Does Wildlife-Vehicle Collision Frequency Increase on Full Moon Nights? A Case-Crossover Analysis

Kentaro Iio, Dominique Lord

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Highlights

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- We counted nighttime wildlife-vehicle collisions (WVCs) over 112 synodic periods.
- Full moon nights had nearly 46% more WVCs than new moon nights.
- The effect was more apparent in rural areas than urban areas.
- Non-WVCs showed no statistical difference between the two lunar phases.
- Where wild animals are, it is better to drive carefully even on bright nights.

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Kentaro Iio[a], Dominique Lord[b]

[a]*Brahe, Imazucho Otomo, Takashima, 520-1635, Shiga, Japan*
[b]*Zachry Department of Civil and Environmental Engineering, Texas A&M University, 3127 TAMU, College Station, 77843-3127, Texas, United States*

Abstract

Wildlife-vehicle collisions (WVCs) raise concerns for both human safety and animal welfare. As the literature has reported increased animal-related crash frequency on full moon nights in several regions, we investigated if a similar pattern is observed in Texas. We counted WVC and non-WVC frequencies on full moon nights and new moon nights in Texas between January 2011 and January 2020. The analysis revealed a 45.80% (95% confidence interval (CI): 29.94%–61.29%) increase in WVCs on full moon nights compared to new moon nights, with no statistically significant difference for non-WVCs (95% CI: -2.58%–1.45%). The association was more pronounced in rural areas than in urban areas. It is likely that brighter moonlight is strongly associated with higher WVC rates. The results illuminate the importance of heightened caution for drivers even on bright nights, particularly when driving through areas with high wildlife density.

Keywords: wildlife-vehicle collision, synodic month, lunar phase, roadkill, wildlife protection

1. Introduction

"*O, swear not by the moon, th' inconstant moon, That monthly changes in her circled orb, Lest that thy love prove likewise variable.*" As Shakespeare (1597) depicted in *Romeo and Juliet*, the Moon changes its appearance moment by moment. The celestial object has been present in mythology, folklore, and superstitions since ancient times. Even in modern times, some people believe that the changes in lunar phases are correlated with various phenomena in our daily lives (Meyer-Rochow et al., 2021; Stomp et al., 2011).

In the field of highway safety, some researchers have also explored the potential relationship between crash frequency and lunar phases. So far, the studies have been mixed about whether crashes increase during certain lunar phases (Colino-Rabanal et al., 2018; Laverty et al., 1992; Vrkljan et al., 2020). Because few studies have distinguished the effects of traffic exposure from those attributed to lunar illumination, the objective of this study was to fill this gap by focusing on the effect of Moon illumination on crash risk. In the next section, we review literature to summarize what has been revealed and highlight the challenges that remain.

2. Literature review

One of the early studies on the relationship between moon phases and crashes was done by Templer et al. (1982), who claimed statistically significant increases in crash frequency in California, Illinois, and Texas on nights with the new or full moon in 1980. However, the work was later criticized (Kelly and Rotton, 1983) for using data only from one year because a disproportionately large portion of the new moon days and full moon days were Fridays and Saturdays in 1980. Later, Laverty et al. (1992) reviewed crash records in Saskatchewan, Canada, between 1984 and 1989 and reported no statistically significant differences in overall crash frequency by lunar phase.

Redelmeier and Shafir (2017) compared the distributions of fatal crash frequency on full moon nights against the mean fatal crash frequency of the nights a week before and after the full moon nights, which controlled weekday, yearly, and seasonal trends (Redelmeier and Tibshirani, 2018). They found that full moon nights were associated with a 5% increase in motorcycle fatalities in the United States between 1975 and 2014 compared to the control. The researchers attributed the observed difference to the riders' momentary distractions by the full moon. However, their findings do not automatically lead to the explanations they claimed because the researchers did not test for human distractions. As recent research suggests that motorcyclists are more likely to suffer serious injuries in wildlife-vehicle collisions (WVCs) compared to car occupants (Bíl et al., 2024), it is not out of the question that their study findings could be attributed to WVCs.

