Observational Study

Medicine®

OPEN

Life-threatening motor vehicle crashes in bright sunlight

Donald A. Redelmeier, MD, FRCPC, MS(HSR), FACP[a,b,c,d,e,*], Sheharyar Raza, HBSc[a,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.[5,6] The health care demands are extensive and include patients with airway obstruction, tension pneumothorax, cardiac tamponade, intracranial hemorrhage, spinal cord compression,

---

Editor: Abdelouahab Bellou.

Authorship: The lead author (DAR) wrote the first draft. Both authors contributed to study design, manuscript preparation, data analysis, results interpretation, critical revisions, and final decision to submit.

Funding/support: This project was supported by a Canada Research Chair in Medical Decision Sciences, the Canadian Institutes of Health Research, the BrightFocus Foundation, and the Comprehensive Research Experience for Medical Students at the University of Toronto. The views expressed are those of the authors and do not necessarily reflect the Ontario Ministry of Health.

The funding organizations had no role in the design and conduct of the study; collection, management, analysis, and interpretation of the data; and preparation, review, or approval of the manuscript. All authors have no financial or personal relationships or affiliations that could influence the decisions and work on this manuscript.

The study protocol was approved by the Research Ethics Board of Sunnybrook Health Sciences Center including a waiver for direct patient consent. All patient data are available through the Sunnybrook Trauma Center Archive.

Patient privacy laws prohibit from making individual-level data publicly available. Aggregate data are shown in the paper and appendix. Researchers interested in replicating or extending the work can seek access to individual-level data through the Institute for Clinical Evaluative Sciences (contact http://www.ices.on.ca).

The authors disclose no conflicts of interest.

Supplemental Digital Content is available for this article.

[a] *Department of Medicine, University of Toronto,* [b] *Evaluative Clinical Sciences, Sunnybrook Research Institute,* [c] *Institute of Clinical Evaluative Sciences (ICES),* [d] *Institute for Health Policy Management and Evaluation,* [e] *Division of General Internal Medicine, University of Toronto, Toronto, Ontario, Canada.*

[*] *Correspondence: Donald A. Redelmeier, Sunnybrook Health Sciences Centre, G-151, 2075 Bayview Ave, Toronto, ON M4N 3M5, Canada (e-mail: dar@ices.on.ca).*

Copyright © 2017 the Author(s). Published by Wolters Kluwer Health, Inc.
This is an open access article distributed under the Creative Commons Attribution-NoDerivatives License 4.0, which allows for redistribution, commercial and non-commercial, as long as it is passed along unchanged and in whole, with credit to the author.

Medicine (2017) 96:1(e5710)

Received: 25 May 2016 / Received in final form: 21 November 2016 / Accepted: 24 November 2016

http://dx.doi.org/10.1097/MD.0000000000005710

abdominal organ damage, orthopedic fractures, or long-term complications.[7–10] Almost all life-threatening motor vehicle crashes can be avoided by a small change in individual behavior.[11–14]

We hypothesized that the risk of a life-threatening motor vehicle crash might be partially predictable due to a common perceptual error.[15] Safe driving relies on vision (with lesser contributions from auditory, tactile, and vestibular feedback).[16] Visual illusions, however, predispose healthy people to recurrent mistakes when judging size, position, and motion.[17–19] Judgments 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.[20,21] 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).[22,23] Aerial perspective, however, is a source of visual error in judging the distances and speeds of far objects in natural settings.[24–26]

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.[27] The faulty impression could then lead drivers to compensate by accelerating faster (particularly for individuals on uncongested roads with seemingly easy driving conditions).[28] 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.[29–31] 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.[32–34] 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.[35–38] Information on date, time, and location of the crash was based on paramedic reports when available (hospital records otherwise).[39] Similarly, chart review provided data on patient age, sex, alcohol involvement, comorbidity, Injury Severity Score, Glasgow Coma Scale, and vital signs (after paramedic resuscitation).[40,41] Further clinical details included surgical procedures, intensive care unit admission, total length of stay, and hospital mortality.[42] 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.[43,44] 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.[45] 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).[46–48]

