## Research on Daylight Saving Time from Scott Yates

The twice-annual clock change provides a golden chance for academics to study external factors on human behavior, so there are literally hundreds of fully vetted research papers available.

Below are links and a very short summary of the most important findings. Attached you will find the available research.

- Heart attacks go up because of the clock change. (New England Journal of Medicine, Sleep Medicine Journal)
- There's NO increased risk to children in rural areas.
  - (American Journal of Public Health)
- Traffic accidents spike on the Monday after "Spring Forward." (American Economic Association, New England Journal of Medicine)
- Workplace injuries go up.
  - (Journal of Applied Psychology)
- Staying in DST will improve traffic safety in the winter months, and there is no increased risk to students waiting for school buses.
  - (Journal of Safety Research)
- Permanent DST saves energy.
  - (U.S. Department of Energy)
- Permanent DST helps in the fight against childhood obesity. (Journal of Behavioral Nutrition and Physical Activity and Journal of Physical Activity and Health)
- Workplace productivity goes down because of the clock changes. (Journal of Applied Psychology, story here)
- Permanent DST will help decrease air pollution.
  - (Journal of the Air & Waste Management Assn. and Steve Spangler Science)
- Getting rid of clock changing will make the stock market perform better. (Journal of Psychological Reports)
- Clock-changing brings harsher sentences from judges. (Psychological Science)
- Staying in DST all year can save wildlife. (The Royal Society Biology Letters)

What follows is 94 pages of prints from various research journals, all cited above.

The only one not included is the report from the Wall St. Journal about how clock-changing harms relationships.

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## Shifts to and from Daylight Saving Time and Incidence of Myocardial Infarction

N Engl J Med 2008, 359 1966-1968 October 30, 2008 DOI: 10.1056/NEJMc0807104

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FIGURE 1

Incidence Ratios of

Infarction on the First 7

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Acute Myocardial

and Autumn Clock

Shifts for Daylight

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To the Editor:

More than 1.5 billion men and women are exposed to the transitions involved in daylight saving time; turning clocks forward by an hour in the spring and backward by an hour in the autumn. These transitions can disrupt chronobiologic rhythms and influence the duration and quality of sleep, and the effect lasts for several days after the shifts.12

We examined the influence of these transitions on the incidence of acute myocardial infarction. To calculate the incidence ratio, we compared the incidence of acute myocardial infarction during each of the first 7 days after the spring or autumn transition and the mean of the incidences on the corresponding weekdays 2 weeks before and 2 weeks after the day of interest. For example, for the Tuesday after the transition, we would have divided the incidence on that Tuesday by the mean of the incidence on the Tuesday 2 weeks earlier and the incidence on the Tuesday 2 weeks later. We used data from the Swedish registry of acute myocardial infarction, which provides high-quality information on all acute myocardial infarctions in the country since 1987. The incidence ratios, as measures of relative risk, and exact 95% confidence intervals were calculated.

The incidence of acute myocardial infarction was significantly increased for the first 3 weekdays after the transition to daylight saving time in the spring (Figure 1A). The incidence ratio for the first week after the spring shift, calculated as the incidence for all 7 days divided by the mean of the weekly incidences 2 weeks before and 2 weeks after, was 1.051 (95% confidence interval [CI], 1.032 to 1.071). In contrast, after the transition out of daylight saving time in the autumn, only the first weekday was affected significantly (Figure 1B); the incidence ratio for the whole week was 0.985 (95% CI, 0.969 to 1.002).

The effect of the spring transition to daylight saving time on the incidence of acute myocardial infarction was somewhat more pronounced in women than in men, and the autumn effect was more pronounced in men than in women. The separate analyses of the 1987–1996 and 1997–2006 periods yielded essentially the same results as those for the whole 1987-2006 period. The

effects of transitions were consistently more pronounced for people under 65 years of age than for those 65 years of age or older.

The most plausible explanation for our findings is the adverse effect of sleep deprivation on cardiovascular health. According to experimental studies, this adverse effect includes the predominance of sympathetic activity and an increase in proinflammatory cytokine levels.3.4 Our data suggest that vulnerable people might benefit from avoiding sudden changes in their biologic

It has been postulated that people in Western societies are chronically sleep deprived, since the

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average sleep duration decreased from 9.0 to 7,5 hours during the 20th century,4 Therefore, it is important to examine whether we can achieve beneficial effects with prolonged sleep. The finding that the possibility of additional sleep seems to be protective on the first workday after the autumn shift is intriguing. Monday is the day of the week associated with the highest risk of acute myocardial infarction, with the mental stress of starting a new workweek and the increase in activity suggested as an explanation. Our results raise the possibility that there is another, sleep-related component in the excess incidence of acute myocardial infarction on Monday. Sleep-diary studies suggest that bedtimes and wake-up times are usually later on weekend days than on weekdays; the earlier wake-up times on the first workday of the week and the consequent minor sleep deprivation can be hypothesized to have an adverse cardiovascular effect in some people. This effect would be less pronounced with the transition out of daylight saving time, since it allows for additional sleep. Studies are warranted to examine the possibility that a more stable weekly pattern of waking up in the morning and going to sleep at night or a somewhat later wake-up time on Monday might prevent some acute myocardial infarctions.

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Rickard Ljung, M.D., Ph.D.
National Board of Health and Welfare, SE-106 30 Stockholm, Sweden

Supported by a postdoctoral grant (2006-1146, to Dr. Janszky) from the Swedish Council of Working Life and Social Research, Ansgarius Foundation, King Gustaf V and Queen Victoria's Foundation, and the Swedish Heart and Lung Foundation.

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Daylight saving time shifts and incidence of acute myocardial infarction - Swedish Register of Information and Knowledge About Swedish Heart Intensive Care Admissions (RIKS-HIA)

Imre Janszky 11. Staffan Ahnve<sup>1</sup>, Rickard Ljung<sup>1</sup>, Kenneth J. Mukamal<sup>1</sup>, Shiva Gautam<sup>1</sup>, Lars

Efficacy and safety of dopamine agonists in restless legs syndrome Homyak, Magdolna et al.

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DOI: http://dx.doi.org/10.1016/j.sleep.2011.07.019

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## Abstract

## Background

Daylight saving time shifts can be looked upon as large-scale natural experiments to study the effects of acute minor sleep deprivation and circadian rhythm disturbances. Umited evidence suggests that these shifts have a short-term influence on the risk of acute myocardial infarction (AMI), but confirmation of this finding and its variation in magnitude between individuals is not clear.

