NOCTURNAL WAKEFULNESS AND SUICIDE RISK REVISTED: AN ANALYSIS OF THE NATIONAL VIOLENT DEATH REPORTING SYSTEM 2003 TO 2017

By

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Nocturnal Wakefulness and Suicide Risk Revisited: An Analysis of the National Violent Death Reporting System 2003 to 2017

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ABSTRACT

Introduction: Suicide is the 10th leading cause of death in the United States, and poor sleep contributes to suicide risk. Part of this risk occurs at night when individuals are awake in opposition to their circadian rhythms. This study replicates and expands on prior investigations of nocturnal wakefulness as a suicide risk factor.

Methods: Data on 78,647 suicides between 2003 to 2017 were extracted from the National Violent Death Reporting System and tabulated by time of fatal injury, whether the data had been previously analyzed (2003-2010) or new (2011-2017), sociodemographic factors, and alcohol or marijuana intoxication. Data were matched with estimates of population wakefulness from the American Time Use Survey. Robust Poisson regression models then estimated the hourly incident risk ratio for suicide after adjusting for population wakefulness.

Results: Although suicides peaked at noon, the incident risk for suicide was highest at night (IRR 5.18 [3.21, 8.36]) at 3AM. Results did not differ between previously analyzed and new data. Moreover, there was an age by blood alcohol level interaction in nighttime suicide risk such that risk increased with younger age and higher blood alcohol levels.

Conclusion: The behavioral risk for suicide appears highest at night and is increased among younger adults and those with greater alcohol intoxication. Part of this risk occurs at night when individuals experience irregularities in their circadian rhythms that may result in disturbances relating to executive function and behavior.

KEYWORDS

Suicide, nocturnal wakefulness, sleep, insomnia.

INTRODUCTION

Suicide is an increasingly prevalent cause of death in the United States, with rates rising over 35% since 1999[1, 2]. Suicide rates spiked during the COVID-19 pandemic, possibly due to fear of contracting the virus, grief, lockdowns, social isolation, and socioeconomic stressors[3-6]. In 2020, 45,000 Americans died by suicide, with 1.2 million suicide attempts[7]. Prior research emphasizes the relationship between sleep and suicide, and sleep disturbances during the pandemic were closely associated with increased suicidal ideation due to COVID-19 related anxiety and insomnia[7]. Suicide is also a rising concern among older adults, for whom suicide risk is more difficult to detect and sleep difficulties and disorders are more pronounced[8]. Suicide prevention efforts that target proximal risk factors may reduce risk and alter the trajectory of rising suicide rates.

Epidemiological studies of suicide deaths show that suicide occurs most frequently around noon. However, raw suicide counts do not account for how many people are awake and thus "eligible" to die by suicide. Since most people are awake at noon, it is likely that most suicides occur at that time. Assessing the underlying behavioral time-of-day risk for suicide requires adjusting for how many people are awake at that time. Perlis and colleagues demonstrated this approach by using the American Time Use Survey to adjust for population wakefulness in analyzing suicide data in the National Violent Death Reporting System, and they found that the adjusted risk of suicide was 3-fold higher at night than any other time of day[9]. Subsequent studies found an 8-fold increase in nocturnal suicide risk among Veterans[10] and that the adjusted risk for suicide remained highest at night across months and methods of suicide[11].

Sleep and circadian-dependent changes in physiology may explain the observed nocturnal increase in suicide risk. Circadian rhythms synchronize a person's sleep/wake cycle with the external light/dark environment, and this leads to nocturnal suicide risk because of the brain's

decreased ability to function correctly at night. The synaptic homeostasis hypothesis[12] underlies the importance of sleep as an essential process that regulates synaptic connections. During continuous wakefulness, synapses become overloaded due to sustained use such that it becomes difficult to appropriately process and interpret new information. Sleep restores normal synaptic functioning by eliminating many irrelevant connections while retaining important connections. Thus, sleep deprivation promotes inefficient and ineffective cortical functioning because these synapses are still overloaded. This combination of sleep and circadian dependent changes in brain functioning form the basis for the Mind after Midnight hypothesis[13], which details the differences in brain function at night versus day and emphasizes the cognitive and behavioral disturbances resulting from nocturnal wakefulness.