While the four aforementioned studies were not limited to WVCs (Kelly and Rotton, 1983; Laverty et al., 1992; Templer et al., 1982; Redelmeier and Shafir, 2017), multiple recent studies have specifically investigated potential relationships between lunar phases and WVCs. Colino-Rabanal et al. (2018) studied crash frequencies with four ungulate species: 3,815 wild boars (*Sus scrofa*), 1,892 roe deer (*Capreolus capreolus*), and 565 red deer (*C. elaphus*) in Spain as well as 35,831 white-tailed deer (*Odocoileus virginianus*) in New York. In their data, the crash frequency peaked on the full moon days among the species except for red deer. In particular, roe deer crash frequency was higher by 71.3% on the full moon days than on new moon days. Muller et al. (2014) examined 1,220 white-tailed deer crashes in Tennessee from 1975 to 2008 and found increased crash frequency only during the deer gestation seasons. They mentioned the animal's dispersal events as a probable cause of the association. Laliberté and St-Laurent (2020) looked into 198 moose and 252 white-tailed deer collisions in Québec, Canada, between 1990 and 2015. Using telemetry data from the cervids, the researchers concluded the cervids' spatiotemporal movement patterns were the main factor in the WVC frequency. Steiner et al. (2021) investigated 11,771 roe deer roadkills in Austria. They found relatively high frequency in roadkills in May, October, and November as well as Fridays and full moon days. While they listed hunting activities as a potential contributing factor to the monthly variation, they insisted on the existence of more prominent unknown factors for seasonal variation. In Croatia, Vrkljan et al. (2020) reviewed 436 WVC records from 2012 and 2016. They found no significant associations between roe deer or wild boar crash frequency and lunar phase.

In recent years, scientists have tried to capture the relationship at higher resolutions. For example, Ignatavičius et al. (2021) analyzed the 14,437 WVC police reports in Lithuania from 2014 to 2018. They reported a weak positive rank correlation between the illuminated percentage of the lunar disk and WVCs. In Slovenia, Cerri et al. (2023) looked into the effect of lunar phase and cloud cover on 49,259 European deer roadkill counts between 2010 and 2019. The study reported an increase in roadkill frequency along with an increase in the illuminated portion of the moon.

A series of recent studies have found fluctuations in WVC frequency along a synodic month (Cerri et al., 2023; Colino-Rabanal et al., 2018; Ignatavičius et al., 2021; Steiner et al., 2021). Although these results could be useful for transportation agencies in formulating policies and regulations from an ecological standpoint, they do not provide good evidence of a driver's crash risk. This is because they did not distinguish between the effect of illumination of the Moon and potential traffic volume difference during hours the Moon was visible. For example, both the first-quarter moon and the third-quarter moon have approximately half of the lunar disk illuminated, but they culminate at different times. Because the traffic volumes while the Moon is above the horizon may differ as well, it would be misleading to conclude that the crash risk for a driver is increased or decreased due to moonlight on those nights by averaging these two moon phases. The distinction between the effects of traffic exposure and the lunar illumination on crash frequency would be beneficial when one desires to form a policy based on a driver's perspective (i.e., risk per exposure).

Previous studies have essentially investigated the relationship between crash frequency and the lunar phase as a calendar rather than addressing its illumination (Cerri et al., 2023; Colino-Rabanal et al., 2018; Ignatavičius et al., 2021; Steiner et al., 2021; Vrkljan et al., 2020). To the authors' knowledge, no study has extracted the direct effect of the Moon illumination by controlling the hours the Moon appears above the horizon. This study aimed to fill this research gap.

Ideally, research of this kind should be conducted regionally because wildlife species, their distribution, and their behavior can vary across different regions. In light of this, our study examined the relationship between lunar illumination and the frequency of WVCs in Texas by testing the null hypothesis that there is no difference in WVC frequency between full moon nights and new moon nights.