## Methods

To identify AMI incidence on specific dates, we used the Register of Information and Knowledge about Swedish Heart Intensive Care Admission, a national register of coronary care unit admissions in Sweden. We compared AMI incidence on the first seven days after the transition with mean incidence during control periods. To assess effect modification, we calculated the incidence ratios in strata defined by patient characteristics.

## Results

Overall, we found an elevated incidence ratio of 1.039 (95% confidence interval, 1.003-1.075) for the first week after the spring clock shift forward. The higher risk tended to be more pronounced among individuals taking cardiac medications and having low cholesterol and triglycerides. There was no statistically significant change in AMI incidence following the autumn shift. Patients with hyperlipidemia and those taking statins and calciumchannel blockers tended to have a lower incidence than expected. Smokers did not ever have a higher

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## Conclusions

Our data suggest that even modest sleep deprivation and disturbances in the sleep-wake cycle might increase the risk of AMI across the population. Confirmation of subgroups at higher risk may suggest preventative strategies to mitigate this risk.

Keywords:

Daylight saving time, Circadian rhythm, Sleep deprivation, Myocardial Infarction, Sleep, Chronobiology, Circadian Misalignment

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Am J Public Health. 1995 January; 85(1): 92-95.

PMCID: PMC1615292

# Daylight saving time and motor vehicle crashes: the reduction in pedestrian and vehicle occupant fatalities.

S A Ferguson, D F Preusser, A K Lund, P L Zador, and R G Ulmer

Insurance Institute for Highway Safety, Arlington, Va 22201.

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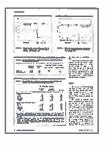
Fatal crashes were tabulated for 6-hour periods around sunrise and sunset, from 13 weeks before the fall change to standard time until 9 weeks after the spring change to daylight saving time. Fatal-crash occurrence was related to changes in daylight, whether these changes occurred abruptly with the fall and spring time changes or gradually with the changing seasons of the year. During daylight saving time, which shifts an hour of daylight to the busier evening traffic hours, there were fewer fatal crashes. An estimated 901 fewer fatal crashes (727 involving pedestrians, 174 involving vehicle occupants) might have occurred if daylight saving time had been retained year-round from 1987 through 1991.

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• Fridstrøm L, Ingebrigtsen S. An aggregate accident model based on pooled, regional time-series data. Accid Anal Prev. 1991 Oct;23(5):363-378. [PubMed]

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# Spring Forward at Your Own Risk: Daylight Saving Time and Fatal Vehicle Crashes

Austin C. Smith

AMERICAN ECONOMIC JOURNAL: APPLIED ECONOMICS

VOL. 8, NO. 2, APRIL 2016

(pp. 65-91)

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## **Abstract**

Daylight Saving Time (DST) impacts over 1.5 billion

people, yet many of its impacts on practicing populations remain uncertain. Exploiting the discrete nature of DST transitions and a 2007 policy change, I estimate the impact of DST on fatal automobile crashes. My results imply that from 2002-2011 the transition into DST caused over 30 deaths at a social cost of \$275 million annually. Employing four tests to decompose the aggregate effect into an ambient light or sleep mechanism, I find that shifting ambient light only reallocates fatalities within a day, while sleep deprivation caused by the spring transition increases risk. (JEL I12, Q48, R41)

## Citation

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## Daylight Savings Time and Traffic Accidents

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N Engl J Med 1996; 334:924-925 April 4, 1996 DOI: 10.1056/NEJM199604043341416

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To the Editor:

It has become increasingly clear that insufficient sleep and disrupted circadian rhythms are a major public health problem. For instance, in 1988 the cost of sleep-related accidents exceeded \$56 billion and included 24,318 deaths and 2,474,430 disabling injuries. Major disasters, including the nuclear accident at Chemobyl, the Exxon Valdez oil spill, and the destruction of the space shuttle Challenger, have been linked to insufficient sleep, disrupted circadian rhythms, or both on the part of involved supervisors and staff, 2,3 It has been suggested that as a society we are chronically sleepdeprived4 and that small additional losses of sleep may have consequences for public and individual safety.2

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We can use noninvasive techniques to examine the effects of minor disruptions of circadian rhythms on normal activities if we take advantage of annual shifts in time keeping. More than 25 countries shift to daylight savings time each spring and return to standard time in the fall. The spring shift results in the loss of one hour of sleep time (the equivalent in terms of jet lag of traveling one time zone to the east), whereas the fall shift permits an additional hour of sleep (the equivalent of traveling one time zone to the west). Although one hour's change may seem like a minor disruption in the cycle of sleep and wakefulness, measurable changes in sleep pattern persist for up to five days after each time shift.<sup>5</sup> This leads to the prediction that the spring shift, involving a loss of an hour's sleep, might lead to an increased number of "microsleeps," or lapses of attention, during daily activities and thus might cause an increase in the probability of accidents, especially in traffic. The additional hour of sleep gained in the fall might then lead conversely to a reduction in accident rates.

We used data from a tabulation of all traffic accidents in Canada as they were reported to the Canadian Ministry of Transport for the years 1991 and 1992 by all 10 provinces. A total of 1,398,784 accidents were coded according to the date of occurrence. Data for analysis were restricted to the Monday preceding the week of the change due to daylight savings time, the Monday immediately after, and the Monday one week after the change, for both spring and fall time shifts. Data from the province of Saskatchewan were excluded because it does not observe daylight savings time. The analysis of the spring shift included 9593 accidents and that of the fall shift 12,010. The resulting data are shown in Figure 1.

The loss of one hour's sleep associated with the spring shift to daylight savings time increased the risk of accidents. The Monday immediately after the shift showed a relative risk of 1.086 (95 percent confidence interval, 1.029 to 1.145;  $\xi^2$  = 9.01, 1 df; P<0.01). As compared with the accident rate a week later, the relative risk for the Monday immediately after the shift was 1.070 (95 percent confidence interval, 1.015 to 1.129;  $\xi^2 = 6.19$ , 1 df; P<0.05). Conversely, there was a reduction in the risk of traffic accidents after the fall shift from daylight savings time when an hour of sleep was gained. In the fall, the relative risk on the Monday of the change was 0.937 (95 percent confidence interval, 0.897 to 0.980;  $\xi^2 = 8.07$ , 1 df; P<0.01)

FIGURE 1

Numbers of Traffic Accidents on the after the Shifts to and from Daylight Savings Time for the Years



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These data show that small changes in the amount of sleep that people get can have major consequences in everyday activities. The loss of merely one hour of sleep can increase the risk of traffic accidents. It is likely that the effects are due to sleep loss rather than a nonspecific disruption in circadian rhythm, since gaining an additional hour of sleep at the fall time shift seems to decrease the risk of accidents.