2.4. Bright sunlight

Hourly weather data were obtained from the official National Climate Data and Information Archive, as validated in past research.[49,50] 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 analysis).[51] 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).[52,53] 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.[54–57] 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.[58–60]

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 crash severities, reasoning that faster speeds contribute to higher fatality risks.[65,66] We distinguished mostly and fully cloudy weather, reasoning that traffic flow is unaffected by clouds.[67] 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 nighttime crashes as indicated by the frequency of abnormal vital signs, distribution of Injury Severity Scale scores, or decreased Glasgow Coma 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)	**Patients excluded (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	2598 (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)	1451 (32)
15–24	1995 (29)	1270 (28)
25–34	1449 (21)	967 (21)
≥35	1303 (19)	889 (19)

Data are count (percentage) of each column.

* Bicyclists and other vulnerable road users.

¶ Seatbelts or helmets when indicated.

† Hypotension (BP <100 mm Hg), tachycardia (HR >120 bpm), or tachypnea (RR >25).

§ Decreased consciousness (value <15).

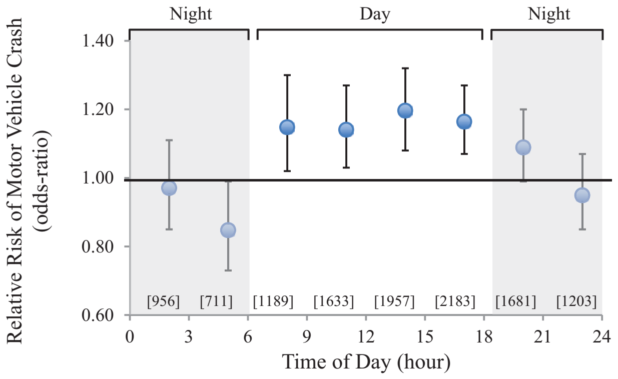

Figure 1. Relative risk of a life-threatening motor vehicle crash associated with bright sunlight according to time of day and accompanied by equivalent nighttime hours of clear sky. X-axis shows time grouped in consecutive 3-hour segments that span full 24-hour interval and center on noon as midpoint. 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	505	1.28	1.14–1.44
Miscellaneous	278	1.34	1.15–1.56
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	1934	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	1839	1.17	1.11–1.25
Unknown	206	1.17	0.98–1.40
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

risk was evident for all demographic subgroups, all traffic groups, and the full range of Injury Severity Scale scores (Table 2). The increased risk was mostly explained by patients who were drivers without alcohol detected and no medical comorbidity. The largest increased risk associated with bright sunlight was among the infrequent patients involved as pedestrians or miscellaneous incidents. All estimates overlapped the primary analysis, all subgroups with at least 500 crashes in bright sunlight showed a statistically significant increased risk, and no subgroup showed a statistically significant contrary result.

The increase in risk associated with bright sunlight involved crashes with diverse features. The increased risk was not confined to the weekend or summer (Table 3), contrary to trends around increased travel from variable driving. The increased risk was not confined to crashes with inexact locations or distant from the trauma center, despite uncertainties in referral or barriers to pre-hospital care. The increased risk spanned the spectrum of life-threatening severity as assessed by ambulance involvement, surgical procedures performed, intensive care unit admission, and length of hospital stay. The largest increased crash risk was for patients who died (n = 707) and showed a 32% increase associated with bright sunlight (95% confidence interval: 13–55).

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]

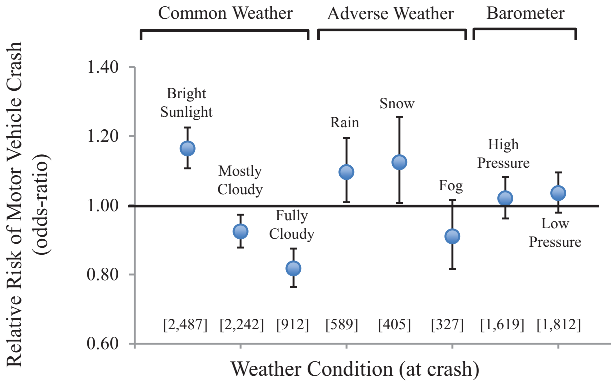

Figure 2. Relative risk of a life-threatening motor vehicle crash associated with bright sunlight and other daytime weather. X-axis shows weather condition starting with bright sunlight and ending with the pair of high barometric pressure (above 100 kPa) and low barometric pressure (below 99 kPa). Y-axis 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.