3. Methods

The present study implemented a matched design with double controls (Redelmeier and Tibshirani, 2018), an approach to compare the frequency of count data while minimizing the effects of unmeasured confounders. In this design, two control groups with temporal symmetry with the day of interest are established. One then tests whether the total event frequency in the control groups is twice the frequency of the events on the day of interest. Previously, Redelmeier and Shafir (2017) used the days one week before and after the full moon as double controls, but we compared nightly crash counts on full moon days (y_{fm}) against the nights two weeks before ($y_{\text{nm,p}}$) and after ($y_{\text{nm,f}}$) the full moon as double controls to avoid the indeterminacy attributed to the correlation between the lunar phase and the time during the night the Moon is above the horizon.

We obtained 4,525,048 crash records from the Texas Department of Transportation Crash Records Information System (CRIS) (Texas Department of Transportation, 2023) between January 4–5, 2011 (new moon), and January 24–25, 2020 (new moon). Although the database had more recent data, we did not use data after January 25, 2020, to avoid capturing travel pattern changes during the coronavirus 2019 (COVID-19) pandemic (Cerri et al., 2023; García-Martínez-de Albéniz et al., 2022; Iio et al., 2021). Among the obtained crashes, the records whose contributing factor 1 and contributing factor 2 were "ANIMAL ON ROAD - WILD" were extracted. Because the state had "ANIMAL ON ROAD - DOMESTIC" as a separate contributing factor, domestic animals were not explicitly included in our analysis.

Analyses were performed with Microsoft Excel 16.86, Python 3.10.9, and R 4.4.1. To ensure that we only study nighttime crashes, the study hours were determined to be between 11:00 p.m. and 4:15 a.m. by filtering hours meeting the following conditions:

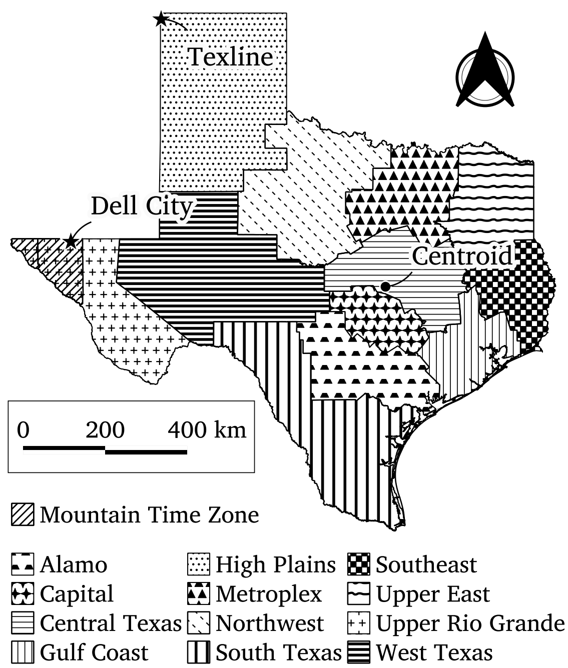
- A: The latest transition from astronomical twilight to night in Texline, Texas, and the earliest transition from night to astronomical twilight in Dell City, Texas[1] (Time and Date AS, 2023).
- B: On full moon nights, hours when the Moon was completely above the horizon.
- C: On new moon nights, hours when the Moon was completely below the horizon.

After filtering the reported crashes satisfying condition A, 13,815 WVCs and 426,238 non-WVCs remained. Using *Python Lunar* 0.6.0 (Reuter, 2020), we computed the Moon's fractional phase (between 0

[1]Texline is located near the northwestern corner of the Texas Panhandle. Dell City is situated near the northeastern corner of Hudspeth County. While most of Texas observes the Central Time Zone, Hudspeth County follows Mountain Time. As a result, sunrise in Dell City appears earlier on clocks than the eastern parts of Texas. Similarly, sunset in Texline comes later on clocks than in the westernmost city of Texas.