Although groundbreaking, no subsequent studies have replicated the findings of Perlis and colleagues in other US datasets. Therefore, the present study replicates and expands previous findings via more data and subgroup analyses to confirm that the wakefulness-adjusted risk for suicide is greatest at night. Suicide deaths from 2011 to 2017 (new) were compared to data from 2003 to 2010 (old), and all data were combined to provide an hour-by-hour assessment of suicide risk. Subgroup analyses examined demographic and clinical characteristics associated with increased nocturnal suicide risk; alcohol or drug intoxication and age under 25 were hypothesized to show greater nocturnal risk for suicide due to impaired frontal cortical functioning[14, 15].

METHODS

Datasets

Data were acquired on 78,647 suicides between 2003 and 2017 from the National Violent Death Reporting System (NVDRS)[16]. NVDRS data are derived from autopsies and coroner's reports at

the state level and are maintained by the Centers for Disease Control and Prevention. Although the NVDRS currently receives data from all 50 U.S. states, the District of Columbia, and Puerto Rico, this was not always the case and so suicide data are not nationally representative for all years assessed. Basic descriptive suicide data are available through the Web-based Injury Statistics and Query System (WISQARS, https://wisqars.cdc.gov/nvdrs), with additional information accessible through an application to the NVDRS Restricted Access Database (https://www.cdc.gov/violenceprevention/datasources/nvdrs/dataaccess.html). The primary NVDRS variables used in this study were the type of injury (i.e., suicide), time of fatal injury, date of fatal injury, age, sex, race, ethnicity, positive alcohol on autopsy, and positive cannabis on autopsy.

Concurrent population estimates of sleep/wake timing were derived from the American Time Use Survey (ATUS, https://www.bls.gov/tus). The ATUS consists of daily activity diaries where respondents report that they did in 30-minute increments for 24 hours. These responses are then coded, and estimates of population wakefulness were derived based on when participants reported sleeping. Population estimates of epoch-by-epoch wakefulness were calculated by age, sex, race, and ethnicity for 2003 to 2017 and averaged to obtain hour-by-hour estimates of wakefulness.

The University of Arizona Institutional Review Board determined that this project did not involve human subjects (because data were de-identified) and was thus exempt from further review.

Statistical Analyses

All analyses were conducted in R (version 4.1.2, R Foundation for Statistical Computing, Vienna, Austria), and the code used for this analysis is freely available at https://github.com/atubbs-sleep. Simple comparisons were made using Wilcoxon rank-sum tests or Chi-squared tests. Suicides were tabulated by clock hour, age, sex, race, and ethnicity, and combined with age/sex/race/ethnicity-matched estimates of population wakefulness. Robust Poisson models were used with the observed homicide count as the outcome/dependent variable, clock hour as the predictor/independent variable, and the population-estimated wakefulness as the offset/exposure term. Model estimates are reported as incidence risk ratios (IRR). Weighted effect coding was used so that individual clock hour estimates were compared to the average across all clock hours, rather than a particular clock hour. Models were first unadjusted (clock hour was the only predictor) and then adjusted for age, sex, race, and ethnicity. Subgroup analyses examined whether the hourly incident risk ratios for homicide varied by age block (young: 15-34; middle: 35-64; older: 65+), sex, presence of alcohol on autopsy, and presence of cannabis on autopsy. Statistical significance was tested using one-way ANOVAs with post-hoc hour-by-hour Wald tests for significant interactions. A second exploratory analysis examined whether dying by homicide at night was more prevalent among certain demographic groups or those who tested positive for alcohol or cannabis on autopsy. Robust Poisson models provided IRR estimates for each group of interest.

RESULTS

Sample data and characteristics for 78,647 suicides are presented in Table 1. The fewest suicides occurred in the morning, with a total of 18,062 (23%) suicides, and the highest suicides occurred in the afternoon, totaling 24,573 (31%). However, some demographics were over/underrepresented at different times of day. Ages 25-34 were overrepresented at night, with 3,351 (22.8%) suicides at night while only accounting for 13,311 (17.1%) of overall suicides.

Alcohol users were significantly overrepresented among nighttime suicides, accounting for 4,441 (53.6%) suicides.

