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ORIGINAL ARTICLE

Small shifts in diurnal rhythms are associated with an increase in suicide: The effect of daylight saving

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Abstract

Large disruptions of chronobiological rhythms are documented as destabilizing individuals with bipolar disorder; however, the impact of small phase altering events is unclear. Australian suicide data from 1971 to 2001 were assessed to determine the impact on the number of suicides of a 1-h time shift due to daylight saving. The results confirm that male suicide rates rise in the weeks following the commencement of daylight saving, compared to the weeks following the return to eastern standard time and for the rest of the year. After adjusting for the season, prior to 1986 suicide rates in the weeks following the end of daylight saving remained significantly increased compared to the rest of autumn. This study suggests that small changes in chronobiological rhythms are potentially destabilizing in vulnerable individuals.

Key words: chronobiology, daylight saving, jet lag, suicide.

INTRODUCTION

Many of the body's most fundamental biological processes follow a circadian pattern, such as temperature, hormonal secretion, cardiovascular, respiratory and metabolic functions.[1] Phenomenological findings of sleep and activity disturbance in people with bipolar disorder are well established, and there is more recent evidence of a number of neuroendocrine abnormalities in the circadian system of bipolar patients.[2] Seasonal variation also occurs and is perhaps most evident in those with seasonal affective disorder where variations in light levels appear to trigger depressive episodes that adjunctive light therapy has been demonstrated to reduce.[3] There also appears to be some seasonal variation in suicide, with one group indicating that in people with affective disorders, a peak in suicide occurs around the summer solstice.[4] Another group demonstrated a gender variation in this response. In this study, only women with depressive illness demonstrated a significant spring peak in suicides.[5]

Artificial manipulations of the sleep–wake cycle have pronounced effects on bipolar patients. The depressive phase of the illness may respond to sleep deprivation, however, sleep deprivation is known to trigger[6] or worsen manic episodes.[7] Circadian rhythms are being increasingly recognized as an integral aspect of bipolar disorder and suicide, with some studies demonstrating variations in suicide occurring at specific times of day.[4] Recently management of the sleep–wake cycle through enforced bed rest and darkness has been shown to improve the symptoms of mania.[8,9] Research has demonstrated that twins discordant for bipolar disorder, the

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affected twins were much more vulnerable to seasonal changes in mood, weight, appetite and levels of energy than their unaffected twin.[10] In terms of biological foundations for these abnormalities, evidence indicates that melatonin (a hormone involved in circadian and seasonal rhythm regulation and entrainment to light) is abnormally suppressed by light in bipolar patients[11] and in twins discordant for bipolar disorder, melatonin sensitivity is discordant between bipolar probands and their sibling.[12]

The integration of these phenomenological and biological findings about seasonal, circadian and sleep dysregulation has lead to the development of a form of psychotherapy, interpersonal and social rhythm therapy (IPSRT), that focuses on the regulation of sleep–wake cycles and social rhythms.[13] While environmental factors are becoming increasingly integrated into our understanding and treatment of these disorders, the clinical impact of relatively small disruptions to the sleep–wake cycle have not been investigated. It is of theoretical and clinical relevance if such small chronobiological shifts have impacts on mood or behavior. These smaller shifts may prove triggers for episode onset, yet are potentially easier to manage than shift work or jet lag, increasing the rationale for addressing these as part of illness management. The aim of this article was to discover whether the time shift associated with daylight saving (DLS) has a measurable behavioral impact in changes in suicide rates.

METHODS

A list of registered suicide deaths requiring a coroner's report that the death was a potential suicide was obtained from the Australian Bureau of Statistics. The date of the event and gender of every person in Australia for whom the documented cause of death was suicide was collected from 1 January 1971 to 31 December 2001. There were 47 215 male and 14 383 female suicide victims in Australia during the study period. DLS was introduced into Victoria, Australian Capital Territory, South Australia, Tasmania and New South Wales in 1971. Two other states, Queensland and Western Australia briefly experimented with DLS (1971, 1974, 1983, 1989,1990 and 1991).

In all cases the change to DLS from standard time occurred at 02:00 hours in October and the change to standard time from DLS occurred at 03:00 hours in March. The Northern Territory did not participate in DLS. In this study, we compared time periods, both at two and four weeks after the transition to start of DLS and then again at the return to normal time. As the data were not broken down by state, the date chosen as the transition date was the date that most states started or ceased DLS. After adjusting for the year, two-way ANOVA assessed the average number of suicides for the time period after commencement of DLS, after the end of DLS and the rest of the year. This analysis was repeated on the ranks of the data and as the results were consistent, no deviation from the parametric test assumptions was apparent. Seasonality has a strong association with suicide. Therefore the analysis was repeated, comparing the time period immediately after the commencement of DLS with the number of suicides for the rest of spring, and adjusted for year. Similarly, the suicides for the time period after the end of DLS was compared to the rest of autumn.