and 1) at the midpoint of the observation hours (1:37:30 a.m.) viewed from the centroid (geographic coordinates: 31.014277, -97.615659) of the 13,815 WVCs (Figure 1). One hundred twelve nights were selected as full moon nights. Because one synodic month is 29.53 days on average (Chapront-Touze and Chapront, 1988), the preceding control nights and following control nights were determined as 14 nights before and after the full moon nights, respectively. The mean fractional lunar phases were 1.00 (standard deviation (SD) < 0.01) for the full moon nights and 0.01 ($SD = 0.01$) for both control nights. Because the fractional phase of the moon was quite small on the control nights, they are referred to as new moon nights hereafter.

Figure 1: Map of the centroid and Texas economic regions.



Conditions B and C were considered true when $0.5\theta_M < h_M$ and $h_M < -0.5\theta_M$, respectively, where θ_M denotes lunar angular size in degrees and h_M denotes lunar altitude in degrees. In this dataset, condition A had already satisfied conditions B or C.

Using the *moonlit* R package (Śmielak, 2023), the mean moonlight intensity at the centroid on the full moon nights was calculated to be 0.32 ($SD = 0.07$) lx. In interpreting the results, moonlight intensity, nevertheless, should be considered on an ordinal scale or lower in this study. This is because moonlight intensity varies depending on time and location though there is a positive rank correlation between the Moon's fractional phase and nightly average moonlight intensity at a given location on the Earth.

There were 1,359 reported WVCs on the full moon nights and new moon nights. We extracted non-WVCs (n = 42,349) in the same manner to see if any difference in crash frequency between the full moon nights and new moon nights was specific to WVCs.

The 95% confidence intervals (CIs) of relative risks of full moon nights against new moon nights were calculated. When there were fewer than 500 crashes on the control nights, the small sample size bias was corrected using a method proposed by Hauer (1997). To assess the consistency of the results, the analysis was performed not only for the entire state of Texas, but also across different levels of urbanization defined by the Texas Department of Transportation, as well as 12 economic regions (Texas Comptroller of Public Accounts, 2024) (Figure 1) and seasons.

4. Results

Table 1 presents the descriptive statistics of reported crash counts, while Figure 2 displays the histograms of nightly WVC counts. During the study period, 573 WVCs (5.12 crashes per night) had been reported on the full moon nights whereas 786 WVCs (3.51 crashes per night) had occurred on the new moon nights. For WVCs, the relative risk of the full moon nights compared to the new moon nights was 1.46 (95% CI: 1.30–1.61), indicating significantly more frequent WVCs on the full moon nights than the new moon nights. On the other hand, 14,063 non-WVCs (125.56 crashes per night) and 28,286 non-WVCs (126.28 crashes per night) had been recorded on the full moon nights and new moon nights, respectively. The relative risk of the full moon nights compared to the new moon nights was 0.99 (95% CI: 0.97–1.01) for non-WVCs, which was not different from 1 at the 5% significance level.

Table 1: Descriptive statistics of crash counts

Group	*n*	*S*	*M*	*SD*	*Min*	*Mdn*	*Max*	*Skw*	*Krt*	*VMR*	*PZ*
WVC											
Full moon	112	573	5.12 (4.58–5.76)	3.18 (2.66–4.08)	0	5	19	1.27	3.00	1.98	3.57
Preceding control	112	411	3.67 (3.26–4.15)	2.41 (2.04–2.94)	0	3	13	1.15	1.78	1.58	3.57
Following control	112	375	3.35 (2.93–3.85)	2.48 (2.10–2.95)	0	3	11	1.21	1.31	1.84	6.25
Non-WVC											
Full moon	112	14,063	125.56 (113.91–138.50)	66.48 (59.24–73.29)	40	96	275	0.84	-0.68	35.19	0.00
Preceding control	112	14,354	128.16 (115.80–142.09)	70.91 (62.65–81.58)	43	99	360	0.98	0.00	39.24	0.00
Following control	112	13,932	124.39 (112.81–137.82)	67.33 (59.26–77.30)	44	96	341	1.03	0.04	36.45	0.00

Note. n = sample size; S = sum; M = mean; SD = standard deviation; Min = minimum; Mdn = median; Max = maximum; Skw = skewness; Krt = kurtosis; VMR = variance-to-mean ratio; PZ = percentage-of-zeros; Brackets indicate 95% bias-corrected and accelerated (BCa) bootstrap intervals with 100,000 resampling.