Table 1: Sociodemographic Factors and Suicide Risk

		Time of Day*				
Characteristic	**Overall**	**Morning**	**Afternoon**	**Evening**	**Night**	***p***
N	78,647	18,062	24,573	21,179	14,833	
Age	**Overall**	**Morning**	**Afternoon**	**Evening**	**Night**	<0.001
15-24	11,114 (14.3%)	1,918 (10.7%)	3,080 (12.7%)	3,260 (15.7%)	2,856 (19.4%)	
25-34	13,311 (17.1%)	2,628 (14.6%)	3,589 (14.8%)	3,743 (18.0%)	3,351 (22.8%)	
35-44	13,725 (17.6%)	2,864 (16.0%)	4,118 (16.9%)	4,002 (19.2%)	2,741 (18.6%)	
45-54	15,297 (19.7%)	3,514 (19.6%)	5,047 (20.8%)	4,250 (20.4%)	2,486 (16.9%)	
55-64	11,253 (14.5%)	2,867 (16.0%)	3,824 (15.7%)	2,871 (13.8%)	1,691 (11.5%)	
65-74	6,622 (8.5%)	1,940 (10.8%)	2,373 (9.8%)	1,509 (7.2%)	800 (5.4%)	
75+	6,462 (8.3%)	2,210 (12.3%)	2,265 (9.3%)	1,191 (5.7%)	796 (5.4%)	
Unknown	863	121	277	353	112	
Sex	**Overall**	**Morning**	**Afternoon**	**Evening**	**Night**	<0.001
Male	63,979 (81.4%)	14,871 (82.3%)	19,767 (80.4%)	17,146 (81.0%)	12,195 (82.2%)	
Female	14,664 (18.6%)	3,190 (17.7%)	4,806 (19.6%)	4,030 (19.0%)	2,638 (17.8%)	
Race	**Overall**	**Morning**	**Afternoon**	**Evening**	**Night**	<0.001
White	68,528 (87.3%)	15,823 (87.7%)	21,656 (88.3%)	18,452 (87.3%)	12,597 (85.3%)	
Black	5,838 (7.4%)	1,342 (7.4%)	1,697 (6.9%)	1,582 (7.5%)	1,217 (8.2%)	
Asian	1,133 (1.4%)	237 (1.3%)	356 (1.5%)	304 (1.4%)	236 (1.6%)	
Other Race	2,991 (3.8%)	637 (3.5%)	824 (3.4%)	807 (3.8%)	723 (4.9%)	
Unknown	157	23	40	34	60	
Ethnicity	**Overall**	**Morning**	**Afternoon**	**Evening**	**Night**	<0.001
Non-Hispanic	74,028 (94.9%)	17,044 (95.2%)	23,291 (95.5%)	19,915 (94.8%)	13,778 (93.7%)	
Hispanic	3,981 (5.1%)	861 (4.8%)	1,090 (4.5%)	1,100 (5.2%)	930 (6.3%)	
Unknown	638	157	192	164	125	
Alcohol	16,281 (36.9%)	2,593 (27.0%)	3,702 (27.1%)	5,545 (44.2%)	4,441 (53.6%)	<0.001
Unknown	34,555	8,453	10,928	8,631	6,543	
Marijuana	3,942 (15.9%)	817 (14.7%)	1,126 (14.6%)	1,043 (15.4%)	956 (20.2%)	<0.001
Unknown	53,870	12,491	16,885	14,393	10,101	

* Morning: 0500-1100, Afternoon: 1100-1700, Evening: 1700-2300, Night: 2300-0500

The first analysis compared previously analyzed data (2003-2010) and new data (2011-2017) using two different analytic methods, IRR and SIR. IRR is based on a statistical model while SIR

is based on algebra. IRR is preferred since SIR often overstates risk. The two metrics show a similar pattern of suicide incidence per time of day, as seen in Figure 1. IRRs for each time of day did not significantly differ between 2003-2010 and 2011-2017 (t-test, all p > 0,05). IRR further supports the incident risk for suicide is highest at night for both old and new data, respectively (IRR: 3.06 [2.54-3.68]) and (IRR: 3.85 [3.18-4.65]).