RESULTS

There was no difference in suicide rates after the transition to DLS or from DLS compared to the rest of the year in the female data set, either, unadjusted or adjusted for season.

For the men there was a significant difference ($P < 0.05$) in the unadjusted data with more suicides for the weeks after DLS commenced than in the weeks after it finished (mean difference ± SE, [2 weeks] 0.44 ± 0.15 suicides per day, [4 weeks] 0.48 ± 0.10 suicides per day) and for the rest of the year ([2 weeks] 0.36 ± 0.10 suicides per day, [4 weeks] 0.37 ± 0.08 suicides per day). After adjusting for season, as season is a significant predictor of suicide, the relationship weakened greatly. Comparing suicides in men for the weeks after DLS finished to the rest of autumn found that there was an increase before 1986 (mean difference ± SE, [2 weeks] 0.52 ± 0.14 suicides per day and [4 weeks] 0.30 ± 0.11 suicides per day) ($P < 0.05$); but there was no significant difference after 1986 ([2 weeks] $P = 0.22$ and [4 weeks] $P = 0.51$). Comparing suicides in men for the 2 weeks after DLS started to the rest of spring found no significant relationship. Comparing suicides in men for the 4 weeks after DLS started to the rest of spring found a non-significant trend towards an increase in suicides (mean difference ± SE, 0.13 ± 0.09 suicides per day) ($P = 0.138$).

DISCUSSION

The results of this study suggest that the period following the change to DLS was associated with an increase in completed suicides in men. This increase could be due to the change in season, but the relationship remained as a trend after analysis of individual seasons. The impact was greater for shifts associated with phase advance than phase delay. There was a gender effect in these data, with significant results in men but not women. This may be related to the fact that suicides in men are three times greater than those in women, giving greater statistical power to the former group.

This could also be the result of the trend found in former studies of a bimodal distribution of illness and suicide in women.[5,14] This would indicate that data for females may be "washed out" by a number of elevated periods. A final explanation for the stronger signal detection in men than women is that women have a significantly more complicated hormonal milieu. For example, while the circadian hormone melatonin shows gender differences in both light sensitivity[15] and melatonin secretion,[16] light sensitivity as a zeitgeber is unaffected by the menstrual cycle. In contrast, numerous circadian and rhythmic processes are disrupted by changes in the menstrual cycle, including overall melatonin secretion, luteinizing hormone and progesterone and temperature amplitude.[17–20] This may indicate that multi-oscillatory systems working through external zeitgebers and internal cues in women may be more robust in countering small environmental changes.

It is not possible to determine why this finding was only significant before 1986. However, it is likely to reflect the complex and varied factors which influence an individual's decision to attempt suicide. Suicide is influenced by a diversity of sociological, cultural and economic factors[21] and perhaps the influence of these factors overrode more subtle factors such as shifts in diurnal rhythms.

This study was conducted in a temperate climate, and the effects of such time shift may differ in areas with varying distances to the equator, and photoperiod, and the magnitude of the shift. For example, Melbourne is located at −37.81° latitude and 144.97° longitude. Seasonal variation in the light–dark cycle varies between 9:50 h of light during mid-winter to 14:50 h in mid-summer. As some of the more robust findings on diurnal variations were found in the Netherlands, where light varies more markedly between seasons,[4] multi-country comparisons would be informative. The pooling of data from all states is a limitation of the study: state-specific data may have increased the signal intensity.

These data provide the first evidence to support the notion that modest changes to diurnal rhythm have a measurable impact on a clinically critical outcome. This study suggests that phase advance is more significant in terms of suicide risk than phase delay. In a study of psychiatric presentations following travel across time zones, significantly more eastbound travellers showed symptoms of mania, whereas significantly more westbound travellers showed symptoms of depression. A number of explanatory models have been proposed for such change with small diurnal modifications. In particular, the "beat phenomena" proposed by Georgi (as cited in Goodwin and Jamison[22]) proposes that mood disturbance may be the result of a desynchronization between multiple circadian rhythms. In the case of DLS changes, the endogenous circadian rhythms may be uncoupled from the external environment (exogenous desynchrony) leading to a circadian system destabilization where multiple oscillators operate in isolation, disrupting mood and behavior. Such small changes in external zeitgebers have previously been shown to have marked effects on mood, for example, the depression- and mania-stimulating effects of long-haul travel on vulnerable individuals.[23] This adds support to the notion that attention to even modest changes in diurnal rhythms and phase positioning is clinically salient, and reinforces the value of biological and environmental considerations in the development of disorder specific psychotherapy and psycho-educational approaches such as IPSRT.[24] It also suggests that the level of control of such rhythms may need to be tighter than previously thought.

