# The diurnal pattern of on-the-job injuries

*Data from two sources indicate that the injury hazard is substantially higher late at night than during regular daytime work hours; the best explanation for this finding is that work at night is dangerous, even adjusting for broad industry-occupation composition and worker fatigue*

Kenneth N. Fortson

Kenneth N. Fortson is a Ph.D. candidate, Department of Economics, Princeton University, Princeton, NJ.

Shortly after 4:00 A.M. on March 28, 1979, mechanical equipment at the nuclear power plant at Three Mile Island, near Harrisburg, Pennsylvania, malfunctioned. In the course of responding to the emergency, operators working the late-night shift made errors that exacerbated the situation, resulting in the worst accident in the short history of U.S. commercial nuclear power.[1] Seven years later and halfway around the globe, at 1:23 A.M. on April 26, 1986, negligence by night shift workers at the nuclear reactor in Chernobyl, U.S.S.R., led to an even more catastrophic nuclear disaster.[2]

In the popular press, it is often asserted, without explanation, that workplace injuries are more common at night.[3] In the academic literature, economists have largely ignored the diurnal pattern of on-the-job injuries and, by extension, the economic ramifications. This article uses data on workers' compensation claims from Texas to estimate the empirical distribution of injuries. The results show that the injury rate is high during off-hours late at night and low during the regular nine-to-five shift.

The article also decomposes the factors causing the observed injury pattern and explores the possibility that the empirical injury cycle is merely an artifact of compositional changes in the age or industry and occupation of workers throughout the day. Late-night workers have longer shifts as well, so fatigue is examined as a possible explanation of the injury pattern. Both of these possibilities, however, are rejected as the lone explanation of the injury pattern.

Instead, the article argues that there are inherent physiological implications of late-night work that make off-hours jobs more hazardous than daytime jobs. This is an important distinction because it suggests that, in scheduling work hours, firms should consider shift *time* in addition to factors such as shift *length*, which is merely correlated with late-night work and contributes to a higher injury rate, but is not unique to night work.

*Texas Workers' Compensation Commission*. The Texas Workers' Compensation Commission provided data on age, time, date, and nature of injury for workers injured between 1998 and 2002. Texas was chosen because of the particularly accurate and detailed records of workers' compensation injuries maintained by the commission and because Texas has an industrial composition similar to that of the United States as a whole.[4] The 5-year time span in the data provides a large sample size, but is short enough that shifts in the industrial mix should not be a factor. The sample is a complete count of all workers who were employed by a firm carrying workers' compensation insurance and who were injured during that period. Unlike nearly all other States, Texas does not require firms to provide workers' compensation insurance,[5] and the sample does not include those who work for firms that do not carry such insurance; however, there does not appear to be any compelling reason to believe that the diurnal injury pattern would be different among firms opting out of the workers' compensation insurance system.

In addition to furnishing data on the time of day the worker was injured and the worker's age at the time of injury, the commission provided information about the type and severity of the injury, as well as the body part injured. More than 400,000 injuries are recorded in the commission's database, of which the analysis that follows examines the 42,902 severe fractures or lacerations and the 29,074 severe falls. The primary advantage of focusing on these injuries is that they are acute and likely to be reported immediately, whereas back injuries, for example, are caused by cumulative conditions; hence, the time they are reported is somewhat arbitrary.

*Current Population Survey*. Data on work schedules come from the May 2001 Work Schedules Supplement to the Current Population Survey (CPS). In addition to affording data on such common factors as age, education, industry, occupation, race, and gender, the 2001 supplement provides data on when each worker's shift usually began and ended. For respondents who reported that they worked a regular work schedule, shift beginning and end times are used to determine whether a worker was at work during each hour of the day.

Workers responding to the supplement report their usual shift in two ways: by citing the usual times they start and end work and by giving categorical descriptions of the hours they work. In the latter case, they indicate whether their shift is best described as a regular daytime schedule, an evening shift, a night shift, a rotating shift, a split shift, or an irregular schedule. Of the 47,047 observations examined from the Work Schedule Supplement, 9,636 lack data on either when the shift usually began or when the shift usually ended (or both).