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).[94–96]

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 by 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]

Acknowledgments

We thank the following for helpful comments: Peter Austin, Junaid Bhatti, Allan Detsky, Michael Fralick, Gordon Guyatt, Katie Herron, Alex Kiss, Avery Nathens, Andrea Phillips, Conrad Pow, Jason Rajchgot, Joel Ray, Jonathan Rolison, Raffi Rush, Shohinee Sarma, Damon Scales, Matthew Schlenker, Francesca Schulten-Baumer, Hal Sox, Robert Tibshirani, Homer Tien, Jason Woodfine, Christopher Yarnell, and Jeremy Zung.

References

[1] Fenelon A, Chen LH, Baker SP. Major causes of injury death and the life expectancy gap between the United States and other high-income countries. JAMA 2016;315:609–11.
[2] WHO. The Top 10 Causes of Death Worldwide. Geneva, Switzerland: World Health Organization; October 2008 [cited June 9, 2015]. Available at: http://www.who.int/mediacentre/factsheets/fs310/en/index.html.
[3] Redelmeier DA, Bayoumi AM. Time lost by driving fast in the United States. Med Decis Making 2010;30:E12–9.
[4] Blincoe L, Seay A, Zaloshnja E, et al. The Economic Impact of Motor Vehicle Crashes, 2000. Dept of Transportation (US), National Highway Traffic Safety Administration (NHTSA), Washington, DC: 2002.
[5] Shackford SR, Mackersie RC, Holbrook TL, et al. The epidemiology of traumatic death: a population-based analysis. Arch Surg 1993;128:571–5.
[6] World Health Organization. Projections of Mortality and Causes of Death, 2015 and 2030. Geneva: World Health Organization; 2015 [cited 2015 July 15, 2015]. Available at: http://www.who.int/healthinfo/global_burden_disease/projections/en/index.html.
[7] Chandran A, Hyder AA, Peek-Asa C. The global burden of unintentional injuries and an agenda for progress. Epidemiol Rev 2010;32:110–20.
[8] Glance LG, Osler TM, Mukamel DB, et al. Outcomes of adult trauma patients admitted to trauma centers in Pennsylvania, 2000-2009. Arch Surg 2012;147:732–7.
[9] Osler T, Glance LG, Li W, et al. Survival rates in trauma patients following health care reform in Massachusetts. JAMA Surg 2015;150:609–15.
[10] Zwingmann J, Hagelschuer P, Langenmair E, et al. Lower health-related quality of life in polytrauma patients: long-term follow-up after over 5 years. Medicine 2016;95:e3515.
[11] Treat JR, Tumbas NS, McDonald ST, et al. Tri-level Study of the Causes of Traffic Accidents: Executive Summary. NHTSA, U S Department of Transportation, Washington, DC:1979.
[12] Evans L. Traffic Safety. Science Serving Society, Bloomfield, MI:2004.
[13] Redelmeier DA, Yarnell CJ. Road crash fatalities on US income tax days. JAMA 2012;307:1486–8.
[14] Singh S. Critical Reasons for Crashes Investigated in the National Motor Vehicle Crash Causation Survey. National Traffic Safety Administration; 2015 [cited September 23, 2015]. Available at: http://www-nrd.nhtsa.dot.gov/Pubs/812115.pdf.

[15] Kahneman D. Thinking, Fast and Slow. Farrar, Straus & Giroux, New York:2011.

[16] Owsley C, McGwin G. Vision and driving. Vis Res 2010;50:2348–61.

[17] Bressan P, Garlaschelli L, Barracano M. Antigravity hills are visual illusions. Psychol Sci 2003;14:441–9.

