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# Relation of the Weather and the Lunar Cycle With the Incidence of Trauma in the Groningen Region Over a 36-Year Period

Wouter Stomp, MD, Vaclav Fidler, PhD, Henk-Jan ten Duis, MD, PhD, and Maarten W. N. Nijsten, MD, PhD

**Background:** The time distribution of injuries is not random. To assess the potential impact of weather and the phase of the moon on accidents, adjustment for known periodic and nonperiodic factors may be important. We compared the incidence of injuries with quantitative and qualitative weather variables as well as the lunar cycle, after correction for calendar and holiday-related factors.

**Methods:** We extracted the daily number of trauma patients treated at the emergency department over 36 years (1970–2005) from the trauma database of our regional hospital. For each patient, age, sex, cause of injury, and severity of injury were recorded. This was combined with daily meteorological data including temperature, precipitation, sunshine, humidity, air pressure, and wind as well as the lunar phase. We also related the rate of change of these parameters with the incidence of injuries. A qualitative weather variable derived from temperature, sunshine duration, and precipitation was defined as bad, normal, or good. Periodicities were adjusted for with Poisson regression spline fitting analysis.

**Results:** Several weather variables were related with the number of injuries. For most of these, better weather conditions were associated with an increase in trauma incidence. Good weather, which was present on 16.5% of the days, resulted in 10.1% (9.3–11.4 95% CI) more traumas compared with normal weather. Full moon was associated with a 2.1% (1.1–3.0 95% CI) lower trauma incidence than new moon.

**Conclusions:** Better weather conditions contribute to an increased incidence of trauma. Full moon is associated with a slightly lower trauma incidence.

**Key Words:** Trauma incidence, Weather, Temperature, Moon, Children.

(*J Trauma*. 2009;67: 1103–1108)

Trauma patients constitute a substantial proportion of all emergency department visits and hospital admissions. The number of patients seen at a trauma emergency department strongly varies from time to time. Although these variations may appear random, several factors that can be quantified may affect the occurrence of trauma. The weather may influence the incidence of trauma in various ways. For example, poor weather conditions may adversely affect traffic safety and thus lead to more accidents. On the other hand, during good weather more people may be on the road or recreating outside. Other factors that might play a role are

school holidays and even the lunar cycle. Because of the immense impact that both light and severe injury have on the individual as well as on society, more insight into the environmental factors that contribute to the incidence of trauma is valuable. We investigated the relation of these factors with the number of trauma patients seen at the emergency department. For this purpose, all patients referred to our regional trauma service over a period spanning several decades were studied. We hypothesized that aside from obvious patterns related to the calendar, the quality of weather might have a significant impact on the number of trauma patients.

## PATIENTS AND METHODS

### Patients

The University Medical Center Groningen is situated in the northern part of the Netherlands. It is a Level I trauma center and is 1 of the 10 recognized trauma centers in the Netherlands and 1 of the 4 trauma centers that have a helicopter service available. Our catchment area covers the Northern part of the Netherlands with a population of approximately 2 million people. Approximately 10,000 patients visit the emergency department each year as a consequence of trauma. In this retrospective study, all trauma visits in a 36-year period (1970–2005) were included. Anonymized data were extracted from the hospital's trauma database.<sup>1</sup> For each patient, date of trauma, age, sex, and location of the accident were recorded. The location of trauma was classified as: (1) public road, (2) sport and recreation, or (3) in and around the house and otherwise.

The primary outcome variable was the daily trauma incidence. We also separately investigated daily trauma incidence of adults and children (defined as younger than 18 years old).

### Calendar-Related Factors

We explored several calendar-related factors for their relation with trauma volume. Graphs were constructed for daily, monthly, and yearly variance as well as for school holidays. The number of patients for each variable was compared with each other and with the mean number of patients. Since 1993, on Wednesdays and every fifth weekend, orthopedic surgery participated in trauma care and treated the trauma patients with simple trauma. On these days, only patients with injuries to head, neck, and torso were treated by the trauma service. Patients treated by the orthopedics were not registered in the trauma database. This caused a reduced number of patients registered on Wednes-

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days and in the weekends. The calendar variables were defined as the year, the month, the month by year interaction, and the day of the week and were all treated as categorical. In this way, the coverage differences in Wednesdays and every fifth weekend were automatically adjusted.