In order to maximize the sample size, the categorical description of the shift was used to impute the starting and ending times whenever possible. Among those who reported the starting and ending times of their shift, there was wide variation in actual schedules within the rotating shift category, as well as within the split shift and irregular shift categories. However, within the day, evening, and night shift categories, the typical starting and ending times were quite consistent. Thus, for these three types of schedule, when the individual refused to say or did not know when the shift usually started, or when the person reported that the starting time varied, his or her starting time was coded as the adjusted median starting time of those who worked the same type of shift—day, evening, or night—but *did* report their starting and ending times. An adjusted median was used because shift times are reported as the time of day (on a 24-hour clock) and simply using the median would incorrectly estimate the usual schedule for each type of shift. For example, using the median would consider midnight a very late time and 1:00 A.M. a very early time. Conceptually, however, it is usually more reasonable to consider 1:00 A.M. 1 hour later than midnight, rather than 23 hours earlier.

To get around this issue, for each of the three shifts, the 24-hour day was bisected into two 12-hour segments, one based on the shift starting time and one based on the shift ending time. Median shift times were then calculated only for those shifts with a starting time within the first segment and an ending time within the second, and the 12-hour windows were iteratively selected so as to maximize the number of observations used in the calculation for each shift.[6]

Each of the 12-hour windows was rescaled such that when the median was calculated, the beginning of the window was treated as early and the end of the window as late. The median of the rescaled windows were then used in the study. The resulting imputed shift times for those who reported working a day shift were 8:00 A.M. to 5:00 P.M.; for those who reported working an evening shift, they were 3:00 P.M. to 11:00 P.M.; and for those who reported working a night shift, they were 9:00 P.M. to 7:00 A.M. For the day and evening shifts, the shift times imputed with the use of the adjusted median are identical to the modal shift times, and the modal shift times for night shifts are very close to the adjusted median, providing additional support for the imputations. Exactly 6,849 observations were imputed in this manner; consequently, 44,260 of the original 47,047 observations in the Work Schedules Supplement could be used.[7]

## Diurnal injury distribution

Table 1 reports the share of hours worked in each of the 24 time intervals. The share is computed from the Work Schedules Supplement for all workers aged 21 to 69 years and separately for each of three age subgroups. All calculations are weighted with the supplement's sample weights.

Two important features stand out. First, hours of work are heavily concentrated during the day: a full 80 percent of the share of hours worked fall between 8:00 A.M. and 5:00 P.M. Second, the distribution of hours throughout the day is remarkably similar for all three age groups. Only slightly more 21- to 39-year-olds work evening shifts than 40- to 49-year-olds and 50- to 69-year-olds, while the latter two groups work marginally more during normal business hours.

The data from the Texas commission can be used to compute the share of injuries incurred during each hour-long interval for two distinct categories of injuries: fractures and

**Table 1. Share of hours worked in each hour of the day**

| Hour of day | Age group, years | | | |
|---|---|---|---|---|
| | 21 to 69 | 21 to 39 | 40 to 49 | 50 to 69 |
| 24:01 to 1:00 | 0.006 | 0.007 | 0.006 | 0.005 |
| 1:01 to 2:00 | .007 | .007 | .007 | .006 |
| 2:01 to 3:00 | .007 | .007 | .006 | .006 |
| 3:01 to 4:00 | .007 | .007 | .006 | .006 |
| 4:01 to 5:00 | .007 | .007 | .007 | .006 |
| 5:01 to 6:00 | .009 | .009 | .009 | .008 |
| 6:01 to 7:00 | .018 | .017 | .018 | .018 |
| 7:01 to 8:00 | .041 | .039 | .044 | .043 |
| 8:01 to 9:00 | .082 | .079 | .084 | .085 |
| 9:01 to 10:00 | .092 | .090 | .093 | .094 |
| 10:01 to 11:00 | .094 | .092 | .095 | .096 |
| 11:01 to 12:00 | .095 | .093 | .095 | .097 |
| 12:01 to 13:00 | .094 | .092 | .095 | .096 |
| 13:01 to 14:00 | .093 | .092 | .094 | .095 |
| 14:01 to 15:00 | .092 | .091 | .093 | .094 |
| 15:01 to 16:00 | .087 | .087 | .087 | .087 |
| 16:01 to 17:00 | .071 | .073 | .070 | .070 |
| 17:01 to 18:00 | .030 | .032 | .029 | .027 |
| 18:01 to 19:00 | .017 | .019 | .016 | .016 |
| 19:01 to 20:00 | .013 | .014 | .012 | .012 |
| 20:01 to 21:00 | .011 | .013 | .010 | .010 |
| 21:01 to 22:00 | .010 | .012 | .009 | .009 |
| 22:01 to 23:00 | .009 | .011 | .008 | .008 |
| 23:01 to 24:00 | .008 | .008 | .007 | .007 |

SOURCE: Author's calculations from May 2001 Work Schedules Supplement of Current Population Survey. Total sample size is 44,260, including 20,125 aged 21 to 39 years, 12,761 aged 40 to 49 years, and 11,374 aged 50 to 69 years.