[18] Horswill MS, Helman S, Ardiles P, et al. Motorcycle accident risk could be inflated by a time to arrival illusion. Optom Vis Sci 2005;82:740–6.

[19] Computational Illusion Team. Optical Illusions on Roads and Measures for Their Reduction. Alliance for Breakthrough between Mathematics and Sciences; July 2013 [cited January 20, 2015]. Available at: http://compillusion.mims.meiji.ac.jp/pdf/roadillusions_eng.pdf.

[20] Cavallo V, Colomb M, Doré J. Distance perception of vehicle rear lights in fog. Hum Fact 2001;43:442–51.

[21] Ichihara S, Kitagawa N, Akutsu H. Contrast and depth perception: effects of texture contrast and area contrast. Perception 2007;36:686–95.

[22] Leonardo da V. Treatise on Painting, translated and annotated by McMahon AP. Princeton University Press, Princeton, NJ:1956.

[23] Fry GA, Bridgman CS, Ellerbrock VJ. The effects of atmospheric scattering on binocular depth perception. Am J Optom 1949;26:9–15.

[24] Ross HE. Water, fog and the size-distance invariance hypothesis. Brit J Psychol 1967;58:301–13.

[25] O'Shea RP, Blackburn SG, Ono H. Contrast as a depth cue. Vis Res 1994;34:1595–604.

[26] Brooks K. Stereomotion speed perception is contrast dependent. Perception 2001;30:725–31.

[27] Tversky A, Kahneman D. Judgment under uncertainty: heuristics and biases. Science 1974;185:1124–31.

[28] Redelmeier DA, Tibshirani RJ. Why cars in the next lane seem to go faster. Nature 1999;401:35.

[29] McKenna FP, Albery IP. Does unrealistic optimism change follow a negative experience? J Appl Soc Psychol 2001;31:1146–57.

[30] Evans L. Traffic fatality reductions: United States compared with 25 other countries. Am J Public Health 2014;104:1501–7.

[31] Traffic Safety Facts [Internet]. U.S. Department of Transportation: National Highway Traffic Safety Administration; 1994–2013 [cited January 1, 2015]. Available at: http://www-nrd.nhtsa.dot.gov/cats/listpublications.aspx?Id=E&ShowBy=DocType.

[32] Boulanger BR, McLellan BA, Sharkey PW, et al. A comparison between a Canadian regional trauma unit and an American Level I trauma center. J Trauma 1993;35:261–6.

[33] Brenneman FD, Boulanger BR, McLellan BA, et al. Acute and long-term outcomes of extremely injured blunt trauma victims. J Trauma 1995;39:320–4.

[34] Sunnybrook Health Sciences Center. Annual Report 2010–2011. Toronto: Sunnybrook Health Sciences Center; 2015. p. 5–6.

[35] Kondziolka D, Schwartz ML, Walters BC, et al. The Sunnybrook neurotrauma assessment record: improving trauma data collection. J Trauma 1989;29:730–5.

[36] Walters BC, McNeill I. Improving the record of patient assessment in the trauma room. J Trauma 1990;30:398–409.

[37] Tien HC, Spencer F, Tremblay LN, et al. Preventable deaths from hemorrhage at a Level I Canadian trauma center. J Trauma 2007; 62:14–6.

[38] Pirouzmand F. Epidemiological trends of spine and spinal cord injuries in the largest Canadian adult trauma center from 1986 to 2006. J Neurosurg Spine 2010;12:131–40.

[39] Cusimano M, Marshall S, Rinner C, et al. Patterns of urban violent injury: a spatio-temporal analysis. PLoS One 2010;5:e8669.

[40] Davidson GH, Hamlat CA, Rivara FP, et al. Long-term survival of adult trauma patients. JAMA 2011;305:1001–7.

[41] Morrison LJ, Baker AJ, Rhind SG, et al. The Toronto prehospital hypertonic resuscitation: head injury and multiorgan dysfunction trial: feasibility study of a randomized controlled trial. J Crit Care 2011; 26:363–72.