Stanley Coren, Ph.D. University of British Columbia, Vancouver, BC V6T 1Z4, Canada

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# Changing to Daylight Saving Time Cuts Into Sleep and Increases Workplace Injuries

Christopher M. Barnes and David T. Wagner Michigan State University

The authors examine the differential influence of time changes associated with Daylight Saving Time on sleep quantity and associated workplace injuries. In Study 1, the authors used a National Institute for Occupational Safety and Health database of mining injuries for the years 1983–2006, and they found that in comparison with other days, on Mondays directly following the switch to Daylight Saving Time—in which 1 hr is lost—workers sustain more workplace injuries and injuries of greater severity. In Study 2, the authors used a Bureau of Labor Statistics database of time use for the years 2003–2006, and they found indirect evidence for the mediating role of sleep in the Daylight Saving Time—injuries relationship, showing that on Mondays directly following the switch to Daylight Saving Time, workers sleep on average 40 min less than on other days. On Mondays directly following the switch to Standard Time—in which 1 hr is gained—there are no significant differences in sleep, injury quantity, or injury severity.

Keywords: sleep, fatigue, safety in the workplace, work injuries, work scheduling

Workplace injuries have long been an important topic in the management and applied psychology literatures (for a recent review, see Clarke, 2006). Workplace injuries can lead to a host of problems for organizations, including lost productivity, legal action, turnover, and lost human capital. Workplace injuries also lower the quality of life of employees, may result in lost income, and in extreme cases can result in death. The National Safety Council (2008) reported that there were 3.7 million disabling work injuries and 4,988 work fatalities in the United States in the year 2006, with an estimated cost to businesses of \$164.7 billion. Researchers have examined many antecedents of workplace injuries, including organizational climate (Hofmann & Stetzer, 1996; Zohar, 1980, 2000), work design (Barling, Kelloway, & Iverson, 2003), transformational leadership (Barling, Loughlin, & Kelloway, 2002), and perceived organizational support (Hofmann & Morgeson, 1999).

Despite the many antecedents that have been studied, to date, the management and applied psychology literatures have not considered the set of twice-yearly time changes associated with Daylight Saving Time. As of 2008, 74 countries around the world participate in Daylight Saving Time (Timeanddate.com, 2008). In the spring, there is a 1-hr shift such that clocks are set forward ! hr—referred to as a phase advance—to switch from Standard Time to Daylight Saving Time. In the fall, there is a 1-hr shift in the opposite direction—referred to as a phase delay—to reset to Standard Time.

As organizational researchers have noted, changes to time schedules can have important implications to members of organizations (Blount & Janicik, 2001), and changes to systems that are linked to cycles of time can be far-reaching and powerful (Ancona & Chong, 1996). Human sleep and activity cycles are both linked to the 24-hr cycles of the Earth's rotation, Twice yearly, countries adjust their activity cycles, which have important implications for sleep cycles (Monk, 1980). Given the importance of sleep to brain functioning (Maquet et al., 1997; Saper, Scammell, & Lu, 2005), this is likely to impact organizational phenomena, including work-place injuries.

Researchers in fields outside of management and applied psychology have examined the influence of time changes associated with Daylight Saving Time on accidents in general, with conflicting results (cf. Coren, 1996; Hicks, Lindseth, & Hawkins, 1983; Holland & Hinze, 2000; Monk, 1980). Studies examining clock change effects on car accidents have found significant results in traffic settings (Coren, 1996; Hicks et al., 1983; Monk, 1980); however, confounds with light patterns noted by Holland and Hinze (2000) and Coate and Markowitz (2004) limit the applicability of this effect in most organizations. Holland and Hinze examined the effect of time changes on accidents in a construction setting in which light is more likely to be controlled, making the results of their study more applicable to organizations. They found no significant relationship between time changes and accidents, but the small number of days included in their study limited their statistical power, and thus their findings should be interpreted with caution. Nevertheless, Holland and Hinze's null findings may reinforce the assumption that 1-hr clock adjustments could not impact injury rates in organizations.

The purpose of this article is to challenge that potentially dangerous assumption. Drawing from previous theory and research examining schedule entrainment and circadian rhythms of sleep, we contend that the spring and fall time changes associated with Daylight Saving Time have differential effects on sleep quantity. Drawing from research examining the effects of human sleep quantity on human brain function, we contend that these changes

Christopher M. Barnes and David T. Wagner, Eli Broad Graduate School of Management, Michigan State University.

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in sleep are associated with important differences in the number and severity of workplace injuries. Moreover, we explore whether employees with low levels of experience are especially vulnerable to these effects. Finally, we close with a discussion of the practical implications that our findings have for managers, suggesting work scheduling strategies that might mitigate the effects of time changes on workplace injuries. We hope that knowledge of these effects will enable future actions that can prevent injuries associated with time change and potentially save lives.

## Workplace Injuries

Highlighting the importance of safety and work injuries to organizations and employees, the National Safety Council (2008) reported that American work injuries cost \$164.7 billion in the year 2006 alone. Despite this enormous cost, Barling et al. (2002) noted that less than 1% of organizational research published in top journals has focused on workplace safety. The majority of this research has considered antecedents of work injuries that are relatively stable over time, such as organizational climate, work design, leadership, and management-employee relations (Barling et al., 2002; Clarke, 2006; Hofmann & Morgeson, 1999; Hofmann & Stetzer, 1996; Neal & Griffin, 2006; Wallace, Popp, & Mondore, 2006; Zacharatos, Barling, & Iverson, 2005; Zohar, 1980, 2000). One would expect these antecedents to remain relatively stable from day to day. Perhaps this focus on relatively stable antecedents is because, as Neal and Griffin (2006) noted, the majority of this research has been cross-sectional in nature; we add that researchers have also conceptually focused on relatively stable antecedents of workplace injuries (for an exception, see Humphrey, Moon, Conlon, & Hofmann, 2004).