lacerations, and falls. These injury shares can then be weighted by the share of hours in each interval *t* by taking the ratio of the share of injuries to the share of hours for each age group *a* from the Work Schedules Supplement to obtain the injury ratio:[8]

$$\text{Injury ratio}_{at} = \left( \frac{\text{Injuries}_{at}}{\sum_t \text{Injuries}_{at}} \right) \Bigg/ \left( \frac{\text{Hours}_{at}}{\sum_t \text{Hours}_{at}} \right). \quad (1)$$

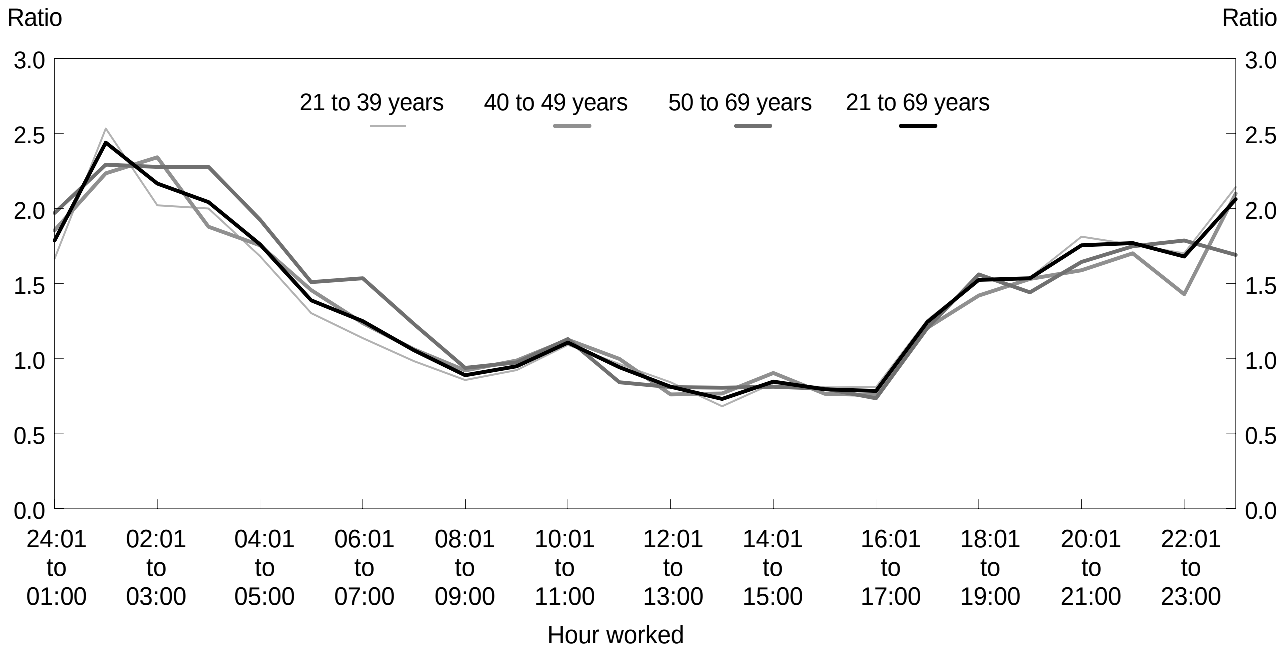
If there is a constant hazard of being injured, the ratio in equation (1) should be constant at unity across the day; that is, an increase in the share of injuries should be offset by a commensurate increase in the share of hours worked in that time interval. The results of this calculation for severe lacerations and fractures are shown in chart 1 and for falls in chart 2. Both charts demonstrate that the injury rate is far from constant. Indeed, the injury ratio is almost 3 times greater very early in the morning than it is at midafternoon. The two categories of severe injuries display similar patterns, both peaking in the 1:01 A.M-to-2:00 A.M. hour and then steadily declining until 8:00 A.M., from which point the injury rate stays low and flat until 5:00 P.M., before gradually rising again through the evening hours.

The profiles of the three age groups in charts 1 and 2 reveal little discernible difference in injury rates between older and younger workers throughout the day, a point taken up in the next section. There is wider dispersion between the age groups in the late night and early morning hours, compared with the normal business hours of 8:00 A.M. to 5:00 P.M., but the differences are not systematic, and given the much larger number of observations used in the calculations for daytime hours, it is not surprising that there is more "noise" in the wee hours of the night.