[42] Cuschieri J, Johnson JL, Sperry J, et al. Inflammation and Host Response to Injury, Large Scale Collaborative Research Program. Benchmarking outcomes in the critically injured trauma patient and the effect of implementing standard operating procedures. Ann Surg 2012;255:993–9.

[43] Statistics Canada. Land and Freshwater Area, by Province and Territory. 2005 [cited August 15, 2015]. Available at: http://www.statcan.gc.ca/tables-tableaux/sum-som/l01/cst01/phys01-eng.htm.

[44] Kelusky R. 2001 Geocode Street Guide. Toronto Works and Emergency Services, Toronto:2001.

[45] Haas B, Doumouras AG, Gomez D, et al. Close to home: an analysis of the relationship between location of residence and location of injury. J Trauma Acute Care Surg 2015;78:860–5.

[46] Schuurman N, Hameed SM, Fiedler R, et al. The spatial epidemiology of trauma: the potential of geographic information science to organize data and reveal patterns of injury and services. Can J Surg 2008;51:389–95.

[47] Hameed SM, Schuurman N, Razek T, et al. Access to trauma systems in Canada. J Trauma 2010;69:1350–61.

[48] Ahmed MM, Abdel-Aty M, Lee J, et al. Real-time assessment of fog-related crashes using airport weather data: a feasibility analysis. Accid Anal Prev 2014;72:309–17.

[49] Winters M, Friesen MC, Koehoorn M, et al. Utilitarian bicycling: a multilevel analysis of climate and personal influences. Am J Prev Med 2007;32:52–8.

[50] Fralick M, Denny CJ, Redelmeier DA. Drowning and the influence of hot weather. PLoS One 2013;8:e71689.

[51] Meteorological Service of Canada. Environment Canada; 1994–2014 [cited June 1, 2015]. Available at: http://climate.weather.gc.ca/historical_data/search_historic_data_e.html.

[52] Meteorological Service of Canada. Glossary. Environment Canada; 1994–2014 [cited June 15, 2015]. Available at: http://climate.weather.gc.ca/glossary_e.html.

[53] Manual of Surface Weather Observation. Environment Canada; April 2015 [cited August 1, 2015]. Available at: http://www.ec.gc.ca/manobs/73BC3152-E142–4AEE-AC7D-CF30DAFF9F70/MANOBS_7E-A19_Eng_web.pdf.

[54] Richter ED, Barach P, Ben-Michael E, et al. Death and injury from motor vehicle crashes: a public health failure, not an achievement. Inj Prev 2001;7:176–8.

[55] Redelmeier DA, Stewart CL. Driving fatalities on Super Bowl Sunday. N Engl J Med 2003;348:368–9.

[56] Redelmeier DA, Stewart CL. The fatal consequences of the Superbowl telecast. Chance 2005;17:19–24.

[57] Maguire LH, Song M, Strate LL, et al. Association of geographic and seasonal variation with diverticulitis admissions. JAMA Surg 2015; 150:74–7.

[58] Janes H, Sheppard L, Lumley T. Case-crossover analyses of air pollution exposure data: referent selection strategies and their implications for bias. Epidemiology 2005;16:717–26.

[59] Bhatti JA, Nathens AB, Thiruchelvam D, et al. Self-harm emergencies after bariatric surgery: a population-based cohort study. JAMA Surg 2016;151:226–32.

[60] Redelmeier DA, Tibshirani RJ. A simple method for analyzing matched designs with double controls: McNemar's test can be extended. J Clin Epidemiol 2016;[Epub ahead of print].

[61] Hosmer D, Lemeshow S. Applied Logistic Regression. 2nd ed. 2000; Wiley and Sons, New York:243-259.

[62] Arfken CL. Temporal pattern of alcohol consumption in the United States. Alcohol Clin Exp Res 1988;12:137–42.

[63] Hu PS, Reuscher TR. Summary of Travel Trends: 2001 National Household Travel Survey. US Department of Transportation. 2004 [cited November 17, 2015]. Available at: http://nhts.ornl.gov/2001/pub/stt.pdf.

[64] Cambridge Systematics Inc. Traffic Congestion and Reliability. Federal Highway Administration. 2005 [cited November 10, 2015]. Available at: http://www.ops.fhwa.dot.gov/congestion_report/congestion_report_05.pdf.