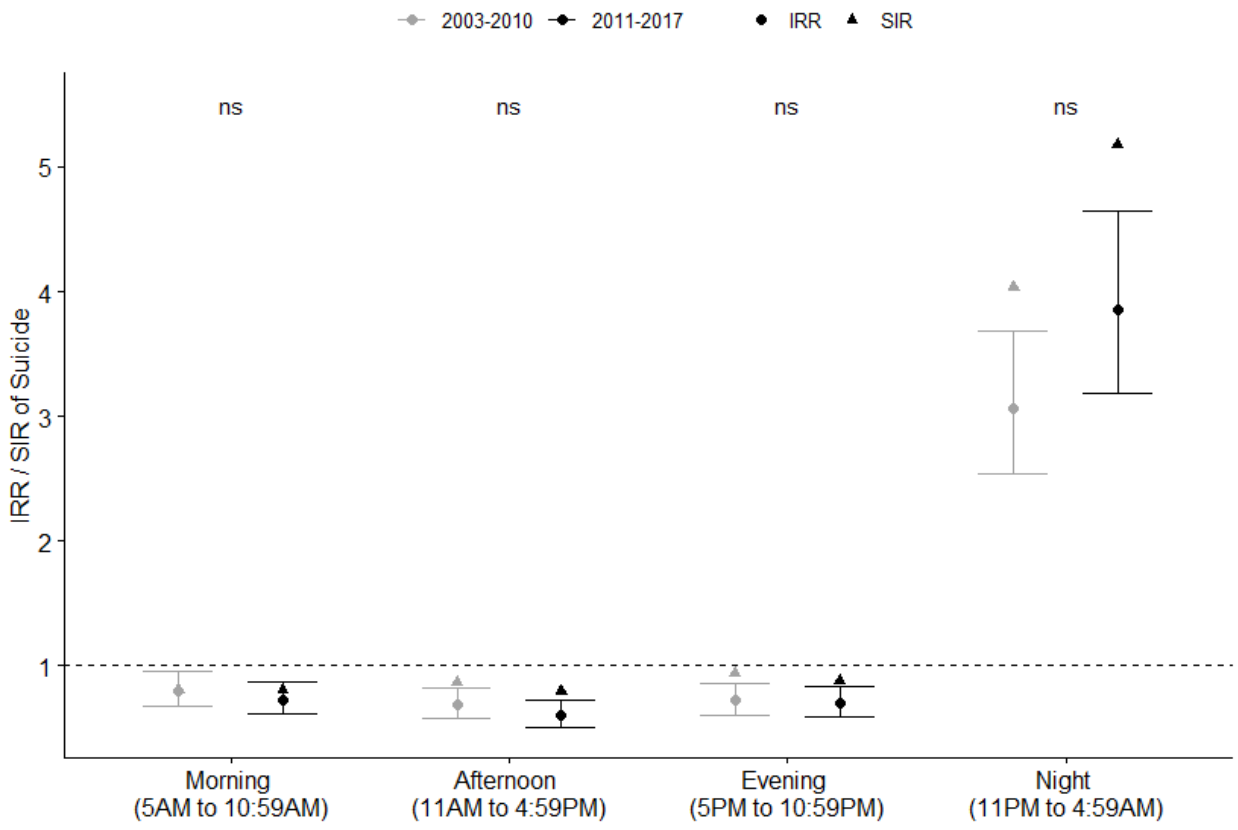

FIGURE 1: Comparing nocturnal suicide risk by time period and analysis method. Raw suicide counts were extracted from the NVDRS for 2003-2017 along with hourly estimates of population wakefulness for the same period. Data were then divided into previously analyzed (grey) or new (black) data. The standardized incidence ratio (SIR, triangle) estimated risk by comparing observed suicide counts to expected counts assuming proportionate distribution by population-wakefulness. The Incident Risk Ratio (IRR, circles) estimated risk using robust

Poisson regression models with population wakefulness as an offset term. Suicide counts were combined into 4, 6-hour time categories per prior analyses. ns = not significant.

The next analysis modeled the predicted risk of suicide per-hour while accounting for population wakefulness. Although suicide counts were highest at noon and lowest at night, suicide risk was highest at night (peak at time 0200, IRR 5.26 [95% CI]) and lowest during the day (trough at time 1600, IRR 0.58 [95%]). These results are presented in Table 2 and Figure 2. Models were first unadjusted and then adjusted for age, sex, race, and ethnicity, but adjusting for covariates did not significantly alter results. Suicide count data are represented by the raw maximum percentage of suicides, with a peak in deaths at noon. Data modeling accounts for IRR values and 95% confidence intervals, with the maximum incidence occurring at 0200 hours (IRR: 5.26 [3.26, 8.47] unadjusted, 4.47 [3.98, 5.02] adjusted). IRR is statistically significant between 23:00-5:00.