Figure 3 plots the estimated relative risks on the full moon nights compared to the new moon nights by spatial and temporal crash characteristics.

For WVCs, the relative risks of the full moon nights were 1.23 (95% CI: 0.89–1.57) in urbanized areas and 1.50 (95% CI: 1.32–1.67) in rural areas, indicating a pronounced risk in rural areas whereas the increase

Figure 2: Histograms of WVCs on the nights with a preceding new moon, full moon, and following new moon.

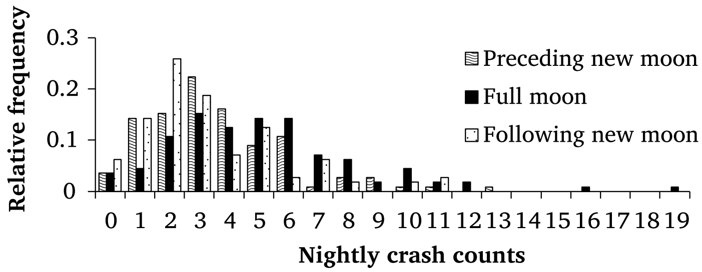
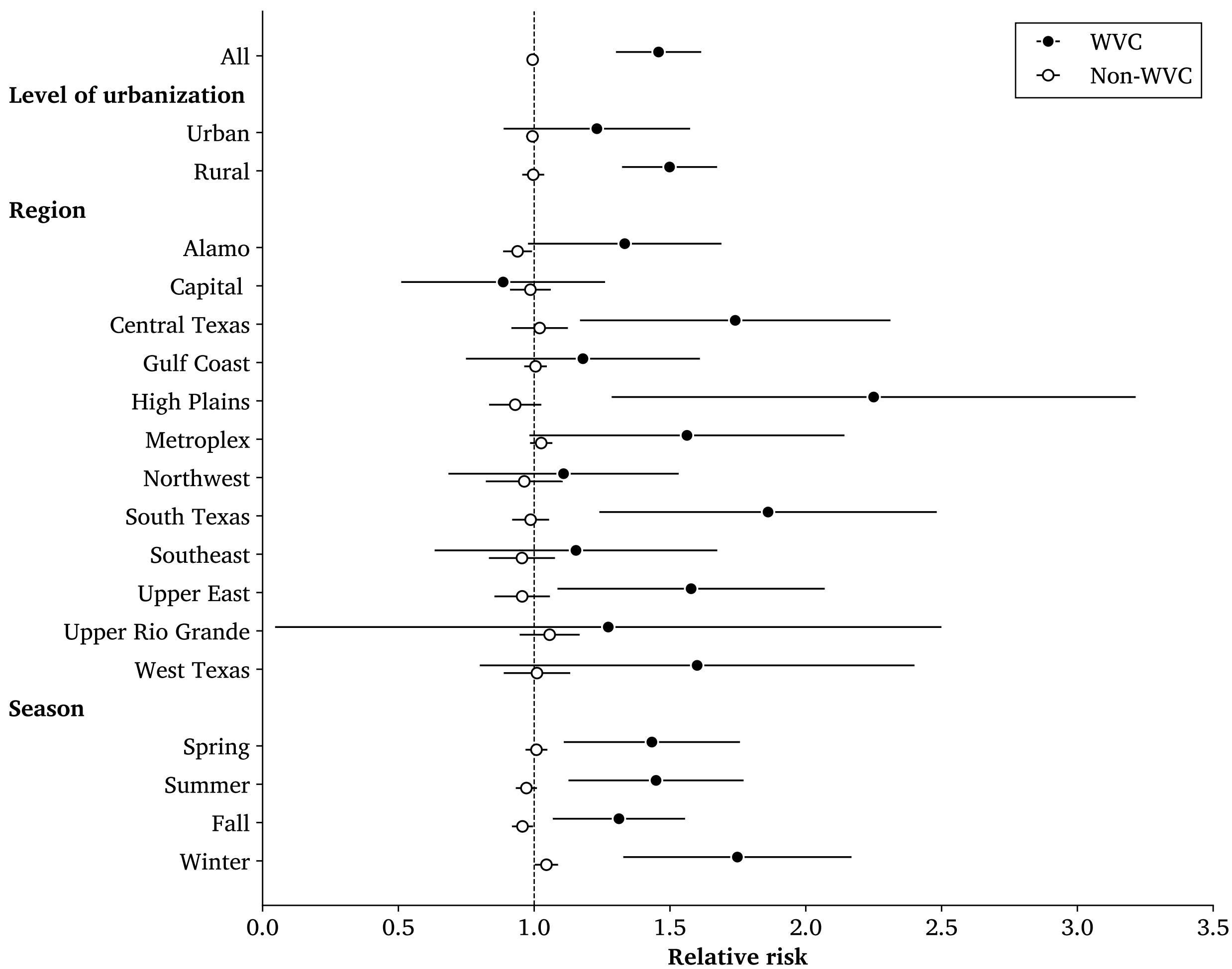