## Possible explanations

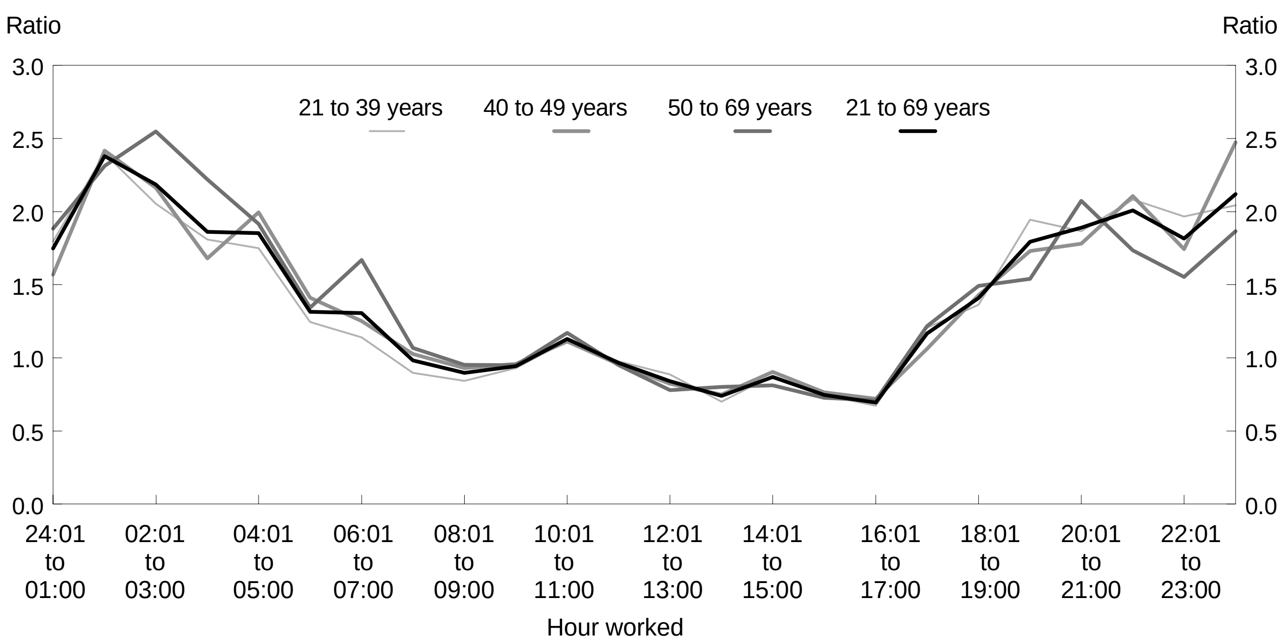
*Compositional differences.* In a 1996 study, Daniel S. Hamermesh found that age is negatively related to the probability of working late at night.[9] Young workers also may be more prone to injuries due to inexperience, which could drive the results. However, there is little difference in the distribution of hours across the day for the three age groups in the sample presented here, as reported in table 1 and noted in the previous section. Furthermore, as also mentioned in that section, the injury ratio patterns reported in charts 1 and 2 are quite comparable for each age group. This finding is notable because it indicates that the overall injury pattern is not driven purely by compositional changes in the age of the workforce; that is, the injury pattern is not simply an artifact of a disproportionately young and inexperienced workforce working late at night.

**Chart 1.** **Ratio of share of lacerations and fractures to share of hours, by hour worked, all workers under 70 years**




SOURCE: Author's calculations from May 2001 Work Schedules Supplement to Current Population Survey and from unpublished data from Texas Workers' Compensation Commission.

**Chart 2.** **Ratio of share of falls to share of hours, by hour worked, all workers under 70 years**




SOURCE: Author's calculations from May 2001 Work Schedules Supplement to Current Population Survey and from unpublished data from Texas Workers' Compensation Commission.

Still, there are other compositional differences that should be of concern. For one, the distribution of injuries throughout the day may be a corollary of the differential distribution of industries and occupations throughout the day. If, for example, more dangerous jobs are also more likely to have night shifts, then the composition of jobs could alone explain the dramatic increase in injuries in the hours shortly before and after midnight. Table 2 reports the broad industry and occupation of employment for those working between 1:01 A.M. and 2:00 A.M. and also for those working between 1:01 P.M. and 2:00 P.M. Note that, although the shares of blue-collar and white-collar workers are comparable in the early morning (35.7 percent and 40.5 percent, respectively), there are fewer than half as many blue-collar jobs as white-collar jobs in the afternoon (25.9 percent and 64.2 percent, respectively).[10]