[65] Richter M, Krettek C, Otte D, et al. Correlation between crash severity, injury severity, and clinical course in car occupants with thoracic trauma: a technical and medical study. J Trauma 2001;51:10–6.

[66] Aarts L, van Schagen I. Driving speed and the risk of road crashes: a review. Accid Anal Prev 2006;38:215–24.

[67] Edwards JB. Speed adjustment of motorway commuter traffic to inclement weather. Transp Res F Traffic Psychol Behav 1999;2:1–4.

[68] Brown ID. Driver fatigue. Hum Fact 1994;36:298–314.

[69] Unrau D, Andrey J. Driver response to rainfall on urban expressways. J Transp Res Board 2006;1980:24–30.

[70] Redelmeier DA. The fallacy of interpreting deaths and driving distances. Med Decis Making 2014;34:940–3.

[71] Woodfine JD, Redelmeier DA. Berkson's paradox in medical care. J Intern Med 2015;278:424–6.

[72] Redelmeier DA, Yarnell CJ. Lethal misconceptions: interpretation and bias in studies of traffic deaths. J Clin Epidemiol 2012;65:467–73.

[73] Cummings P, McKnight B, Rivara FP, et al. Association of driver air bags with driver fatality: a matched cohort study. BMJ 2002;324:1119–22.

[74] Evans L. Traffic Safety. 2004;Science Serving Society, Bloomfield, MI:247–248.