A few special days were excluded from the analysis. The activities during these days differ considerably from other days. Thus, they might produce a number of trauma patients that deviates from other days during the same period: New Year's day, Queen's day (April 30), Easter (Sunday and Monday), Pentecost (Sunday and Monday), Christmas (December 25 and 26), and New Year's Eve. Since the total number of these days (365) was too small to include them as a separate category in the analysis, we decided to exclude them. Days during a vacation were not excluded but recorded with holiday as an independent variable. Dates of school holidays were provided by the Dutch Ministry of Education, Culture, and Science.

## Weather

Daily local weather data were obtained from the Royal Netherlands Meteorologic Institute.<sup>2</sup> The data consist of automated measurements that were recorded at Eelde airport, a meteorological station located approximately 10 km from our hospital. The following variables were used: temperature, sunshine, cloud cover, visibility, air pressure, precipitation, humidity, wind direction, and wind speed.

The average daily temperature and maximum and minimum temperatures were measured in degrees Celsius. The duration of sunshine was expressed in hours and as a percentage of the maximum theoretical possible sunshine duration considering the variations in day length over the year. Cloud cover was defined as the fraction of the sky obscured by clouds in octants, or eighths, of the sky. The minimal visibility was measured in kilometers. The mean daily air pressure was expressed in millibar. Precipitation was measured in millimeters and its duration in hours. This included any form of moisture falling on earth, including rain, drizzle, snow, sleet, or hail. The relative humidity was expressed as a percentage of the amount of moisture in the air, related to the maximum amount possible at that temperature. Wind speed was measured 10 m above ground level in meters per second, as a daily average, maximum hourly average wind speed, and the maximum wind gust, which was the maximum wind speed recorded at any moment during the day. For all parameters, the respective day to day rate of change was also calculated.

In addition to these quantitative variables, we classified daily weather in three categories: good, normal, or bad. Limits were chosen to include both days with good or bad weather irrespective of the time of year and days with good or bad weather relative to the average weather expected for the time of the year. A day was thus defined to have good weather when the maximum temperature was above 20°C or 68°F, the sun was shining for more than 6 hours, and there was no precipitation. Additionally, all days on which the maximum temperature was more than 5°C (9°F) above the average for that month were also considered good weather days. Bad weather was defined as a day with a maximum temperature of

less than 10°C (50°F), less than 6 hours of sunshine, or with any amount of precipitation. All days with a maximum temperature more than 5°C (9°F) under the mean for the relevant month were also considered as bad. All days that were not classified as good or as bad were defined as "normal."

## Lunar Cycle

The lunar phases were derived from an ephemeris and divided into four intervals of equal length namely first quarter, full moon, last quarter, and new moon.

## Statistical Analysis

To study the relation between the outcome and explanatory variables, we used Poisson regression spline fitting analysis. This analysis assumes that the daily trauma incidence follows the Poisson distribution. The logarithm of the mean daily trauma incidence is assumed to be a linear function of the explanatory variables.

A model was constructed to adjust for the periodic fluctuations in the number of patient visits. To explore the possible nonlinear effect of individual weather variables, we used Poisson generalized additive models to describe the data separately for each weather variable. Each of these models included the calendar variables year, month, and weekday. This model describes nonlinear relationships between the variables after correcting for all other included variables.

All statistical analyses were performed using SPSS 14.0 and R.<sup>3</sup> A *p* value of <0.05 was considered statistically significant.