To examine this phenomenon more closely, additional data on workers' compensation were extracted from the CPS March 2001 Annual Demographic Survey. For each broad industry-occupation combination, the percentage of people working in that category who received workers' compensation payments in the previous year was calculated. The percentage was then used as a measure of the injury rate in the category. Not surprisingly, there was a fair amount of dispersion across industry-occupation cells: although less than one-half of 1 percent of white-collar workers in the commerce industry (including trade, finance, and insurance) received income from workers' compensation insurance, nearly 2 percent of blue-collar manufacturing workers reported that they received workers' compensation payments. Table 2 further reveals that, in addition to being more likely to be injured, blue-collar manufacturing workers make up 19.7 percent of workers between 1:01 A.M. and 2:00 A.M., but only 7.0 percent of workers between 1:01 P.M. and 2:00 P.M. The reverse is true of white-collar commerce workers, who represent only 11.6 percent of the workers in the early morning, but 18.1 percent by the afternoon.

To test the hypothesis that these broad industries and occupations fully explain the distribution of injuries throughout the day, a weighted average of injuries throughout the day was created as follows: Let $\omega_i$ be the percentage of workers in each cell $i$ who received workers' compensation, according to the March CPS Supplement. Let $S_{i,t}$ be the percentage of workers at each hour $t$ of the day who were employed in cell $i$, according to the May 2001 Work Schedules Supplement. Then the following formula computes the share of injuries that is explained purely by differential industry and occupation injury rates:[11]

$$\text{Explained share}_t = \sum_i \omega_i S_{i,t}. \qquad (2)$$

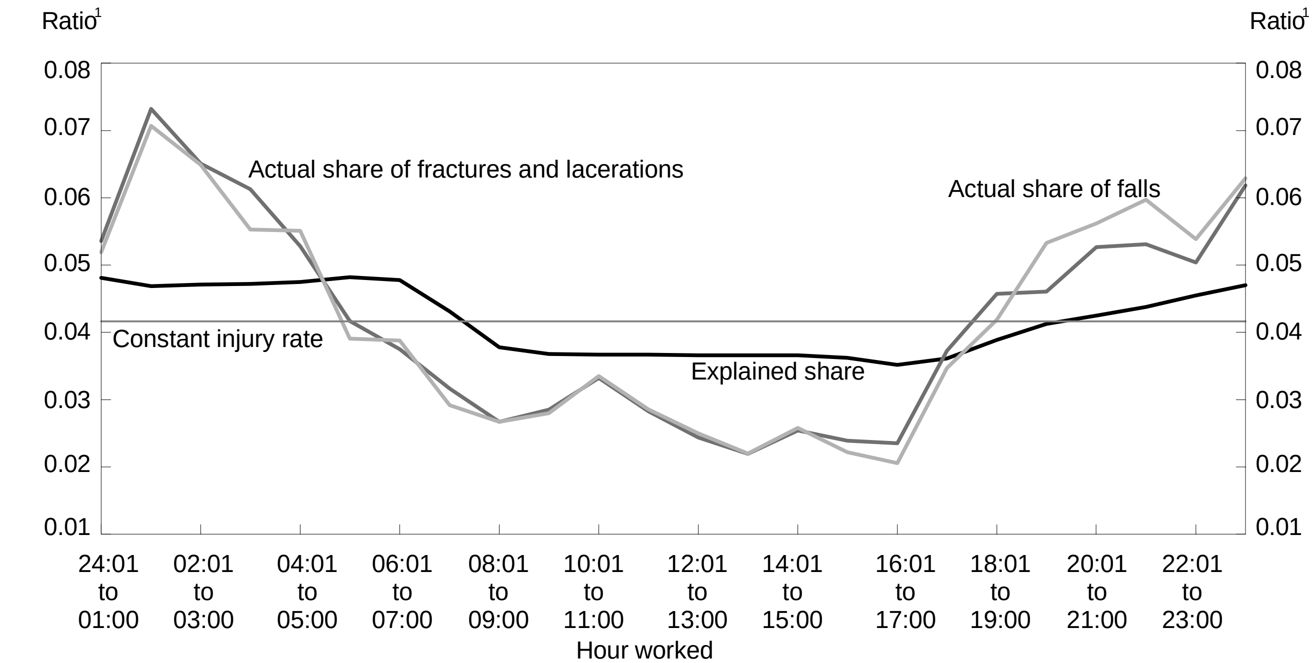
Chart 3 plots the explained injury share for each hour against both the actual share of fractures and lacerations in each hour and the actual share of falls in each hour. For comparability, the injury shares are normalized to sum to 1 throughout the day. The horizontal line through the middle of the chart, labeled "Constant injury rate," represents the hypothetical flat line that would be observed if the ratio of injuries to hours worked were constant throughout the day. The shape of the explained share curve is similar to the shapes of the actual injury rate curves, dipping below the constant injury rate during normal daytime hours and increasing above it during hours late at night and very early in the morning. Nonetheless, the magnitude of the difference between the constant injury rate and the explained share is less than half of the difference between the constant injury rate and the actual shares. In other words, compositional differences in industries and occupations throughout the day account for less than half of the diurnal variation in injury rates.