However, management and applied psychology researchers have also begun to examine antecedents of work injuries that could demonstrate substantial variation across time. For example, Frone (1998) examined the influence of workload on workplace injuries, and although Frone did not examine this relationship dynamically, previous research suggests that workload can vary over time (Barnes et al., 2008; Huey & Wickens, 1993; Ilies et al., 2007). Likewise, the antecedents of personal and work accidents examined by Legree, Heffner, Psotka, Martin, and Medsker (2003) included stress, fatigue, sleep, and distractions; each of these antecedents is likely to be more dynamic over time than the relatively stable antecedents of safety climate and leadership. In the next section, we draw from theory examining entrainment to offer one explanation for accidents and injuries across time.

## Entrainment Theory and 24-hr Cycles

Several researchers have recently emphasized the importance of time in organizations (Ancona, Goodman, Lawrence, & Tushman, 2001; Ancona, Okhuysen, & Perlow, 2001; Blount & Janicik, 2001; Mitchell & James, 2001). One especially important type of time is cyclical time, in which the timing of events recurs regularly (Ancona, Okhuysen, & Perlow, 2001). Ancona and Chong (1996) noted that cycles in organizations can be captured by outside cycles in a process they refer to as entrainment. More specifically, they define entrainment as adjustment of the pace or cycle of one activity to match or synchronize with that of another. That adjust-

ment could be in the phase, periodicity, or magnitude of the activity (Ancona & Chong, 1996).

According to Ancona and Chong (1996), the fundamental idea behind entrainment theory in organizations is that endogenous cycles exist within individuals, groups, organizations, and environments. They contend that these endogenous cycles are often influenced by other cycles within or outside of the system resulting in synchrony between the systems; in entrainment language, the cycles are "captured" by an external pacer so as to have the same phase, periodicity, or magnitude.

Perhaps the most powerful external pacer of a very broad set of cycles on the planet Earth is the 24-hr cycle of the Earth's rotation. This cycle has been important to humans throughout their evolutionary development, in part because humans are generally better suited for activity during daylight than during darkness (Siegel, 2005). Thus, two sets of complimentary periods of human behavior have been entrained to this 24-hr period; sleep and waking activity.

Sleep is a recurring period in human activity that is defined as a state of immobility with greatly reduced responsiveness, which can be distinguished from coma or anesthesia by its rapid reversibility (Siegel, 2005). Borbely and Achermann (1999) noted that a major process that underlies sleep regulation is the circadian process, a clocklike mechanism that is basically independent of prior sleep and waking and determines the alternation of periods with high and low sleep propensity. This process regulates sleep such that it conforms to the 24-hr rotation cycle of the Earth, with sleep and activity phases regulated within this 24-hr cycle.

A large body of research indicates that the suprachiasmatic nuclei of the hypothalamus are the locus of an endogenous self-sustaining circadian pacemaker in the mammalian brain (Dijk & Czeisler, 1995; Ruby, Dark, Burns, Heller, & Zucker, 2002; Saper et al., 2005; Weaver, 1998). Working on a 24-hr cycle that is generally entrained with the light cycle created by the Earth's 24-hr rotation, the suprachiasmatic nuclei relay neural signals to the pineal gland to secrete melatonin (Dijk & Czeisler, 1995; Lavie, 2001). Melatonin inhibits the wakefulness-generating mechanisms, thereby enabling the brain's sleep-related structures to be activated unopposed by the drive for wakefulness (Lavie, 1986, 1997, 2001).

Research indicates that exposure to light can promote the production of melatonin (Lavie, 2001), suggesting the direct influence of daylight periods associated with the Earth's rotation on sleep entrainment. Despite the importance of daylight for human cycles of sleep and wakefulness, research also indicates a powerful endogenous component of the circadian sleep period, such that even in the absence of variance in light exposure humans still conform rather closely to a 24-hr cycle in sleep (Czeisler et al., 1999). Consistent with Siegel's (2005) suggestion that humans are better suited for daytime activity than nighttime activity. Czeisler et al. (1999) speculated that natural selection has favored this endogenous circadian rhythmicity. Further consistent with these contentions is research that indicates that although there are individual differences in sleep schedules (cf. Lavic, 1986; Soehner, Kennedy, & Monk, 2007), sleep periods generally occur during hours of darkness, usually beginning within 1-2 hr of 11:00 p.m. (Lavie, 1986; Monk, Buysse, Carrier, & Kupfer, 2000; Soehner et al., 2007). Consequently, activity periods including work generally occur in complementary phases that overlap daylight hours.

In addition to physiological mechanisms that regulate phases of human activity, societal norms promote the use of clocks, which are an additional mechanism for regulating periods of human activity within the 24-hr cycle. Research indicates that clocks are very influential in how humans schedule and pace their work activity (Blount & Janicik, 2001; Gersick, 1988, 1989; Labianca, Moon, & Watt, 2005). "Clock time" allows for more precise coordination and scheduling of activities than do internal physiological clocks or observation of the position of the sun. Although most of the time the period of the Earth's rotation and the period of clocks are identical (i.e., 24 hr), as we note below, twice a year 74 countries make adjustments to clock periods that are independent of the Earth's natural daylight cycle. Because most activity within organizations is scheduled on the basis of clock time, this time shift in 74 countries is particularly important for organizations and workers throughout the world. Thus, even though humans were initially entrained to the 24-hr rotation period of the Earth, reliance on clocks as a tool for tracking the 24-hr cycle has led to the entrainment of human activity to clock time.

## Daylight Saving Time and Entrainment

As proposed by Benjamin Franklin, the purpose of Daylight Saving Time is to better match the waking activity phase of the human sleep/wake cycle with the daylight phase of the Earth's rotation cycle (Kamstra, Kramer, & Levi, 2000). As noted above, researchers suspect that humans have been selected over time such that the waking phase of their sleep/wake period corresponds with the daylight phase of the Earth's period (Czeisler et al., 1999; Siegel, 2005). Therefore, one would expect that implementing Daylight Saving Time would be beneficial to human activity, including work. However on the basis of entrainment theory, we contend that there are also negative consequences associated with the phase changes associated with Daylight Saving Time. We develop these arguments below, beginning with the influence of clock changes on sleep.