Table 2: Incident risk ratios of suicide by clock hour

	Unadjusted			Adjusted*		
Clock Hour	**IRR**	**95% CI**	***p***	**IRR**	**95% CI**	***p***
0:00	2.88	[1.77, 4.66]	0.0000	3.06	[2.78, 3.37]	0.0000
1:00	3.69	[2.25, 6.05]	0.0000	3.44	[3.19, 3.71]	0.0000
2:00	5.26	[3.26, 8.47]	0.0000	4.47	[3.98, 5.02]	0.0000
3:00	5.18	[3.21, 8.36]	0.0000	4.63	[4.13, 5.19]	0.0000
4:00	3.35	[2.11, 5.34]	0.0000	2.64	[2.17, 3.22]	0.0000
5:00	2.09	[1.31, 3.31]	0.0018	1.63	[1.37, 1.93]	0.0000
6:00	1.20	[0.75, 1.92]	0.4418	1.02	[0.87, 1.19]	0.8118
7:00	0.88	[0.54, 1.43]	0.6181	0.78	[0.67, 0.91]	0.0014
8:00	0.71	[0.44, 1.16]	0.1685	0.75	[0.66, 0.86]	0.0000
9:00	0.67	[0.41, 1.1]	0.1103	0.71	[0.62, 0.81]	0.0000
10:00	0.66	[0.4, 1.08]	0.0969	0.70	[0.6, 0.82]	0.0000
11:00	0.63	[0.39, 1.03]	0.0650	0.74	[0.65, 0.85]	0.0000
12:00	0.73	[0.45, 1.19]	0.2096	0.82	[0.74, 0.91]	0.0002
13:00	0.59	[0.36, 0.96]	0.0320	0.63	[0.56, 0.71]	0.0000
14:00	0.61	[0.38, 0.98]	0.0416	0.65	[0.58, 0.72]	0.0000
15:00	0.60	[0.37, 0.98]	0.0399	0.66	[0.6, 0.72]	0.0000

16:00	0.58	[0.36, 0.95]	0.0289	0.64	[0.58, 0.7]	0.0000
17:00	0.58	[0.36, 0.93]	0.0231	0.64	[0.59, 0.69]	0.0000
18:00	0.62	[0.38, 1.01]	0.0536	0.62	[0.57, 0.67]	0.0000
19:00	0.56	[0.35, 0.91]	0.0180	0.59	[0.55, 0.63]	0.0000
20:00	0.60	[0.37, 0.97]	0.0376	0.57	[0.52, 0.62]	0.0000
21:00	0.61	[0.37, 1.01]	0.0535	0.60	[0.55, 0.66]	0.0000
22:00	0.81	[0.49, 1.33]	0.4035	0.82	[0.73, 0.92]	0.0007
23:00	1.36	[0.84, 2.22]	0.2145	1.30	[1.18, 1.42]	0.0000