**Table 2. Occupation and industry composition, 1:01 A.M. to 2:00 A.M. and 1:01 P.M. to 2:00 P.M.**

| Industry | Type of occupation, 1:01 A.M. to 2:00 A.M. | | | | Type of occupation, 1:01 P.M. to 2:00 P.M. | | | |
|---|---|---|---|---|---|---|---|---|
| | White collar | Blue collar | Services | Industry share | White collar | Blue collar | Services | Industry share |
| Total occupation share | 0.405 | 0.357 | 0.238 | 1.000 | 0.642 | 0.259 | 0.099 | 1.000 |
| Agriculture, mining, construction | .008 | .036 | .000 | .044 | .026 | .088 | .001 | .115 |
| Manufacturing | .030 | .197 | .003 | .230 | .068 | .070 | .002 | .140 |
| Infrastructure | .046 | .047 | .005 | .098 | .040 | .029 | .002 | .070 |
| Commerce | .116 | .050 | .059 | .225 | .181 | .035 | .020 | .236 |
| Services | .206 | .026 | .170 | .403 | .327 | .037 | .075 | .440 |

SOURCE: Author's calculations from May 2001 Work Schedules Supplement of Current Population Survey.

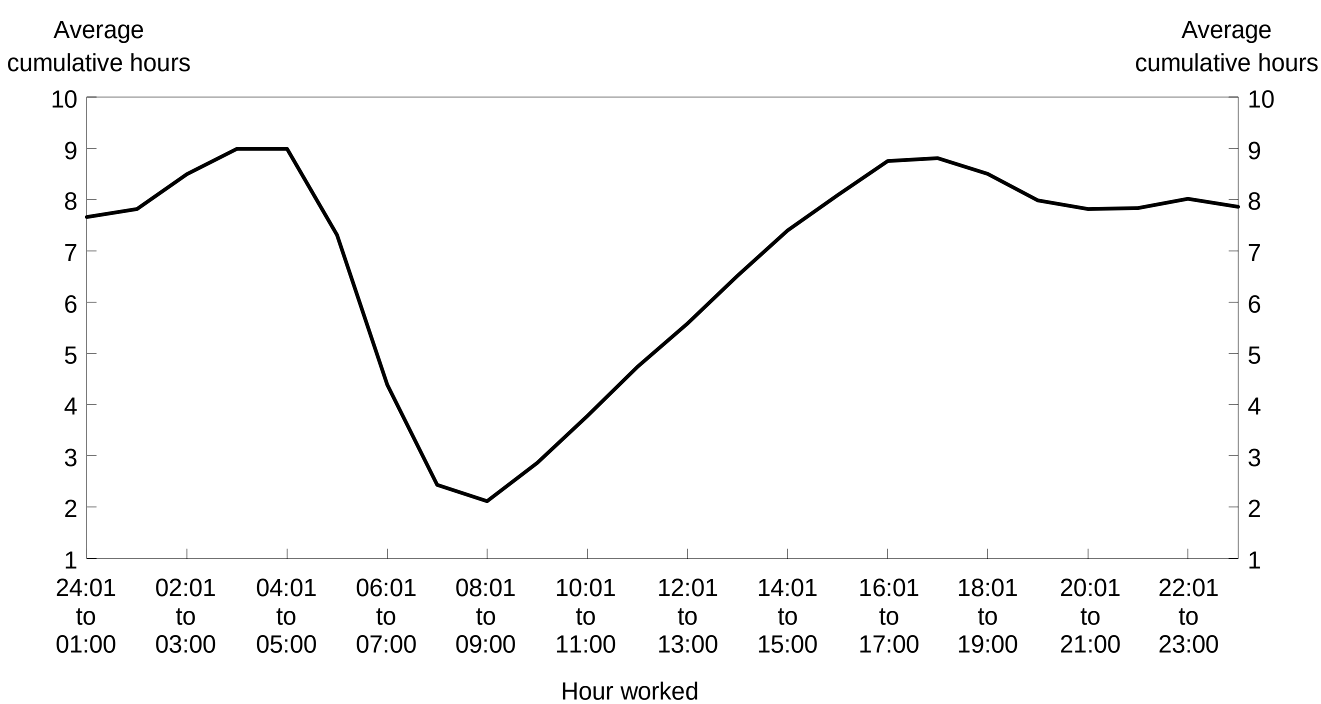
**Chart 3.** **Actual share of injuries and share of injuries explained by industrial and occupational composition, all workers under 70 years**




[1]Ratio of share of injuries to share of hours.