Ancona and Chong (1996) noted that when systems are entrained, altering one system can have considerable effects on the other. In the current context, altering clock time influences human activity schedules. Phase advances in which clocks are set forward I hr bring waking activity, including work, I hr sooner ("spring forward"). Phase delays in which clocks are set backward I hr push waking activity, including work, later ("fall backward"). In America, these phase adjustments occur at 2:00 a.m. on Sundays, adding or subtracting I hr of clock time in the very early morning hours. As an example, a 9:00 a.m. work shift that would normally occur 9 hr after midnight occurs 8 hr after midnight on phase advance days, and 10 hr after midnight on phase delay days. Because work is scheduled on clock time, work can proceed uninterrupted.

However, planned clock changes have no mechanism for creating corresponding phase advances or delays in the human endogenous circadian period, which is a major component to sleep regulation. This endogenous circadian period leads most people to go to sleep within 1-2 hr of 11:00 p.m. On average, people will experience the same sleep propensity function on Saturdays immediately preceding these clock changes as they do throughout the rest of the year. However, on phase advance days, the time at which they would normally begin waking activity is advanced by

I hr, and on phase delay days, the time at which they would normally begin waking activity is delayed by I hr. Therefore, we contend that in comparison with days in which no phase change occurs, phase advance days will lead to lower quantities of sleep, and phase delay days will lead to higher quantities of sleep.

Previous research indicates that the effects of phase advances and phase delays are asymmetric. In a series of three withinsubjects studies involving a total of 22 participants spending 24 hr in the laboratory, Lavie (1986) found that humans experience a low point in sleep propensity from approximately 10:00 p.m. to 11:00 p.m. Following the low point in sleep propensity, melatonin production increased, and the onset of the nocturnal sleep period was abrupt, generally occurring within 1-2 hr (Lavie, 1986). Lavie refers to the low point in sleep propensity as the forbidden zone and refers to the following rapid increase in sleep propensity as the opening of the sleep gate. Thus, melatonin is implicated with the opening of the sleep gate, such that sleep propensity declines just before bedtime, after which it rapidly increases culminating in the sleep phase of the 24-hr period (Lavie, 2001). The sleep gate remains open for several hours, so sleep propensity remains high for several hours (Lavie, 1986). This suggests that it is especially difficult to fall asleep earlier than normal, as would be required to keep sleep constant on a phase advance day. However, there is no biological mechanism that prevents people from delaying sleep onset by 1 hr on phase delay days. On the basis of this research, we contend that the negative effect of phase advances (losing 1 hr) on sleep quantity will be stronger than the positive effect of phase delays (gaining I hr) on sleep quantity.

Previous research provides support for our contentions regarding time changes and sleep. Folkard and Barton (1993) and Monk and Folkard (1976) examined forward rotating shift schedules, and several researchers examined phase shifts due to time zone crossing (Aschoff, Hoffmann, Pohl, & Wever, 1975; Flower, Irvine, & Folkard, 2003; Klein, Wegmann, & Hunt, 1972; Monk et al., 2000). Both bodies of research found that people are more effective at adjusting their sleep period to compensate for phase delays than for phase advances. Although this research did not examine the influence of time changes associated with Daylight Saving Time on sleep, the phase changes associated with rotating shifts and time zone crossings are conceptually similar to phase changes associated with switching to and from Daylight Saving Time.

Hypothesis 1: In comparison with non phase change days, people will sleep less on phase advance days (losing 1 hr).

Hypothesis 2: In comparison with non phase change days, people will sleep more on phase delay days (gaining 1 hr).

Hypothesis 3: The relationship between phase advances (losing 1 hr) and less sleep will be stronger than the relationship between phase delays (gaining 1 hr) and more sleep.

Phase Shifts, Sleep Quantity, and Workplace Injuries

Researchers in the fields of physiology, ergonomics, and experimental psychology have spent decades investigating the effects of sleep quantity on human behavior and performance (for recent reviews, see Dang-Vu et al., 2007; Harrison & Horne, 2000a; Pilcher & Huffcutt, 1996; Siegel, 2005). Although the exact func-

tions of sleep are still under investigation, this body of research indicates that sleep has restorative effects on the brain (Maquet et al., 1997; Saper et al., 2005). The loss of sleep induces a homeostatic process that increases the propensity to sleep (Borbely & Achermann, 1999), generally resulting in extra recovery sleep that is proportional to sleep loss (Saper et al., 2005). Only recently have researchers in the fields of management and applied psychology begun to consider the importance of sleep to organizationally relevant variables (cf. Barnes & Hollenbeck, 2009; Barnes & Van Dyne, 2009; Harrison & Horne, 1999; Scott & Judge, 2006; Sonnentag, Binnewies, & Mojza, 2008).

Of particular importance in the context of workplace injuries is the influence of sleep quantity on cognitive functioning. Electroencephalograph data show decrements in central nervous system arousal as a function of increased sleepiness (Caldwell, Caldwell, Brown, & Smith, 2004). Brain imaging studies of sleep-deprived participants have found that the greatest decrease in cerebral metabolic rate is in the prefrontal cortex (Petiau et al., 1998; Wimmer, Hoffmann, Bonato, & Moffitt, 1992). The prefrontal cortex is an especially important part of the brain for such functions as temporal memory and divergent thinking tasks (Harrison & Horne, 2000b), as well as control of emotional responses and attention (Johnson & Proctor, 2004). Consistent with this contention, empirical research indicates that sleep is an important determinant of alertness and attention deployment and control (Dijk. Duffy, & Czeisler, 1992; Flower et al., 2003; Jewett & Kronauer, 1999; Smith, McEvoy, & Gevins, 2002).

We contend that decrements in alertness and attention are problematic in work contexts, because of the importance of detecting and monitoring cues in the work environment for avoiding workplace injuries (Barkan, 2002; Barkan, Zohar, & Erev, 1998). This is especially problematic as it relates to severe injuries that are often accompanied by complex combinations of cues. An example is the 1994 incident in which American fighter pilots shot down two U.S. Army Blackhawk helicopters in northern Iraq, resulting in the deaths of 26 peacekeepers. As Snook (2002) has indicated, had a number of cues been assembled, this major disaster could have been averted. Sleep quantity is an important determinant of whether employees notice and utilize such important cues that could be utilized to prevent workplace injuries. Consistent with this contention is a Texas train wreck report filed by the National Transportation and Safety Board (2008), which noted that train crew fatigue resulted in the failure of the engineer and conductor to appropriately respond to wayside signals governing the movement of their train, resulting in three deaths and \$5.85 million in damages. Moving beyond case studies, Legree et al. (2003) examined vehicle accidents across 400 U.S. Army soldiers and found a correlation of .20 between insufficient sleep and driver-at-fault accidents. Therefore, we expect that in comparison with non phase change days, phase advances that result in lower sleep quantities will lead to more workplace injuries. Similarly, we expect that in comparison with non phase change days, phase delays that result in higher sleep quantities will lead to fewer workplace injuries.