## RESULTS

### Patients

During the study period of 36 years (13,149 days), 354,150 injured patients were seen in the trauma unit (Table 1). For the analysis, we used data of 12,784 days after exclusion of special days. The mean number of daily admissions was 26.9 (SD 8.2) with a range of 2 to 78. The mean age

**TABLE 1.** Patient Characteristics

Number of patients	354,150
Male/female	61.5%/38.5%
Age (yr)	
≤10	12.4%
11–18	16.2%
19–40	47.8%
41–65	16.8%
66–85	6.0%
>85	0.8%
Patients per day	
1970–1981	28.84
1982–1993	27.09
1994–2005	24.87
Accident setting	
Recreation/sports	13.8%
Public road	13.4%
Around home, other	72.8%

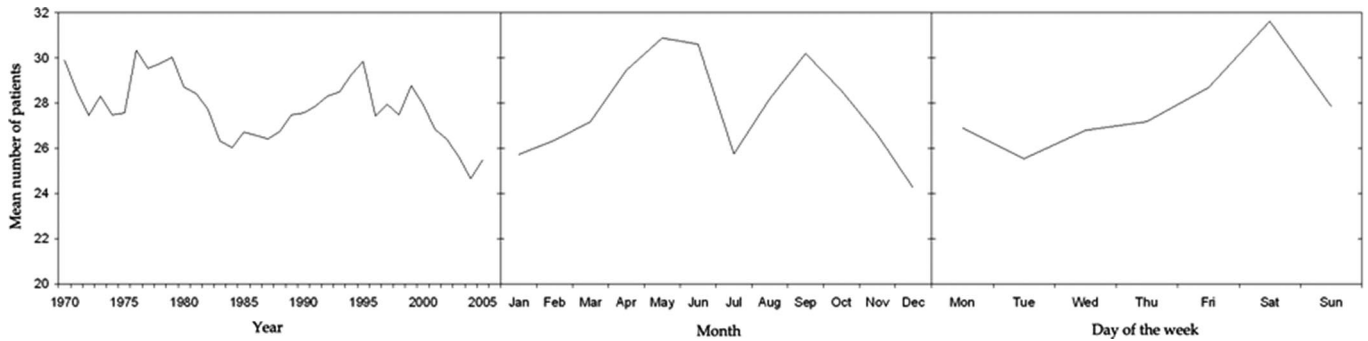


Figure 1. The mean number of trauma patients by day for each year, month, and day of the week.

of all patients was 30 years (range, 0–104 years) and 61% of the patients were men. Twenty-six percent of all patients were younger than 18 years.

**Calendar-Related Factors**

Initially we looked for overall trends, exploring annual and weekly variation in the number of admissions. Figure 1 shows the trauma incidence in relation to basic calendar variables (year, month, and day of the week), after exclusion of the days on which orthopedic surgery took care of trauma patients. There was a significant variation from month to month with an increased number of trauma patients during May, June, and August but with a decreased number of patients in July. Further analysis showed that this decrease was largely due to a decreased incidence of trauma during sport and recreation during the summer holiday period.

There was substantial weekly and daily variation. Friday and Saturday had a 3.8% and 16.4% higher number of patients above average, respectively ( $p < 0.001$ ). No relationship was observed between the day of the month and trauma volume. During school holidays, there were 7.4% less trauma visits than on other days ( $p < 0.001$ ). This effect was equal for adults and children. This was largely the result of a considerably lower number of accidents related to sport and recreation (30.6%,  $p < 0.001$ ) during school holidays.

**Weather**

The North-Eastern Netherlands region has a moderate maritime climate with neither very warm summers nor cold winters. The predominant wind direction is south-west. There is rainfall throughout the year. Table 2 shows the basic weather characteristics in our region. Several weather markers were significantly related with the number of daily trauma admissions. Figure 2 depicts the relation between daily trauma incidence and four of the weather variables. Plotted smoothed curves were obtained by fitting generalized additive models adjusted for the calendar variables and holidays. The vertical axis shows the incidence ratio (with respect to the average incidence corrected for the calendar variables) and the corresponding 95% confidence intervals (CIs). As these intervals indicate, all the variables shown are significantly ( $p < 0.05$ ) related to daily trauma incidence.

The maximum temperature showed a V-shaped relationship with a minimum at about 6°C (43°F). The incidence increased under both lower and higher maximum tempera-

tures. Above 6°C, for each 10°C (18°F) increase in maximum temperature, there were about 15% more trauma patients.