SOURCE: Author's calculations from May 2001 Work Schedules Supplement to Current Population Survey and from unpublished data from Texas Workers' Compensation Commission.

**Chart 4.** **Average cumulative hours by hour worked, all workers under 70 years**




SOURCE: Author's calculations from May 2001 Work Schedules Supplement to Current Population Survey.

*Fatigue*. One explanation for the observed diurnal injury rate pattern could be fatigue. Most of the people working between 10:01 A.M. and 11:00 A.M. have been at work for only a couple of hours, while most of those at work between 3:01 A.M. and 4:00 A.M. have been at work for much longer. Further evidence of the possibility that fatigue is a factor comes from the earlier adjusted median schedule calculations, which show that, for night workers, the typical schedule is 10 hours long, compared with 9 hours for day workers and 8 hours for evening workers. Such differences in the duration of work at each time of the day can have sizable effects on diurnal injury rates if workers are sensitive to the amount of time they spend on the job.

The relevance of fatigue can be considered by first calculating the cumulative hours worked as of each hour of the day by each worker and then taking the average cumulative hours in each hour of the day of employees working during that hour. Chart 4 displays the average cumulative hours worked for each hour (among those who are working). Although both the average duration of the shift and the injury rate dip during the day and peak at night, the shape and extrema of the shift duration plot are remarkably dissimilar to the injury patterns in charts 1 and 2. The patterns of fractures and lacerations and of falls have wide troughs bottoming out between 4:01 P.M. and 5:00 P.M. (charts 1 and 2), while the profile of average cumulative hours has a very narrow, but deep, trough that reaches its minimum between 8:01 A.M. and 9:00 A.M. (chart 4). As cumulative hours on the job rise dramatically from 8:00 A.M. to 5:00 P.M., injury rates remain low and actually decrease slightly. Given the dissimilarities between the diurnal injury patterns and the diurnal fatigue patterns, there is little evidence that fatigue is the primary factor contributing to the late-night spike in the injury rate.

*Other physiological factors*. Up until now, this article has discussed circumstances that are *correlated with* working a late shift, but that are not *intrinsic to* late shifts. For example, working in dangerous industries or occupations and working long hours are relatively more prevalent among workers who work night shifts than day shifts, but neither of these factors can, by itself, explain the high nighttime injury rate. However, Ed Coburn and Martin Moore-Ede argue that there are inherent characteristics of night activity that affect workers' alertness.[12] These characteristics may explain why the injury pattern has such large variation throughout the day.

A well-developed body of research in the physiology and neuroscience literature examines biological patterns known as *circadian rhythms*. These rhythms are biochemically regulated processes that generate a diurnal variation in the body's level of alertness. One recent article, for example, experimentally assesses the influence of circadian rhythms on such behavioral functions as short-term memory, reaction time, and visual vigilance.[13] In this study, the researchers scheduled episodes of sleep in such manner as to "desynchronize" circadian rhythms from the duration of wakefulness, thus independently identifying the two processes. The authors find that functional impairment peaks just after the nadir of the circadian cycle, which is observed in the early morning hours. Although each subject was evaluated intensively throughout the course of 15 to 24 repetitions of a 20-hour cycle, one limitation of the study is that it is based entirely on only six subjects. However, several related studies conducted by many of the same researchers have found similar effects of the circadian cycle on alertness. Although by no means conclusive, these experimental studies, coupled with the empirical results presented in the current article, provide strong evidence that workers are not optimally alert during night shifts, contributing to hazardous work conditions for themselves as well as their fellow employees.

THERE ARE BOTH SUPPLY-SIDE AND DEMAND-SIDE REASONS that workers might work at night. As Hamermesh notes in his 1996 book, working "unusual" times is a more usual event than we might expect.[14] He finds that women with young children often choose to work late at night, arguably because of a lack of affordable childcare during the day. On the demand side, firms can increase the productive capacity of plants by sustaining night shifts to supplement the day shifts.