Beyond the effects of phase changes on the frequency of workplace injuries, we also contend that phase changes will have important effects on the severity of workplace injuries. Injuries can vary in their severity from minor injuries requiring mild first aid treatment all the way up to fatal injuries. Workplace hazards that are highly dangerous are more likely to be protected by multiple safeguards (e.g., multiple keys and switches that must be initiated to start a large and potentially dangerous piece of machinery), whereas smaller hazards might be protected by fewer safeguards (e.g., yellow paint on a doorway with low clearance). Therefore, employees must miss multiple cues to be harmed by highly dangerous workplace hazards, whereas less dangerous hazards, related to less severe injuries, might be encountered by missing only one or a few cues. For example, it might be more likely for an employee to bump his head, resulting in little or no injury, than to inadvertently start a piece of dangerous machinery by pressing the wrong keys, which could subsequently result in severe injury. However, fatigued workers will have less available attention and are more likely to miss cues that might prevent more serious injuries from occurring. On the basis of the logic that phase changes influence sleep and the deployment and control of attention, we expect the same relationships between phase changes and injury severity as we do between phase changes and workplace injuries. That is, we expect that in comparison with non phase change days, phase advances that result in lower sleep quantities will lead to a higher level of workplace injury severity. Similarly, we expect that in comparison with non phase change days, phase delays that result in higher sleep quantities will be negatively related to the severity of workplace injuries.

To date, management and applied psychology researchers have not examined the influence of phase delays and phase advances on injury frequency or severity. Researchers outside of the fields of management and applied psychology have investigated the effects of phase delays and phase advances on accident frequency, which one would expect to be related to injury frequency. This research has generally found a greater risk of traffic accidents following phase advance days but has found conflicting results with respect to accidents following phase delay days (Coren, 1996; Hicks et al., 1983; Monk, 1980; Stevens & Lord, 2006).

A major limitation of the applicability of these traffic accident studies to the workplace is that the phase changes on clock time are confounded with changes in light distribution throughout the day, which is an important determinant of traffic accidents (Coate & Markowitz, 2004; Monk, 1980). Indeed, perhaps the different patterns of light distribution inherent in the different latitudes examined across these studies account for differences among these findings. However, in most organizational contexts, employers and employees have better control over lighting conditions than is seen in traffic settings. A second consideration that might limit the applicability of these studies to organizational settings is that perhaps organizations have better procedures or equipment in place that would minimize the effects of phase changes on accidents than do people driving vehicles. Indeed, one would expect that a majority of the vehicle operators included in these studies were not acting as employees or in a workplace setting while they were driving. Finally, each of these studies only investigated 4 years or fewer, meaning they only included up to four phase advances and/or up to four phase delays. This would not be problematic if there was variance in each event that could allow for the level of analysis to be the event. However, in all of these studies each event had no variance in the accident variable (records were entered only for accidents, not for nonaccidents). Therefore, to obtain variance in accidents, the researchers of those studies had to aggregate to the day level of analysis. Aggregating to the day level of analysis and studying the sum of accidents allows comparisons between the number of accidents on phase change days in comparison with non phase change days. This would be acceptable if there were enough days included in the analysis to ensure adequate statistical power. However, each of these studies made a comparison between four or fewer phase advances with pre- and post controls, and each of these studies made a comparison between four or fewer phase delays with pre- and postcontrols. Such small sample sizes limit the inferences that can be drawn from these studies and raises the question of whether these studies had sufficient statistical power to detect their hypothesized effects.

In contrast to the research on traffic accidents and time changes, a study performed by Holland and Hinze (2000) examined the effect of Daylight Saving Time on construction workplace accidents, finding no significant effects between the constructs. Given the organizational setting of this study, concerns about lighting patterns or nonwork behaviors are mitigated, leading to the assumption that time changes have no bearing on workplace accidents. However, the directions of the effects in the study were consistent with those that we propose, such that there were more accidents following phase advances and fewer accidents following phase delays. Furthermore, Holland and Hinze used only 21 data points (the three Mondays closest to the phase change over a 7-year period) in their analyses, yielding insufficient power to detect even modest relationships. Thus, we argue that the failure to find significant results was due to a lack of statistical power and not to a lack of substantive relationship between phase changes and workplace accidents.

In summary, on the basis of Hypotheses 1 and 2 and in conjunction with research examining the effects of sleep quantity on alertness and attention deployment and control, we hypothesize that in comparison with non phase change days, there will be more workplace injuries and more severe workplace injuries following phase advances, and the opposite to be the case for phase delays. Hypotheses 4 and 5 note these expectations. Moreover, as we note in Hypothesis 3, we expect the phase advance effect on sleep to be stronger than the phase delay effect on workplace injuries to be stronger than the phase delay effect on workplace injuries.

Hypothesis 4: In comparison with non phase change days, there will be (a) more workplace injuries and (b) injuries of greater severity following phase advance days (losing 1 hr).

Hypothesis 5: In comparison with non phase change days, there will be (a) fewer workplace injuries and (b) injuries of lesser severity following phase delay days (gaining 1 hr).

Hypothesis 6: The relationship between phase advances (losing 1 hr) and increases in (a) workplace injuries and (b) workplace injury severity will be stronger than the relationship between phase delays (gaining 1 hr) and decreases in (a) workplace injuries and (b) workplace injury severity.

## **Exploratory Hypotheses**

As noted above, sleep restriction has a disproportionately negative effect on the prefrontal cortex (Petiau et al., 1998; Wimmer et al., 1992), which is especially important for divergent thinking tasks (Harrison & Horne, 2000b). Harrison and Horne (2000b) theorized that this heavier impact of fatigue on the prefrontal cortex is why

complex, divergent tasks are more heavily impacted by fatigue than simpler tasks. Research is consistent with this position (Caldwell et al., 2004; Haslam, 1984). For example, Harrison and Horne (1999) found that a single night of sleep deprivation had a stronger influence on a task requiring high levels of innovative thinking than on a task requiring lower levels of innovative thinking.