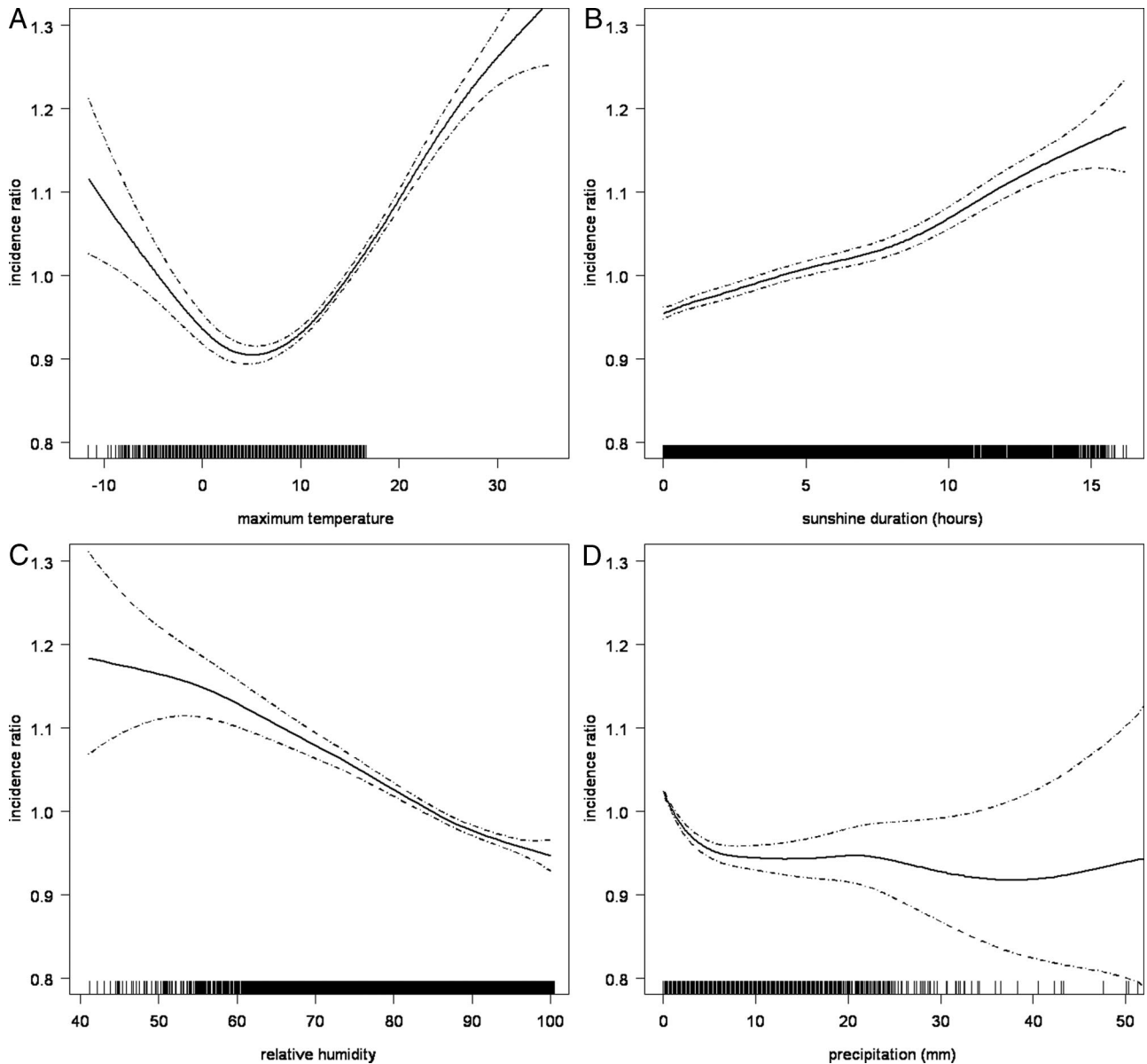
The wind direction had a small but significant influence with a lower trauma incidence with an east wind. Increases in the amount and duration of precipitation, cloud coverage, and relative humidity were associated with a slight decrease in the number of patients.

To gain further insight into seasonal variations, we have performed the analysis of Figure 2 also separately for each month. The trends depicted by these analyses were essentially the same as those for the aggregated data of Figure 2. The inverse relationship between humidity and the number of trauma patients was, however, more prominent from March to September than in the rest of the year.