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The effects of daylight and daylight saving time on US pedestrian fatalities and motor vehicle occupant fatalities

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Abstract

This paper analyzes the effects of daylight and daylight saving time (DST) on pedestrian and motor vehicle occupant fatalities in the United States. Multivariate analyses of county level data from the Fatality Analysis Reporting System for 2-week periods in 1998 and 1999 are used. Results show that full year daylight saving time would reduce pedestrian fatalities by 171 per year, or by 13% of all pedestrian fatalities in the 5:00–10.00 a.m. and in the 4:00–9:00 p.m. time periods. Motor vehicle occupant fatalities would be reduced by 195 per year, or 3%, during the same time periods.

Keywords: Motor vehicle fatalities; Pedestrian fatalities; Daylight saving time

1. Introduction

Daylight saving time (DST) in the US is a federal government regulation to improve the matching of daylight hours with the activities of the population. DST changes clock time to make sunset and sunrise 1 h later in the spring, summer, and early fall.[2]

Ferguson et al. (1995) estimated that the extension of DST to the full calendar year from the present DST period, which runs from the first Sunday in April to the last Saturday in October, would have reduced pedestrian deaths by 727 and motor vehicle occupant deaths by 174 in the 5-year period from 1987 to 1991. Annual pedestrian fatalities and annual motor vehicle occupant fatalities averaged about 7000 and 35,000, respectively, during these years. The authors explain that extended daylight saving time is safety enhancing because there is more vehicle and pedestrian activity in the evening than in the morning and DST substitutes evening hour light for morning hour light. The smaller motor vehicle effect is explained by the presence of vehicle lights, which makes vehicles more visible in the dark to the drivers of other vehicles than are pedestrians. Several other studies that do not estimate full year DST effects have shown an *increase* in motor vehicle fatalities or motor vehicle accidents during the first week of daylight saving time in the spring as drivers adjust to the time change (Coren, 1996; Hicks et al., 1983, 1998). In this paper we revisit the DST—highway safety issue and estimate the effects of daylight and full year DST on pedestrian fatalities and on motor vehicle occupant fatalities for the 1998–1999 period, the most recent years for which data are available from the Fatality Analysis Reporting System.

2. Methods

2.1. Pedestrian and motor vehicle occupant fatality trends in the US, 1998–1999

In Table 1, the number of pedestrian fatalities and motor vehicle occupant fatalities by hour of the day are presented

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[2] Federally mandated DST was first established as a wartime regulation during World War I as an energy conservation measure. It was abolished in 1919 at the end of the war. Federally mandated DST returned during World War II to save energy and was abolished again at the end of the war in 1945. The immediate elimination of DST after the two World Wars was due to opposition in farming communities and a broader concern over the safety of school children during their morning journey to school. However, in 1966, a federal mandate returned and DST was established from the last Sunday in April to the last Saturday in October. Then, in 1973, after the first OPEC oil shock, the US Congress moved the start of DST to 6 January 1974, again with the goal of saving energy. However, concern over the safety of school children in the morning hours led Congress to push forward DST to 23 February 1975 and to its normal April starting date thereafter. This brief history is largely from Barky and Harrison (1979). In 1986, Congress shifted the daylight saving start date from the last Sunday in April to the first Sunday in April.

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Table 1
Pedestrian and motor vehicle occupant fatalities for October and November, 1998 and 1999, by hour of the day