This body of research suggests that tasks that are novel will be more heavily influenced by sleep restriction than tasks that are well learned (Barnes & Hollenbeck, 2009). In many workplace settings, an important determinant of the novelty of a set of tasks is job experience. Employees who have low levels of experience with a given job should experience more novelty in their tasks than those who have high levels of experience with a given job. Thus, variance in sleep should be more influential to the injury rates of employees with low levels of job experience than to the injury rates of employees with high levels of job experience. Therefore, on the basis of Hypotheses 1-6, it is reasonable to expect that (a) phase advances, which lead to lost sleep, will lead to high levels of injuries involving employees with low levels of experience, and (b) phase delays, which lead to gained sleep, will lead to low levels of injuries involving employees with low levels of experience. This, therefore, suggests that employees who are involved in injuries following phase advance days (losing 1 hr) will have a lower average level of job experience than employees involved in injuries on non phase change days. Similarly, employees who are involved in injuries on phase delay days (gaining 1 hr) will have a higher average level of job experience than employees involved in injuries on non phase change days.

Exploratory Hypothesis 1: The level of job experience of employees involved in injuries following phase advance days (losing 1 hr) will be lower than the average level of job experience of employees involved in injuries on non phase change days.

Exploratory Hypothesis 2: The level of job experience of employees involved in injuries following phase advance days (gaining 1 hr) will be higher than the average level of job experience of employees involved in injuries on non phase change days.

## Overview

To test our hypotheses, we conducted two studies. In Study 1, we examined the influence of time changes on workplace injuries, and we utilize national mining injury data from the National Institute for Occupational Safety and Health to test Hypotheses 4-6 and Exploratory Hypotheses I and 2. To support sleep as the likely mediator of the effects of time changes on workplace injuries, in Study 2 we utilized data from the American Time Use Survey of the Bureau of Labor Statistics (2008) to establish the link between phase changes and sleep quantity (Hypotheses 1-3).

## Study 1

## Method

Mine Safety and Health Administration Injury Data

According to Title 30 of the U.S. Department of Labor, all operators of mines located in the United States are legally required to immediately investigate and report to the Mine Safety and Health Administration all injuries stemming from mining injuries (U.S. Department of Labor, 2008). This regulation stipulates that each report contain data including the time and date of each injury and the specific details of each injurious mining accident. As of the writing of this article, the Mine Safety and Health Administration had available data for these mining injuries for the years 1983–2006.

#### **Participants**

Participants included in this study were miners working in the United States from 1983-2006 who were injured while mining. Across these 24 years, there were 576,292 such mining injuries reported to the Mine Safety and Health Administration. Among all these injured workers, 98% were male workers. The mean age of these injured workers was 39.01 years. The mean level of experience of these injured workers in the job that they held when injured was 6.49 years.

## Measures

Phase changes. Date of the workplace injury was recorded by mine operators, including year, month, and day. We created two dummy codes for phase changes. The phase advance variable was coded 1 on phase advance days and 0 on all other days. The phase delay variable was coded 1 on phase delay days on 0 on all other days. From 1983 to 1986, phase advances took place on the last Sunday of April, and phase delays took place on the last Sunday of October. From 1987 to 2006 phase advances took place on the first Sunday of April, and phase delays took place on the last Sunday of October.

Workplace injuries. We counted the number of mining injuries for each of the 8,766 days included in the Mine Safety and Health Administration data set, consistent with past research (cf. Hofmann & Morgeson, 1999; Hofmann & Stetzer, 1996; Humphrey et al., 2004; Neal & Griffin, 2006).

Workplace injury severity. Workplace injury severity was operationalized as the total number of days work missed because of mining injuries (U.S. Department of Labor, 2008).

Job experience. U.S. Department of Labor regulations also stipulate that mine operators report the work experience of each injured worker (U.S. Department of Labor, 2008). This included the number of years worked in the job title that the injured worker held at the time of the injury, which serves as our measure of job experience.

Control variable. Because people may work less and therefore have fewer workplace injuries on federal holidays than on other days, holidays were dummy coded as 1, and all other days were dummy coded as 0.

## Analysis

We expect that employees will work less during certain times of the week (e.g., weekends) or year (e.g., the days surrounding holidays). To control for these patterns of work activity, we created a hierarchical linear model (HLM), with a grouping code specifying the week of the year and the day of the week. For example, March 22, 2003, fell on a Saturday. Therefore, all observations for this date were given the code number 1207, with

"12" representing the 12th week of the year and "07" representing the day of the week (Saturday). In similar fashion, March 22, 2004, was coded 1302, with "13" representing the 13th week of the year and "02" representing the day of the week (Monday). Weeks ran from Sunday to Saturday and Week 1 began with the first Sunday to Saturday period to include January 1. By using these codes as our Level-2 grouping variable, we separate variance in sleep that is due to day-of-the-week effects or to seasonal effects (week of the year) from variance attributable to our Level-1 predictors (e.g., phase advance days, phase delay days).

We used this identification variable as a Level-2 grouping variable in HLM, thereby controlling for effects of day of the week and week of the year on injury frequency and severity. Analyses to test Hypotheses 4 and 5 were performed at Level 1 of various models, with no Level-2 predictors, and the Level-2 grouping variable capturing the variance attributable to seasonal influences. Hypothesis 6 was evaluated by comparing the magnitudes of the regression coefficients, as suggested by Schwab (2005).

Our exploratory hypotheses were also tested in HLMs to control for seasonal effects. In these tests, we regressed job experience on phase change, phase delay, and holiday variables to assess the extent to which the occurrence of injuries at the time of phase changes is contingent upon worker experience in the job. By regressing experience on the phase change variables, we are able to assess the average level of experience of workers injured on particular days (e.g., phase change days), thus providing us with a fitting approach for testing our hypotheses.