TABLE 2. Meteorological Variables

Variable	Value
Temperature (°C)	
Mean	9.2 (0.9–17.0)
Minimum	5.2 (–2.3 to 12.2)
Maximum	13.0 (3.5–22.6)
Temperature (°F)	
Mean	49 (34–63)
Minimum	41 (28–54)
maximum	55 (38–73)
Sunshine	
Duration (h)	3.1 (0–10.3)
Percentage maximum sunshine	26 (0–77)
Cloud cover (octants)	6 (2–8)
Minimal visibility (km)	29 (2–60)
Air pressure	
Mean daily (mbar)	1015.7 (1001.6–1027.2)
Precipitation	
Amount (mm)	0.1 (0.0–7.1)
Duration (h)	0.2 (0.0–5.6)
Humidity (%)	87 (74–96)
Wind	
Mean speed (m/s)	4.1 (2.1–7.2)
Maximum hourly speed (m/s)	6.7 (4.0–10.8)
Maximum wind gust (m/s)	10.8 (6.2–17.0)

Median values with 10th and 90th percentile of meteorological variables from the North-Eastern part of Netherlands, as used in the study.



**Figure 2.** (A–D) Weather variables and trauma incidence. The relation between trauma incidence and maximum temperature, sunshine duration, humidity, and precipitation was determined with Poisson regression spline fitting analysis. Directly above the horizontal axis, the incidence of trauma is indicated with small vertical lines. The uninterrupted spline curve indicates the estimated incidence compared with the overall incidence and the interrupted lines indicate the 95% confidence intervals.

The other weather factors showed no significant correlation with the number of trauma visits. None of the day to day changes in weather variables showed a significant change in number of trauma patients.

The presence of good weather, as classified by the weather quality variable, was associated with an increase in trauma admissions. Good weather, which was present on 16.8% of the days, resulted in 10.1% (9.3–11.4 95% CI) more traumas compared with normal weather. Bad weather, present on 16.1% of all days, resulted in 2.8% (1.7–3.8% 95% CI) less traumas. Both effects were even more pronounced when

only children were considered, with 13.8% (11.7–16.0 95% CI) more traumas during good weather and 6.4% (4.4–8.3 95% CI) less traumas during bad weather.

Table 3 presents the results of Poisson regression regarding the effect of the weather quality per accident location. Presented are incidence ratios and 95% confidence intervals adjusted for the calendar variables. It shows that the effect of the weather was largest at the public road. The other two categories had comparable incidence rates.

The incidence ratio of trauma during new moon compared with full moon was 1.02 (CI: 1.01–1.03). The largest

**TABLE 3.** Relation Between Qualitative Weather and Accidents per Location

	In and Around House	Recreation and Sport	Public Road
Good weather	1.10 (1.08–1.11)	1.11 (1.08–1.14)	1.13 (1.10–1.16)
Normal weather	1.00	1.00	1.00
Bad weather	0.98 (0.96–0.99)	0.98 (0.95–1.01)	0.93 (0.90–0.96)

Relation between good, normal, or bad weather and the incidence of trauma for the three major accident locations. The trauma incidence ratios with a 95% confidence interval are indicated. Note that especially road accidents are related with the weather, with more accidents during good weather.

increase in incidence ratio was on the public road: 1.04 (CI: 1.02–1.07).

## DISCUSSION

Over an observation period that spanned three and a half decades, the presence of good weather was associated more trauma admissions. Several periodicities in the incidence of trauma were observed: daily, weekly, and seasonal. The number of trauma admissions was significantly correlated with several meteorological factors, namely maximum temperature, wind speed and direction, sunshine duration, air pressure, minimum visibility, and relative humidity. A slight decrease in trauma incidence was observed during full moon.