Crash hour	Pedestrian Fatalities				Motor Vehicle Fatalities			
	1998		1999		1998		1999	
	October	November	October	November	October	November	October	November
0:01–0:59 a.m.	22	23	31	10	110	134	160	126
1:00–1:59 a.m.	25	16	12	17	150	127	137	130
2:00–2:59 a.m.	8	13	23	13	127	120	146	129
3:00–3:59 a.m.	7	13	15	8	81	87	97	92
4:00–4:59 a.m.	5	3	13	5	64	54	80	94
5:00–5:59 a.m.	18	15	19	10	76	68	81	69
6:00–6:59 a.m.	26	19	30	14	115	120	96	118
7:00–7:59 a.m.	14	15	25	7	113	104	119	109
8:00–8:59 a.m.	10	14	8	14	97	108	114	109
9:00–9:59 a.m.	11	10	16	11	114	86	123	97
10:00–10:59 a.m.	8	10	10	8	93	105	113	115
11:00–11:59 a.m.	15	9	15	9	130	115	141	97
12:00–12:59 p.m.	11	6	7	8	106	127	111	137
1:00–1:59 p.m.	14	9	10	8	122	113	152	121
2:00–2:59 p.m.	18	14	10	6	148	161	154	155
3:00–3:59 p.m.	19	11	14	32	176	153	182	177
4:00–4:59 p.m.	22	27	13	17	191	179	196	179
5:00–5:59 p.m.	35	64	20	68	171	186	199	183
6:00–6:59 p.m.	36	96	34	71	146	156	140	159
7:00–7:59 p.m.	52	39	63	34	188	156	162	124
8:00–8:59 p.m.	46	31	37	37	124	123	158	138
9:00–9:59 p.m.	43	31	27	23	121	99	127	107
10:00–10:59 p.m.	35	24	32	18	132	117	128	120
11:00–11:59 p.m.	28	20	23	18	139	122	105	119
Midnight	0	0	0	1	1	3	1	4
Unknown	8	2	2	5	31	28	33	29
Total	536	534	509	472	3066	2951	3255	3037

Source: Fatality Analysis Reporting System, National Highway Traffic Safety Administration, 1998 and 1999.

for the months of October and November in 1998 and 1999. DST ended and standard time returned at the very end of October in each of these years (1 November and 31 October, respectively), so comparing data from these 2 months may be a good indicator of daylight effects on pedestrian and motor vehicle occupant fatalities. The population weighted average sunrise and sunset across counties of the US was 7:25 a.m. and 6:35 p.m. in the October months and 6:56 a.m. and 5:06 p.m. in the November months. There was therefore an average of about one and half hours more light in the mornings in November and one and half hours more light in the evenings in October.

A relationship between daylight and pedestrian fatalities is evident in Table 1. From 9:00 a.m. through 3:00 p.m. there is rough equality in the number of fatalities in October and November in the 2 years. These hours are ones of full daylight. The 5:00 and 6:00 p.m. hours contain much more daylight in October than in November and pedestrian fatalities are 125 in the October hours and 299 in the November hours in the 2 years. The 6:00 and 7:00 a.m. hours, in which there is more daylight in November than in October, show 55 fatalities in the November months and 95 in the October months. Repeating this exercise for motor vehicle occupant fatalities reveals no clear differences between the 2 months.

Further evidence of a daylight pedestrian fatality relationship is seen in Figs. 1–3, where pedestrian fatalities in the US in 1998 and 1999 by time of day are plotted against calendar time in 2-week intervals from the first of each year to the end. Fig. 1 shows pedestrian fatalities between 4:00 and 9:00 p.m.; Fig. 2 shows pedestrian fatalities between 5:00 and 10:00 a.m.; and Fig. 3 shows pedestrian fatalities between 10:00 a.m. and 4:00 p.m. The evening and morning

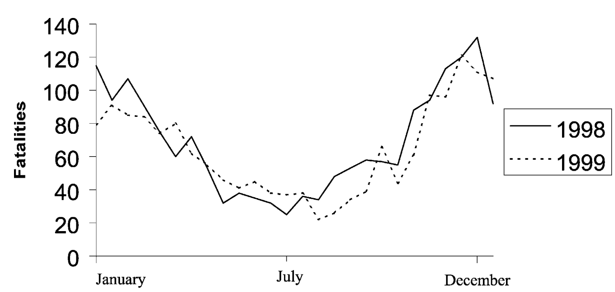

Fig. 1. January–December 2-week periods pedestrian fatalities (10:00 a.m. to 4:00 p.m.).

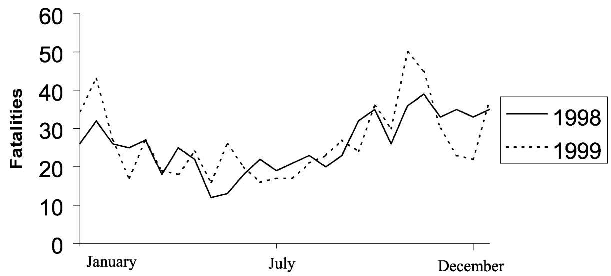

Fig. 2. January–December 2-week periods pedestrian fatalities (4:00–9:00 p.m.).

periods experience substantial light changes throughout the year, with less light at the beginning and end of the year and more light in the middle of the year. There is very little light change in the midday period. The evening period pedestrian fatality graph shows a U-shaped relationship with calendar time. The morning period does also, although the relationship is not as distinct as in the evening. Midday pedestrian fatalities are not obviously related to calendar time.