[75] Galin D. Speeds on two-lane rural roads: a multiple regression analysis. Traffic Eng Control 1981;22:453–60.
[76] Schwarz N, Clore GI. Mood, misattribution, and judgments of well-being: informative and directive functions of affective states. J Pers Soc Psychol 1983;45:13–23.
[77] Rosenbaum PR. The consequences of adjustment for a concomitant variable that has been affected by the treatment. J Roy Stat Soc (General) 1984;147:656–66.
[78] Schisterman EF, Cole SR, Platt RW. Overadjustment bias and unnecessary adjustment in epidemiologic studies. Epidemiology 2009; 20:488–95.
[79] Greenland S, Robins JM. Identifiability, exchangeability and confounding revisited. Epidemiol Perspect Innov 2009;6:4.
[80] Ontario Ministry of Transport. The Official MTO Driver's Handbook: XI. Driving at night and in bad weather. 2015 [cited April 15, 2015]. Available at: http://www.mto.gov.on.ca/english/dandv/driver/handbook/section2.11.4.shtmls.
[81] GOV.UK The Highway Code. Driving in Adverse Weather Conditions [Internet]. 2015 [cited July 31, 2015]. Available at: https://www.gov.uk/driving-adverse-weather-conditions-226-to-237/.
[82] Horswill MS, Waylen AE, Tofield MI. Drivers' ratings of different components of their own driving skill: a greater illusion of superiority for skills that relate to accident involvement. J Appl Soc Psychol 2004;34:177–95.
[83] Center for Excellence in Rural Safety. National Rural Road Safety Public Opinion Survey. [March 2010, cited April 2015]. Available at: http://www.ruralsafety.umn.edu/publications/nationalsafetysurvey/documents/factsheet.pdf.
[84] Amado S, Arikan Elvan , Kaca G, et al. How accurately do drivers evaluate their own driving behavior? An on-road observational study. Accid Anal Prev 2014;63:65–73.
[85] California State Transportation Agency. Driver Handbook 2015 (English). 2015 [cited April 15, 2015]. Available at: https://www.chp.ca.gov/CommunityOutreachAndMediaRelationsSite/Documents/caDriverHandbook.pdf.
[86] GOV.UK The Highway Code. Driving in Adverse Weather Conditions [Internet]. 2015 [cited July 31, 2015]. Available at: https://www.gov.uk/driving-adverse-weather-conditions-226-to-237/.
[87] Ontario Ministry of Transport. The Official MTO Driver's Handbook. 2015 [cited April 15, 2015]. Available at: http://www.mto.gov.on.ca/english/dandv/driver/handbook/index.shtml.
[88] National Motorists Association. Where are You Most Likely to Get a Speeding Ticket This Holiday Weekend. NMA Press Release. May 22, 2012 [cited October 1, 2015]. Available at: https://www.motorists.org/press/speeding-tickets-by-state/.
[89] Lakey J. Traffic Safety is Far Down the List of Reasons for Speed Traps. The Toronto Star [Internet]. March 13, 2013 [cited July 28, 2015]. Available at: http://www.thestar.com/news/the_fixer/2013/03/traffic_safety_is_far_down_the_list_of_reasons_for_speed_traps.html.
[90] Corby S. In Australia, a Revolt Against the Almighty Speed Camera. Car and Driver. [Internet]. February 2014 [cited September 25, 2015]. Available at: http://www.caranddriver.com/columns/stephen-corby-a-revolt-against-the-almighty-speed-camera-column.
[91] Campbell A, Taggart K. The Ticket Machine. Buzzfeed [Internet]. January 26, 2016. [cited January 27, 2016]. Available at: http://www.buzzfeed.com/alexcampbell/the-ticket-machine#.qtNKgx3nRb.
[92] Vanderbilt T. Traffic: Why We Drive the Way We Do. Vintage Canada Ltd, Toronto, ON:2009.
[93] Parker-Pope T. No Respect for Speed Limits. New York Times. [Internet]. November 10, 2008 [cited November 20, 2015]. Available at: http://well.blogs.nytimes.com/2008/11/10/no-respect-for-speed-limits/.
[94] Unni P, Morrow SE, Shultz BL, et al. A pilot hospital-school educational program to address teen motor vehicle safety. J Trauma Acute Care Surg 2013;75(4 Suppl 3):S285–9.
[95] Redelmeier DA, Tien HC. Medical interventions to reduce motor vehicle collisions. CMAJ 2014;186:118–24.
[96] Redelmeier DA, May SC, Thiruchelvam D, et al. Pregnancy and the risk of a traffic crash. CMAJ 2014;186:742–50.
[97] Davis JR, Stepanek J, Johnson R, et al. Aerospace Medicine. 2008; Lippincott Williams and Wilkins, Philadelphia, PA:166.
[98] Douglas S. Why running at night feels faster. Runners World [Internet]. October 19, 2012 [cited September 8, 2015]. Available at: http://www.runnersworld.com/newswire/why-running-at-night-feels-faster.
[99] Parry D, Chinnasamy C, Micklewright D. Optic flow influences perceived exertion during cycling. J Sport Exer Psychol 2012;34: 444–56.
[100] Summala H, Hietamäki J. Drivers' immediate responses to traffic signs. Ergonomics 1984;27:205–16.
[101] Weinstein ND, Klein WM. Unrealistic optimism: present and future. J Soc Clin Psychol 1996;15:1–8.
[102] Bonneh YS, Cooperman A, Sagi D. Motion-induced blindness in normal observers. Nature 2001;411:798–801.
[103] Theeuwes J, Alferdinck JWAM, Perel M. Relation between glare and driving performance. Hum Fact 2002;44:95–107.
[104] Gray R, Regan D. Glare susceptibility test results correlate with temporal safety margin when executing turns across approaching vehicles in simulated low-sun conditions. Opthal Physiolo Opt 2007;27:440–50.
[105] Pashkam MV, Cavanagh P. Blur increases perceived speed. J Vis 2008;8:605.
[106] Mitra S. Sun glare and road safety: an empirical investigation of intersection crashes. Saf Sci 2014;70:246–54.
[107] U.S., Preventive Services Task ForceCounseling about proper use of motor vehicle occupant restraints and avoidance of alcohol use while driving: U.S. Preventive Services Task Force recommendation statement. Ann Intern Med 2007;147:187–93.
[108] Goodwin A, Kirley B, Sandt L, et al. Countermeasures That Work: A Highway Safety Countermeasures Guide for State Highway Safety Offices. 7th ed. (Report No. DOT HS 811 727). National Highway Traffic Safety Administration, Washington, DC:2013.