However, there is a tradeoff for firms employing night shift workers. As this article has demonstrated, injuries are much more prevalent late at night than during normal business hours. The evidence presented here suggests that this difference is not simply because of compositional changes in the age or in the broad industries or occupations of late-night workers. Nor is it attributable to late-night workers having been at work longer. The failure of all of these factors to explain the higher prevalence of injuries on the late-night work shift leads to the conclusion that there are inherent features of night work that make it more hazardous than day work. □

## Notes

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[1] President's Commission on the Accident at Three Mile Island, *Report of the President's Commission on the Accident at Three Mile Island* (Washington, DC, U.S. Government Printing Office, 1979).

[2] OECD Nuclear Energy Agency, *Chernobyl—Ten Years On* (Paris, Organization for Economic Cooperation and Development, 1995); on the Internet at **www.nea.fr**.

[3] See, for example, "No More Nine-to-Five," *The Economist*, Jan. 10, 1998; and Valerie Marchant, "In the Deep of the Night," *Time*, Nov. 1, 1999.

[4] See *Current Employment Statistics* (Bureau of Labor Statistics, various years); on the Internet at **www.bls.gov**.

[5] *State Workers' Compensation Laws* (U.S. Department of Labor, January 2004).

[6] The particular windows chosen with the use of this procedure are as follows:

*Day shift*. Begins between 1:00 A.M. and 1:00 P.M.; ends between 1:00 P.M. and 1:00 A.M.

*Evening shift*. Begins between 7:00 A.M. and 7:00 P.M.; ends between 7:00 P.M. and 7:00 A.M.

*Night shift*. Begins between 12:00 P.M. and 12:00 A.M.; ends between 12:00 A.M. and 12:00 P.M.

[7] In a preliminary analysis, all results in this article were computed without the imputed schedules and were found to be qualitatively similar to the results obtained with imputation.

[8] Note that this formula is equivalent to taking the number of injuries per hour and multiplying by a constant that depends only on the age group. Hence, the informational content of the injury *ratio* calculation used in equation (1) is the same as that contained in the calculation of an injury *rate*, which is the number of injuries divided by the number of hours. However, because the numerator and denominator in the analysis presented here come from two separate sources, the ratio of injury shares to hour shares was calculated in order to avoid confusion and to provide a statistic with a more transparent interpretation. Because of this relationship, the remainder of the article uses the terms "injury ratio" and "injury rate" interchangeably.

[9] Daniel S. Hamermesh, *Workdays, Workhours, and Work Schedules* (Kalamazoo, MI, W.E. Upjohn Institute for Employment Research, 1996).

[10] In this analysis, executive, professional, administrative, managerial, technician, and sales occupations are considered white-collar occupations. Precision production, machine-operating, material-moving, transportation-handling and cleaning, farming, fishing, and forestry occupations are deemed blue-collar occupations, and private household services, protective services, and other services are adjudged service occupations. Industries are divided into five categories: (1) agriculture, mining, and construction, which also includes forestry and fishing; (2) manufacturing, including durable and nondurable goods; (3) infrastructure, comprising transportation, communications, utilities, and sanitation services; (4) commerce, consisting of retail and wholesale trade, finance, insurance, and real estate; and (5) services, including household, repair, personal, recreational, medical, social, educational, and other professional services.

[11] This formula is similar to calculations that Robert Shimer and, in a separate work, Lawrence F. Katz and Alan B. Krueger, used to examine how compositional differences in age and education in the U.S. workforce could account for unemployment patterns over the past three decades. (See Robert Shimer, "Why Is the U.S. Unemployment Rate So Much Lower?" in Ben Bernanke and Julio Rotemberg (eds.), *NBER Macroeconomics Annual 1998* (Cambridge, MA, MIT Press, 1998); and Lawrence F. Katz and Alan B. Krueger, "The High-Pressure U.S. Labor Market of the 1990s," *Brookings Papers on Economic Activity* (Washington, DC, The Brookings Institution, 1999), pp. 1–87.

[12] Ed Coburn and Martin Moore-Ede, "Keeping the Night Shift Alert," *Journal of Workers' Compensation*, vol. 10, no. 2, winter 2001, pp. 22–35.

[13] James K. Wyatt, Angela Ritz-De Cecco, Charles A. Czeisler, and Derk-Jan Dijk, "Circadian Temperature and Melatonin Rhythms, Sleep, and Neurobehavioral Function in Humans Living on a 20-h Day," *American Journal of Physiology*, vol. 277, October 1999, pp. R1152–R1163.

[14] Hamermesh, *Workdays*.