To consider these relationships another way, ordinary least squares regression results are presented with the evening and the morning pedestrian fatalities regressed on the population weighted average county sunset and sunrise, respectively, over the fifty-two 2-week time periods in the 2 years. The results are:

$$\text{PMPedfat} = 455.4_{(t=21.3)} \quad -20.5_{(t=-18.3)}\ (\text{sunset}), \quad R^2 = 0.87\ (n = 52)$$

$$\text{AMPedfat} = -43.0_{(t=-4.4)} \quad +10.3_{(t=7.2)}\ (\text{sunrise}), \quad R^2 = 0.51\ (n = 52)$$

The regression coefficients indicate a 1 h later sunset would reduce 4:00–9:00 p.m. pedestrian fatalities (PMPedfat) by 20 over 2 weeks and a 1 h earlier sunrise would reduce 5:00–10:00 a.m. fatalities (AMPedfat) by 10 over 2 weeks. These effects are roughly one-third of the sample means of 67 in the evening hours and 26 in the morning hours. The results imply that moving an hour of daylight from the morning to the evening year round (making double-hour daylight time during the usual DST period and single-hour daylight time during the standard time period) would result in a net reduction of 10 fatalities (20–10) over 2 weeks, or 260 over 1 year. Pedestrian fatalities were 5228 in 1998 and 4939 in 1999. Although these regression results are meant to just summarize trends in the data, the marginal effects approximate the results for the fuller models estimated below. This is likely due to the fact that sunrise and sunset are not strongly correlated with other independent variables in the fully specified models.

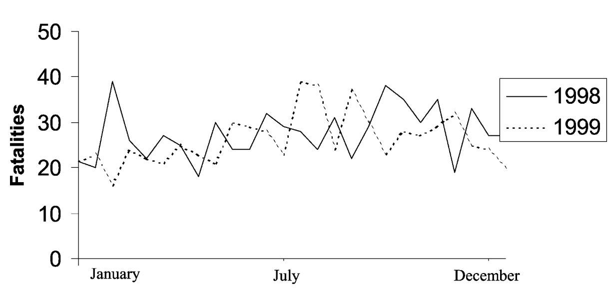

Fig. 3. January–December 2-week periods pedestrian fatalities (5:00–10:00 a.m.).

2.2. Data

The data used to estimate more complete models of the relationships between daylight, daylight saving time, and pedestrian fatalities and motor vehicle occupant fatalities are at the county level for fifty-two 2-week periods in 1998 and 1999. Counties in Alaska and Hawaii are excluded. There are 3111 counties remaining in the US, meaning there are 161,722 observations possible for the analysis (3111 × 52). The advantage of county level observations over 2-week periods is that the variation in sunrise and sunset times in the US can be reflected in the data.[3] There is substantial variation in the sunrise and sunset time by day of the year in the United States and on a given day, by north–south location. Given the day of the year and north–south location, the distribution of sunrise and sunset time depends on east–west location in the time zone and on whether clock time is standard or daylight.

The dependent variables in the models are counts of pedestrian fatalities or of motor vehicle occupant fatalities in the counties during the 2-week periods. Results are presented for the 5:00–10:00 a.m. morning hours and the 4:00–9:00 p.m. evening hours because sunrise and sunset changes occur during these hours in the US.

Independent variables in the fatality models are standard to the highway safety literature (Keeler, 1994; Loeb et al., 1994) and include the following: sunrise or sunset time; the percent of the county population living in a rural area in 1990; the percent of the county population age 25 and up with a 4-year college degree in 1990; motor vehicles miles traveled by states and months for 1998 and 1999, the average annual inches of rain in principal metropolitan area(s) of states for 1998 and 1999; the average annual inches of snow and ice pellets in principal metropolitan area(s) of states for 1998 and 1999; county income per capita in 1990; county unemployment rate in 1990; the percent of county population traveling 30 min or more to work in 1990; and dummy indicators for season and year.

[3] Note that the state of Arizona and many counties in Indiana do not observe daylight saving time. This is accounted for in our data. The computer program we used to calculate sunrise and sunset times was written by James Brimhall. His program provides sunrise and sunset times for any given longitude, latitude, and time zone, and is accurate within 2 min (Sinnott, 1995).

In some of the models we also include state identifiers to capture the effects of highway safety determinants that do not vary within states or for which data are not available at the county level. These determinants include state speed limits, seat belt and motor vehicle inspection regulations, alcohol control policies including excise tax levels, and weather. State identifiers also help to control for the "supply of pedestrians." States in the southern part of the US, for example, have warmer weather than states in the north. As a result, these southern states may have more pedestrian activity in a given hour and more opportunity for a pedestrian death.