Figure 3: Estimated relative risks on full moon nights compared to new moon nights by crash subgroups.



Note. Bars indicate 95% CIs.

was not statistically significant in urban areas. For non-WVCs, the effect of the full moon was insignificant in both urban (95% CI: 0.97–1.02) and rural (95% CI: 0.96–1.04) areas.

The relative risk of WVCs on full moon nights was greater than 1 in all regions except the Capital region (95% CI: 0.51–1.26). However, the increase in the relative risk was statistically significant in only four regions: Central Texas (95% CI: 1.17–2.31), High Plains (95% CI: 1.29–3.21), South Texas (95% CI: 1.24–2.48), and Upper East (95% CI: 1.09–2.07). On the other hand, the relative risk of non-WVCs did not differ significantly from 1 in all regions except the Alamo region, where a slight decrease was observed (95% CI: 0.89–0.99).

Throughout all seasons, the relative risk of WVCs on full moon nights was significantly greater than 1. In contrast, there was no consistent directional deviation from a relative risk of 1 for non-WVCs across different seasons. For non-WVCs, the relative risks were not significantly different from 1 in spring and summer. The upper bound of the relative risk was 0.004 smaller than 1 in fall, and the lower bound was 0.002 greater than 1 in winter, but the absolute values of these deviations, practically speaking, were smaller than WVCs. We would like to note that inter-seasonal comparisons are not feasible here because seasonal differences in traffic volume have not been accounted for.

5. Discussion

This study investigated if a full moon is associated with higher nightly crash frequency in Texas. To assess the effect of Moon illumination as purely as possible, we compared the nightly crash frequency with a full moon and a new moon in a matched design with double controls. The observed increase in WVC frequency on full moon nights was consistent with existing literature on WVCs in several regions (Cerri et al., 2023; Colino-Rabanal et al., 2018; Ignatavičius et al., 2021). In this sense, this study strengthened the hypothesis that the illumination of a full moon is associated with increased WVC frequency. It was intriguing that the relative risk of a full moon night was as large as 1.46. Given a matched design with double controls used in our study, the impact of the full moon seems larger than previously thought. On the other hand, statewide non-WVC counts did not significantly increase or decrease on the full moon days from the new moon days.