*Adjusted for age, sex, race, and ethnicity

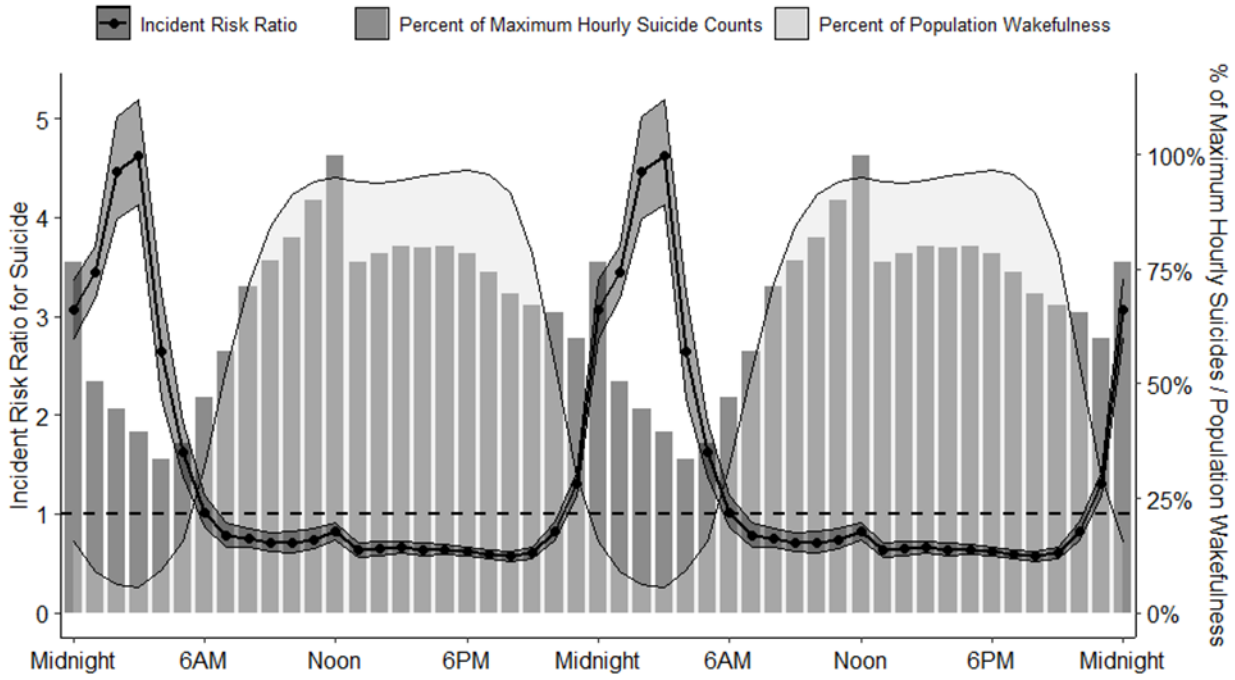

FIGURE 2: Suicide count distribution by clock hour adjusted for population wakefulness, modeled twice. Suicide counts are derived from the National Violent Death Reporting System (grey bars), and population wakefulness is derived from the American Time Use Survey (light grey shaded area). The incident risk for suicide after adjusting for population wakefulness (black line) is statistically elevated between 23:00-5:00. Data are double plotted for visualization.

A subgroup analysis explored whether risk of suicide at night varied as a function of age and/or blood alcohol level (BAL). The data representing incident risk for suicide are presented in Figure

3. Compared to 45–54-year-olds, younger adults had a baseline higher risk of dying at night (IRR 1.29 [1.27, 1.31]). Greater BAL increases risk of nighttime death in all age groups, represented in yellow and red. The age group most affected by the presence of alcohol is 15-24; risk was higher in younger adults than older adults. Ages 75+ had a decreased risk of nighttime death without alcohol compared to the average risk for all age groups (IRR: 0.96 [0.95, 0.98]). In the presence of a positive BAL, there was no longer a decreased risk (IRR: 1.01 [0.96, 1.06]) for ages 75+.

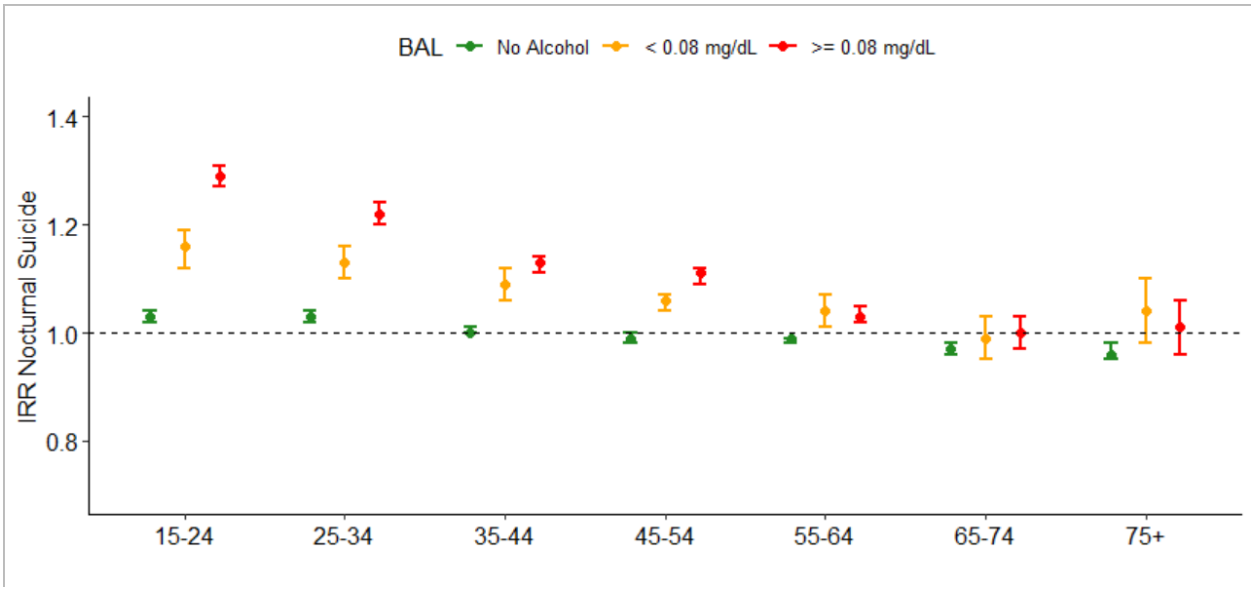

Figure 3: The incident risk for suicide varies as a function of blood alcohol level and age. BAL is categorized as none (green), < 0.08 mg/dL (yellow), and > 0.08 mg/dL (red). IRRs are represented as point estimates and 95% confidence intervals.