2.3. Functional form of the regression models

The dependent variables in the models are counts of pedestrian fatalities or of motor vehicle occupant fatalities in the counties during the 2-week periods. Because the count values are usually small and often zero, a Poisson or a negative binomial distribution will best describe the dependent variables (Long, 1997). The negative binomial distribution is used to characterize the fatality models estimated below because likelihood ratio tests reject the null hypothesis that the underlying distribution is Poisson. Huber robust standard errors clustered on counties are computed because counties repeat in the data and not all independent variables may be accounted for in the models that distinguish one county from another (Huber, 1967). Specifications of count data negative binomial models usually include an independent variable to normalize for exposure. County population is used as the exposure variable in the models presented later.

3. Results

The first three regressions in Table 2 are for pedestrian fatalities occurring from 4:00 to 9:00 p.m. for the full 2-year period. The fourth regression in Table 2 is for pedestrian fatalities occurring from 4:00 to 9:00 p.m. during the standard time period only (approximately November through March in each year). The results presented in columns 1–4 of Table 3 follow the same pattern as Table 2 for the 5:00–10:00 a.m. period. The regressions in column 2 of each table include a larger number of independent variables than those in column 1, while the regressions in columns 3 and 4 include the state identifiers. The marginal effects of sunrise and sunset, presented at the bottom of each table, are stable across the first three regressions for each time period. They indicate that an hour later sunset would reduce pedestrian fatalities in the evening by 0.006 and that an hour later sunrise would increase pedestrian fatalities in the morning by 0.003. These marginal effects refer to changes in the number of fatalities per county per 2 weeks and are 0.27 and 0.38, respectively, of the sample means of 0.022 and 0.008. Thus, an hour later sunset would reduce evening pedestrian fatalities by about one-quarter and an hour later sunrise would increase morning fatalities by about one-third.

The standard time period regression (regression 4) in Tables 2 and 3 can be used to evaluate the effects of a change to full year DST on pedestrian fatalities. The p.m. sunset marginal effect is −0.008 and the a.m. sunrise marginal effect is 0.003. The results indicate that shifting an hour of daylight to the evening from the morning in the standard time period in 1998 and 1999 would have changed pedestrian fatalities by $(-0.008 \times 3111 \times 22) + (0.003 \times 3111 \times 22) =$

Table 2
Results of regressing 4:00–9:00 p.m. pedestrian fatalities on time of sunset and other variables, counties of the US, 1998–1999

	Negative binomial count models			
	1	2	3	4
Sunset	−0.240 (−9.69)	−0.248 (−9.32)	−0.304 (−11.28)	−0.368 (−8.52)
Percent rural	−0.457 (−3.68)	−0.362 (−2.98)	−0.259 (−2.39)	−0.233 (−1.58)
College education	−3.488 (−5.22)	−2.300 (−2.15)	−2.453 (−2.23)	−1.959 (−1.42)
1999	−0.079 (−2.29)	−0.075 (−2.15)	−0.082 (−2.35)	−0.083 (−1.88)
Motor vehicle miles	1.18E−08 (3.04)	−6.59E−09 (−1.14)	2.06E−08 (1.35)	8.02E−09 (0.46)
Spring	−0.159 (−2.08)	−0.127 (−1.64)	−0.044 (−0.58)	
Summer	−0.151 (−1.85)	−0.106 (−1.26)	−0.024 (−0.29)	
Fall	0.083 (1.96)	0.108 (2.56)	0.067 (1.37)	
Rain		−0.002 (−0.58)		
Snow		−0.012 (−6.14)		
Income		9.81E−06 (0.64)	1.36E−05 (0.83)	1.56E−05 (0.64)
Unemployment		4.949 (3.23)	4.697 (3.34)	5.823 (2.66)
Commute		0.106 (0.46)	0.260 (1.19)	−0.053 (−0.18)
Intercept	−9.889 (−21.55)	−9.962 (−18.92)	−9.501 (−14.98)	−8.544 (−9.12)
n	161772	161772	161772	68442
State fixed effects	No	No	Yes	Yes
Sunset marginal effect	−0.0052	−0.0054	−0.0066	−0.0076

The *z*-statistics are in parentheses and are calculated by using Huber standard errors adjusted for clustering by county. Models 1–3 are estimated over fifty-two 2-week periods. Model 4 is estimated over two 11-week standard time periods. County population is the exposure variable in each model, with its coefficient constrained to equal one.