It has been long known that there exists a link between environmental conditions and nontraumatic disease. Warmer than usual temperatures during summer and colder than usual temperatures during winter are associated with increased mortality.<sup>4</sup> Vascular and respiratory disease show a strong seasonal pattern with a peak during winter.<sup>5</sup> Remarkably, a study in 2066 patients observed that the incidence of sudden cardiac death, after correction for age, gender, year, and season, was largely attributable to daily weather, particularly low temperature.<sup>6</sup>

Several studies that tried to demonstrate a correlation between seasonal and weather variables and total emergency department patient volume reported mixed results.<sup>7–12</sup> Statistical models have been constructed forecasting the number of patient visits based on temporal and weather variables.<sup>13–16</sup> Short-term changes in weather failed to predict fluctuations in emergency department use.<sup>17</sup> Studies looking specifically at trauma patients have shown a significant association between trauma admissions and both weather and temporal factors, showing similar trends as observed in our study.

Looking at hourly admission data from the United States National Trauma Data Bank, Vaziri et al.<sup>18</sup> observed a sine-wave pattern in the number of patients admitted with a 3.5-fold increase in admissions in the evening hours, with a peak at 7:00 PM, compared with the morning hours. In a series of 9,408 traumas over 6 years, Bhattacharyya et al.<sup>19</sup> found a significant relationship between weather and trauma center activity, with temperature and precipitation independently associated with trauma volume. Higher temperatures were associated with more admissions. Snowfall and rain reduced the number of admissions. These observations parallel our own results. Atherton et al. showed that maximum and minimum temperature,

hours of sunshine, day of the week, and month of the year correlated with trauma patient admissions. The weather mainly impacted pediatric admissions. For adult admissions and proximal femur fractures, they found none of the weather factors to be of significance. Only admissions to inpatient beds were included during a 1-year period.<sup>20</sup>

Rising et al.<sup>21</sup> studied patients who were admitted for at least 48 hours to the general surgery trauma service. They found the daily maximum temperature and precipitation to be valid predictors of trauma admission value.

The moon is thought by many to affect human behavior and full moon might increase the incidence of injury. However, contrary to popular belief, earlier studies have found no relationship between full moon and trauma incidence or total emergency department patient volume.<sup>22–25</sup> In our data, the number of trauma patients even decreased with 2.2% during full moon compared with new moon. This decrease might be attributed to better visibility during full moon. This hypothesis is supported by stronger effect of full moon on accidents at public roads compared with the other two categories.

Several studies have looked at the influence of societal factors on disease. A recent study found that matches of German soccer team during the 2006 World championship were apparently so stressful that they more than doubled the risk of acute cardiovascular events in the Munich region.<sup>26</sup> The design of the soccer study differed from ours in that the incidence of (cardiovascular) events during a few exceptionally short periods (match of the German team) was compared with the baseline incidence during the rest of the time. In contrast, our study analyzed the overall contribution of the weather over a very long observation period.

Our study is also unique in its size and in that all patients who were referred with trauma were included.

There are no direct clinical implications of our results. As with the incidence of other diseases, better understanding of the factor that are related to trauma may ultimately contribute to improved understanding of its causes and maybe even prevention. In theory, the results might be of use in emergency department planning, where staffing and resources could be matched to weather forecasting. However, the differences in trauma incidence we found were too small to be of practical value. Further statistical models could incorporate weather prospects and other factors to better forecast the trauma patient volume.

The retrospective study that we performed has several limitations. The most fundamental limitation may be that human behavior, which is the tie between some of the exogenous influences we studied and the development of accidents, is obviously very complex. By definition, the majority of factors that will also have affected the incidence of traumas has not been studied and could not be studied by us. Like other studies, no conclusions can be drawn from our study regarding the risk of individual persons during certain weather circumstances. Data were analyzed on a day-by-day basis and not, for example, on an hour-to-hour basis. Such a more precise analysis might have provided clearer informa-

tion on the relation between weather and accidents. However, this was not possible because accurate and complete hourly weather and accident data were not available.

Our data were limited to those patients who were seen in the hospital. Patients who died on the scene of an accident were not accounted. We attempted to obtain data regarding this from the local emergency medical services, but these could not be retrieved.

### CONCLUSION

In conclusion, the number of trauma patients seen in a regional emergency department for the North-Eastern Netherlands was related to the local weather, moon phase, and temporal and societal factors. In general, better weather conditions are associated with an increase in the number of trauma patients.

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