Looking at various regions, there were places where the effect of the full moon was stronger and places where it was weaker. The effect of the full moon on WVC counts was more apparent in rural areas compared to urban areas (Figure 3). As unobserved heterogeneity (especially wildlife habitats) can naturally lead to regional variations in crash risks, the observed variations across different regions were not surprising. After all, while non-WVCs in some subgroups exhibited statistically significant deviations from a relative risk of 1, those effect sizes remained small. Furthermore, there was no consistency in terms of deviation directions across the characteristics in non-WVCs.

While a correlation does not imply causality, our findings might have emerged as a result of an underlying cause-effect relationship because the moon phase had temporal precedence to crashes, external factors were matched in the study design, and no immediate alternative explanations were identified. Human or wildlife activities do not severely impact Earth's rotation or the Moon's orbital motion, whereas lunar illumination could impact human and wildlife activities, leading to crash occurrences. Likewise, the occurrence of individual crashes does not practically influence regionwide human and animal activities. Furthermore, no significant increase was found in the frequency of non-WVCs with a full moon, suggesting that a notable increase in overall vehicular traffic volumes on full moon nights was unlikely.

Collectively, the findings allude to a possible idea that some wildlife activity levels are higher on nights with a full moon than on the darker ones, as perhaps animals can see more of their environment under a full moon. However, we refrain from diving into the details of this explanation because the authors do not specialize in animal ecology. At the end of the day, this hypothesis should be further investigated by wildlife professionals, and the findings call for a need for collaboration between transportation professionals and animal ecologists.

5.1. Limitations

Because we did not have information about wildlife species involved in each crash, examining each crash report to identify the type of animal was beyond the scope of the study. In this regard, our study did not have the resolutions that some of the earlier studies (Cerri et al., 2023; Colino-Rabanal et al., 2018; Ignatavičius et al., 2021; Steiner et al., 2021) had. While prevalent deer species in Texas include white-tailed deer and mule deer (*O. hemionus*) (Avey et al., 2003; Krausman, 1978), further studies would be required to reach species-specific conclusions. Additional regional studies with information on species would shed light on the unobserved heterogeneity.

We would like to reiterate that the level of measurement of lunar illumination intensity in this study's context remains an ordinal scale. If one wishes to treat lunar illumination on an interval scale or higher, one option is to perform a retrospective study using software that estimates moonlight illumination with high precision (Śmielak, 2023) and traffic volume data with a finer spatiotemporal resolution. Because Moon illumination and traffic volume are both strongly linked to the time of night, it may be possible to evaluate the contribution of lunar illumination on a higher level of measurement if spatiotemporally finer traffic volume data become available in the next decade or so.

6. Conclusions

One might think that driving is safer with a brighter Moon because objects are more visible thanks to the moonlight. However, our study illuminates the importance of heightened caution for drivers even on brighter nights in Texas, particularly when you drive in areas with high wildlife density. The finding that WVCs increase on full moon nights can be an interesting trivia, but what matters more is how to use this information to prevent future crashes. If many road users become aware of these findings and use a full moon as a reminder to behave more cautiously (e.g., by avoiding speeding on rural highways), that could save both human and animal lives. If the difference in crash rates observed in this study is not only due to the lunar phase as a calendar but also is attributed to the brightness of the Moon, which may well be possible, then there should be room to prevent WVCs on nights with the other lunar phases as well.

Since this study did not find a statistically significant statewide increase in non-WVCs on full moon nights, the results do not seem to be immediately relevant in areas with little wildlife. Nevertheless, the findings underscore an important aspect of traffic safety policies: even a slight difference in safety can manifest as a clear contrast when there is extensive exposure (e.g., observed across the entire road network, a highway segment driven by many drivers over and over). As a road user, it is difficult to perceive in daily life that the "crash modification factor" of moonlight on WVCs can be as high as 1.46. The observation that even the Moon can have such a big impact on crash rates reminds us of the importance of details and data-driven decision-making in urban planning, traffic engineering, and transportation policy-making.

Data availability statement

The data that support the findings of this study will be available in Mendeley Data at https://doi.org/10.17632/r49tcwnyb6.1 upon publication.

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