Table 3
Results of regressing 5:00–10:00 a.m. pedestrian fatalities on time of sunrise and other variables, counties of the US, 1998–1999

	Negative binomial count models			
	1	2	3	4
Sunrise	0.292 (4.24)	0.368 (5.47)	0.348 (4.43)	0.319 (3.40)
Percent rural	−0.708 (−4.15)	−0.535 (−3.27)	−0.402 (−2.91)	−0.467 (−2.23)
College education	−2.714 (−2.83)	−2.472 (−1.79)	−2.743 (−2.06)	−1.979 (−1.02)
1999	0.018 (0.33)	0.019 (0.35)	0.024 (0.42)	−0.060 (−0.70)
Motor vehicle miles	1.05E−08 (1.95)	−8.78E−09 (−1.35)	−1.07E−08 (−0.51)	6.63E−09 (0.24)
Spring	−0.068 (−0.67)	0.021 (0.21)	−0.005 (−0.05)	
Summer	0.136 (1.46)	0.210 (2.31)	0.200 (1.97)	
Fall	0.198 (2.81)	0.220 (3.11)	0.221 (2.78)	
Rain		−0.004 (−0.96)		
Snow		−0.009 (−4.89)		
Income		1.77E−05 (0.94)	2.25E−05 (1.36)	1.20E−05 (0.45)
Unemployment		4.498 (2.38)	5.132 (2.67)	6.653 (2.40)
Commute		1.105 (4.36)	0.999 (3.35)	1.276 (3.08)
Intercept	−17.424 (−34.18)	−18.424 (−31.32)	−18.244 (−24.25)	−17.657 (−19.52)
n	161772	161772	161772	68442
State fixed effects	No	No	Yes	Yes
Sunrise marginal effect	0.0025	0.0031	0.0029	0.0026

The *z*-statistics are in parentheses and are calculated by using Huber standard errors adjusted for clustering by county. Models 1–3 are estimated over fifty-two 2-week periods. Model 4 is estimated over two 11-week standard time periods. County population is the exposure variable in each model, with its coefficient constrained to equal one.

−343 over these 2 years, or about 171 per year. This is 13% of the pedestrian fatalities that occurred in these morning and evening hours. These results are similar in nominal value to those of Ferguson et al. (1995), which were summarized previously. They reported that an annual average of about 150 pedestrian fatalities would have been avoided with full year DST in 1987–1991. Our results are larger as a proportion of all pedestrian fatalities because of the 30% decline in pedestrian fatalities in the decade of the 1990s. These models show no increased risk to school children from full year DST. When the a.m. models are estimated with pedestrian fatalities in the 5–13 or 5–18 years age group as the dependent variable, sunrise is not an important variable.

If the same procedure is applied to the motor vehicle occupant fatality results in regression 4 of Tables 4 and 5, the calculations show that full year DST would decrease

Table 4
Results of regressing 4:00–9:00 p.m. motor vehicle fatalities on time of sunset and other variables, counties of the US, 1998–1999

	Negative binomial count models			
	1	2	3	4
Sunset	0.050 (3.50)	0.045 (3.29)	0.030 (2.18)	−0.098 (−3.75)
Percent rural	1.252 (18.50)	1.178 (16.72)	1.331 (22.22)	1.402 (16.97)
College education	−3.785 (−8.10)	−0.458 (−0.82)	−2.716 (−5.25)	−2.276 (−3.15)
1999	0.0003 (0.02)	0.003 (0.14)	−0.007 (−0.38)	0.009 (0.29)
Motor vehicle miles	5.94E−09 (1.99)	−3.48E−09 (−1.19)	5.69E−08 (4.50)	9.41E−08 (5.26)
Spring	0.029 (0.66)	0.047 (1.12)	0.032 (0.78)	
Summer	0.152 (3.33)	0.177 (4.04)	0.145 (3.29)	
Fall	0.231 (8.31)	0.237 (8.65)	0.196 (6.75)	
Rain		−0.008 (−5.51)		
Snow		−0.010 (−11.46)		
Income		−7.62E−05 (−6.59)	−1.74E−05 (−1.57)	−1.17E−05 (−0.79)
Unemployment		−2.609 (−4.06)	−1.906 (−2.65)	−1.510 (−1.41)
Commute		−0.052 (−0.25)	−0.249 (−1.53)	−0.117 (−0.54)
Intercept	−14.207 (−52.01)	−12.712 (−42.40)	−12.832 (−40.33)	−11.105 (−20.40)
n	161772	161772	161772	68442
State fixed effects	No	No	Yes	Yes
Sunset marginal effect	0.0060	0.0052	0.0035	−0.0097

The *z*-statistics are in parentheses and are calculated by using Huber standard errors adjusted for clustering by county. Models 1–3 are estimated over fifty-two 2-week periods. Model 4 is estimated over two 11-week standard time periods. County population is the exposure variable in each model, with its coefficient constrained to equal one.