DISCUSSION

This archival analysis of national suicide data re-demonstrated that the population-wakefulness adjusted risk of suicide is highest at night. The larger sample allowed for a more fine-grained evaluation of each clock hour, such that the incident risk ratio was roughly 4.5-fold greater at 2-

3am than the 24-hour average. Moreover, subgroup analyses demonstrated that younger individuals and those intoxicated with alcohol were more likely to die at night by suicide. These findings emphasize the danger posed by nocturnal wakefulness and highlight those who may be particularly vulnerable to this effect.

The first analysis compared previously analyzed data from 2003 to 2010[9] with new data from 2011 to 2017. This analysis did not find any differences in nighttime risk between these time periods. The IRR and SIR metrics also demonstrated a similar pattern of risk: the old data showed an IRR of 3.06 and SIR of 4.04 at night while the new data reported an IRR and SIR of 3.85 and 5.18, respectively. The similar risk estimates between the two different analysis methods increase confidence that the observed risks are real. Similar findings between the two time periods confirm the elevated risk reported in prior studies[9, 10] and enable pooling the data for more fine-grained analyses.

Analyzing risk on an hour-by-hour basis revealed a statistically elevated risk for suicide between 11pm and 5am, but also highlighted a peak in risk at 2-3am. This peak occurred at the lowest point in population wakefulness and may reflect wakefulness that is misaligned with one's circadian rhythms. This circadian misalignment, when combined with sleep deprivation, may induce frontal cortical dysfunction and lead to executive dysfunction and impulsivity that increase risk for suicide[8].

In the subgroup analyses, raw suicide counts were most prevalent among non-Hispanics, Caucasians, males, and individuals between 45-54 years old. However, younger adults (ages 15-24) displayed a higher nighttime suicide risk after adjusting for population wakefulness. Younger adults experience greater sleep disturbances compared to other age groups, including insomnia, nightmares, and sleep variability[11]. Alcohol intoxication also increased nocturnal

suicide risk across age groups, but the biggest increase in risk was observed among younger adults. Alcohol abuse is significant among young adults by a range of influences, from social to the urge to self-medicate for psychiatric disorders, which are associated with an increased risk for suicide[9]. Alcohol accessibility in the home or in social scenes increases the risk of alcohol abuse in young adults and increases impulsive thoughts and behaviors, which may lead to increased nighttime suicide[10]. Alcohol consumption furthermore increases the prevalence of sleep disorders[12]. These factors contribute to a higher incidence of suicide among younger adults.

Based on these data, treatment of alcohol and sleep disorders may be a necessary component in suicide prevention efforts. Outreach to younger adults concerning alcohol abuse education and awareness is one such step towards lowering suicide risk. Since nocturnal wakefulness is positively associated with increased risk of death by suicide, the intervention of sleep medicine may reduce risk[11]. To better enhance suicide prevention given subgroup analysis, allocation of more resources at night and in at-risk communities is a viable option.

Strengths of the present study include the use of a larger dataset than previous studies[9] and a more detailed analysis of risk among specific subgroups. An additional strength was that these analyses adjusted for factors like age, sex, race, and ethnicity that may have confounded the data. Limitations of the study are that the data do not represent all US states. The present study is limited in data concerning mental illness and sleep disorders. The nighttime incidence of suicide may be affected by sleep behaviors and investigation of their influence is recommended.

Conclusion

Using expanded data on U.S. national suicides and patterns of wakefulness, this study confirmed prior findings of a nocturnal peak in suicide risk. Additional data also enabled a more

detailed examination of hour-by-hour risks, which narrowed the peak of risk to 3AM. Finally, subgroup analyses identified increased risk among younger individuals and those with increasing blood alcohol intoxication. These findings suggest nocturnal wakefulness and associated deviations in circadian physiology contribute to the observed increase in risk for nocturnal suicide. Improvements in the identification and treatment of both alcohol and sleep disorders may improve suicide prevention.

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