
| Intensive care admission  |              |                     |                    |
| Yes                       | 1275         | 1.19                | 1.11–1.28          |
| No                        | 1212         | 1.13                | 1.06–1.22          |
| Hospital length of stay   |              |                     |                    |
| ≥7 days                   | 1405         | 1.14                | 1.07–1.22          |
| <7 days                   | 1082         | 1.19                | 1.10–1.29          |
| Patient outcome           |              |                     |                    |
| Dead                      | 266          | 1.32                | 1.13–1.55          |
| Alive                     | 2221         | 1.15                | 1.09–1.21          |

The increased risk of a life-threatening crash associated with bright sunlight was distinct when contrasted with findings from analyses of other weather conditions. The second most frequent circumstance was mostly cloudy weather (present in 2242 crashes) and associated with a small decrease in crash risk (Fig. 2). The third most frequent circumstance was fully cloudy weather (present in 912 crashes) and associated with a substantial decrease in crash risk. Rain and snow were infrequent (present in 589 and 405 crashes, respectively) and associated with the expected increased risk of a life-threatening crash. As anticipated, high barometric pressure and low barometric pressure were not associated with crash risk (negative tracer analysis).

4. Discussion

We studied patients hospitalized because of a life-threatening motor vehicle crash. We found that the majority of crashes occurred during daytime and that the risk of a crash increased further in bright sunlight. The increased crash risk associated with bright sunlight was accentuated in the early afternoon, disappeared at night, extended to different patients, involved crashes with diverse features, differed from cloudy weather, and led to about 5000 additional patient-days in hospital (Appendix 5, http://links.lww.com/MD/B480). The findings were not easily attributed to alcohol consumption, travel distances, motorist fatigue, access to care, or selection bias.68–71
The magnitude of relative risk exceeded the relative safety benefits associated with airbags for crash protection.[72–74]

One limitation of the study is that a randomized trial was not feasible, as it is unethical to assign volunteers to life-threatening hazards. Correlation does not mean causation, as unmeasured factors (e.g., speed, distance, distraction, behavior) might contribute to the crash risk associated with bright sunlight.[75,76]

Our analysis, however, introduces no ambiguities around the direction of causality so that unmeasured factors are rightly called a pathway of risk (mediator) and not a determinant of risk (proxy bias).[77–79]

Unmeasured confounding, therefore, does not directly bias estimates of how changes in circumstances might lead to changes in crash risks. Unmeasured factors would also not readily explain why cloudy weather was associated with decreased crash risks.[67]

A second limitation is that the findings are counterintuitive and conflict with automotive experts who consider sunny weather favorable for vehicle reliability and road traction.[80,81] Average patients, moreover, generally believe they are safe drivers, show above-average skill, and have less trouble in clear weather.[82–84]

Instructional materials from licensing agencies caution against adverse weather and thereby indirectly endorse driving in bright sunlight.[85–87] Roadside police are sometimes criticized for heightened enforcement when road conditions are sunny and clear.[88–91] These preconceptions mean that traffic safety science is not interpreted with the same equipoise as other life-threatening health risks.[92,93]

Our study has several other limitations that merit emphasis.

We examined 1 region that may not match traffic patterns elsewhere even though sunlight can occur on most roads. We identified a risk factor that had a modest prevalence (relative frequency near 32%) and modest magnitude (relative risk increase near 16%), thereby explaining about 1-in-20 daytime life-threatening crashes [Appendix 6, http://links.lww.com/MD/B480]. The study lacked statistical power for subgroup analyses so that the accentuated risk among patients who died could be a chance finding. Moreover, patients cannot change the weather but can lessen crash risks by small changes in behavior added to informed system design, public education, traffic enforcement, vehicle engineering, and economic incentives (Appendix 7, http://links.lww.com/MD/B480).

Several illusions could contribute to a life-threatening crash in bright sunlight. Aerial perspective in bright light can make the approach speed of landscapes seem slow and lead drivers to compensate for accelerating faster.[23–25,97–99] Clear weather may create a false sense of security, overconfidence about traffic risks, and a complacent view to safety [Appendix 8, http://links.lww.com/MD/B480].[100,101] Intense illumination may cause glare, gaze diversion, incomplete attention to the full visual field, reductions in speed-sensation, motion blindness, or dazzle with temporary lost vision.[102–106]

Regardless of explanation, physicians can counsel patients to avoid a life-threatening crash in seemingly harmless circumstances by reinforcing standard safety advice to respect speed limits, minimize distractions, use a seatbelt, and not combine drinking with driving.[107,108]

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Figure 2. Relative risk of a life-threatening motor vehicle crash associated with bright sunlight and other daytime weather. X-axis shows weather condition starting with bright sunlight and ending with the pair of high barometric pressure (above 100 kPa) and low barometric pressure (below 99 kPa). Y-axis shows relative risk of a life-threatening motor vehicle crash comparing crash days and control days. Horizontal line for null effect. Solid circles indicate estimate and vertical bars indicate 95% confidence intervals. Square brackets for count of total crashes for each condition. Main findings show increased risk during bright sunlight, corresponding decrease during cloudy weather, additional increases during rain and snow, and no significant change with high or low barometric pressure.
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