Table 5
Results of regressing 5:00–10:00 a.m. motor vehicle fatalities on time of sunrise and other variables, counties of the US, 1998–1999

	Negative binomial count models			
	1	2	3	4
Sunrise	0.053 (1.76)	0.018 (0.63)	−0.006 (−0.20)	0.059 (1.49)
Percent rural	1.288 (17.07)	1.210 (15.13)	1.402 (19.58)	1.371 (14.37)
College education	−3.588 (−7.11)	−0.217 (−0.34)	−1.960 (−2.99)	−1.321 (−1.46)
1999	0.037 (1.57)	0.038 (1.65)	0.035 (1.52)	−0.003 (−0.09)
Motor vehicle miles	3.03E−09 (0.89)	−7.90E−09 (−2.19)	9.85E−09 (0.59)	2.74E−08 (1.47)
Spring	0.109 (2.29)	0.083 (1.82)	0.046 (0.99)	
Summer	0.224 (5.24)	0.206 (4.98)	0.172 (3.93)	
Fall	0.204 (6.26)	0.216 (6.74)	0.205 (5.85)	
Rain		−0.010 (−5.15)		
Snow		−0.011 (−10.42)		
Income		−7.76E−05 (−6.13)	−2.44E−05 (−1.95)	−2.93E−05 (−1.73)
Unemployment		−2.768 (−3.77)	−2.295 (−2.81)	−1.749 (−1.44)
Commute		−0.004 (−0.02)	−0.256 (−1.37)	−0.238 (−0.98)
Intercept	−14.142 (−58.12)	−12.394 (−41.33)	−12.444 (−38.91)	−13.150 (−28.50)
n	161772	161772	161772	68442
State fixed effects	No	No	Yes	Yes
Sunrise marginal effect	0.0039	0.0013	−0.0004	0.0040

The *z*-statistics are in parentheses and are calculated by using Huber standard errors adjusted for clustering by county. Models 1–3 are estimated over fifty-two 2-week periods. Model 4 is estimated over two 11-week standard time periods. County population is the exposure variable in each model, with its coefficient constrained to equal one.

fatalities by 390, or 3% of motor vehicle occupant fatalities during these morning and evening hours. Evening motor vehicle occupant fatalities are not negatively related to time of sunset in models 1–3 in Table 4, which are estimated over the full sample of fifty-two 2-week periods. When the sample is confined to the two 11-week standard time periods in the 2 years (regression 4), however, the coefficient is negative ($z = -3.75$). These more robust results may be explained by the fact that sunset during the standard time period occurs earlier in the evening when rush hour traffic is heavier.

Tables 2–5 also show the impact of other state and county level variables on pedestrian and motor vehicle occupant fatalities. Counties with larger percentages of the population living in rural areas have lower pedestrian fatalities and higher motor vehicle fatalities. Motor vehicle fatality rates may be higher in rural areas because travel distances and speeds are greater than in urban areas and because travel is on less safe roadways (e.g. more travel on two-way roadways). Pedestrian fatality rates are probably lower in rural areas because the supply of pedestrian activity is less. In urban areas, destinations are more proximate and amenable to pedestrian travel.

In addition, the results show that counties with larger percentages of the population having a 4-year college degree have lower pedestrian and motor vehicle fatalities. Higher unemployment rates are associated with higher pedestrian fatalities and lower motor vehicle fatalities. Higher income is associated with lower motor vehicle fatalities but has no relationship with pedestrian fatalities. Lastly, higher percentages of the population with long commutes raise pedestrian fatalities in the morning, but have no effect on evening pedestrian fatalities or motor vehicle fatalities.

4. Conclusions

Daylight is an important determinant of morning and evening pedestrian fatalities in the US. An additional hour of daylight would reduce pedestrian fatalities by about one-third in the 5:00–10:00 a.m. time period and by about one-quarter in the 4:00–9:00 p.m. time period. Because pedestrian activity is greater in the evening period than in the morning period, full year daylight saving time, or the changing of clock time to make sunset and sunrise 1 h later in the standard time period, would reduce pedestrian fatalities about 171 per year, or by 13% of all pedestrian fatalities in these two time periods. Daylight is a less consistent determinant of motor vehicle occupant fatalities in the morning and evening time periods. However, results for the standard time period indicate that full year daylight saving time would decrease fatalities by 195 per year, or 3% of motor vehicle occupant fatalities during the morning and evening hours. The smaller percentage decrease in motor vehicle occupant deaths relative to pedestrian deaths may be explained by the presence of vehicle lights, which make vehicles visible to other drivers during darkness.

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