## Results

Correlations for the variables in Study 1 are given in Table 1. Hypothesis 4 predicted that following phase advance days, a higher number of injuries will occur, and injuries of greater severity will occur, than following non phase change days. Results indicate that, on average, 3.6 more injuries occurred ( $p \le .01$ ) and 2.649 more days of work were lost because of injuries (p < 05) on days following phase advances than on non phase change days (see Table 2). Not only does this represent a 5.7% increase in the number of injuries on these days but a 67.6% increase in days work lost because of these injuries, representing a considerable increase in injury severity on days following phase advances. These data strongly support Hypothesis 4. Hypothesis 5 predicted that there would be a smaller number of injuries and that injuries would be less severe on days following phase delays. However, the results indicate that phase delays are related to neither the number of injuries nor the severity of these injuries, failing to support Hypothesis 5. Finally, Hypothesis 6 predicted that the relationship between phase advances and injury outcomes is stronger than the relationship between phase delays and injury outcomes. Comparison of the regression coefficients indicates that the coefficients for the phase advance relationships are statistically significant and larger than the coefficients for the phase delay relationships. Further analyses indicate that the coefficient for phase advances predicting injury severity is significantly larger than the coefficient for phase delays predicting injury severity (z' = 2.25, p < .05), whereas the difference in the magnitude of the coefficients when predicting the number of injuries suffered is not significant (z' = 0.37, p = .36). Taken together, these findings offer general support for Hypothesis 6 (see Table 3).

Table 1 Correlations Among Phase Change and Accident Data for Mining Sample

Variable	М	SD	1 ***	2	3	4	5	6
1. Work accidents	63,147	53,644	_					
2. Days lost to injury	3,872,562	4,963.896	.309**	_				
3. Job experience	6.562	1.545	045**	028**	-			
4. Phase delay	0.003	0.052	.021	.000	.016	_		
5. Phase advance	0.003	0.052	.026	.000	.017	003	-	
6. Holidays	0.027	0.163	118**	074	.002	008	007	_

Note. Level-1 N = 8,766 observations; Level-2 N = 372 days. Correlations were computed in a hierarchical linear model, with Level-2 grouping variables accounting for the nonindependence of data collected during the same week or day across various years.

 $n \le .01$  (two-tailed).

Finally, our exploratory hypotheses examined the levels of experience on the job that were related to mining injuries following phase change days. Findings indicate that phase advances (the loss of 1 hr) were not related to employee experience on the job, whereas phase delays (gaining 1 hr) were positively related to employee job experience (p < .01). This suggests that injuries following a phase delay are likely to include more experienced employees than injuries at other times of the year. By inference, this suggests that newer employees, for whom the task is arguably more novel, are less likely to be injured following phase delay days when they might enjoy extra sleep and thereby increased levels of attention and cue recognition, as compared with days when they do not enjoy greater amounts of sleep.

These findings highlight the relationships between clock changes associated with Daylight Saving Time and workplace injury. As indicated in the introduction, we contend that sleep is the mechanism by which this relationship occurs. However, the National Institute for Occupational Safety and Health's data set included in Study 1 did not include sleep. To examine the relationship between clock changes associated with Daylight Saving Time and sleep, we conducted Study 2. Establishing the link between these clock changes and sleep will help uncover the likely causal mechanism between these clock changes and workplace injuries.

Table 2 Influence of Phase Delays and Phase Advances on Total Injuries and Injury Severity

Predictor	No. of injuries	T value	Days lost to injury	T value
Intercept (Ba)	63.89	42.62**	3,916.74	39.99**
Holiday (B <sub>2</sub> )	-35.47	-7.34**	-2,255,70	-6.69**
Phase delay (hour				
gain) (B <sub>3</sub> )	2.18	0.61	200.47	1.02
Phase advance (hour loss) (β <sub>4</sub> )	3.61	2.52**	2,649.21	2.48*

Note. Level-1 N = 8,766 observations, Level-2 N = 372 days. These values were estimated in hierarchical linear models that regressed job experience on a control variable and substantive predictors (phase advance and phase delay) at Level 1. \*p < .05. \*\*p < .01 (two-tailed).

## Study 2

#### Method

#### American Time Use Survey

The American Time Use Survey is a survey conducted by the Bureau of Labor Statistics that measures the amount of time Americans spend doing various activities, such as paid work, child care, volunteering, socializing, and sleeping (Bureau of Labor Statistics, 2008). Employees of the Bureau of Labor Statistics conduct phone interviews with participants and ask participants to describe minute by minute their activity from 4:00 a.m. the day before the interview to 4:00 a.m. the day of the interview. Interviewers code these minute-by-minute activities into specified categories as outlined by the Bureau of Labor Statistics (2008), including the categories utilized by this study. Interviews are conducted nearly every day of the year. As of the time we conducted this study, American Time Use Survey data were posted online and available for years 2003-2006. However, category coding changes between 2003 and 2004 led us to include only years 2004-2006.

## **Participants**

These data were collected from a nationally representative sample of American civilian, noninstitutionalized persons ages 15 years and older. This representative sample was obtained via a

Table 3 Relationship Between Experience and Injuries During Phase Delays and Phase Advances

Predictor	Job experience	T value	
Intercept (B <sub>0</sub> )	6.56	367.92**	
Holiday (B <sub>2</sub> )	-0.01	-0.04	
Phase delay (hour gain) (β <sub>3</sub> )	0.33	16.17**	
Phase advance (hour loss) (β <sub>4</sub> )	0.31	1.28	

Note. Level-1 N = 8.766 observations; Level-2 N = 372 days. These values were estimated in hierarchical linear models that regressed job experience on a control variable and substantive predictors (phase advance and phase delay) at Level 1.

p < .01 (two-tailed).

stratified random sampling approach. To focus on members of organizations, we include data only from individuals who worked greater than 0 min during the period surveyed. The years 2004–2006 included 820,737 call attempts; of these attempts, 41,204 resulted in interviews in which data were collected, whereas 103,148 of these attempts were met with refusals to participate, resulting in a 28.5% participation rate by those who were successfully contacted. The remaining attempts did not result in contact with potential participants. As noted above, to ensure that we were examining employees, we only included participants who worked greater than 0 min during the period noted in the interview, Data were available for 14,310 such interviews. The mean age of respondents was 42,3 years, and 50.8% of the participants were female.

## Measures

Phase changes. Date of the interview was recorded by interviewers, including year, month, and day. We created two dummy codes for these interviews. The phase advance variable was coded I on phase advance days and 0 on all other days. The phase delay variable was coded I on phase delay days and 0 on all other days. In the United States during the years included in this study, phase advances took place on the first Sunday of April, and phase delays took place on the last Sunday of October.

Sleep quantity. A category of activity in the American Time Use Survey was the number of minutes spent sleeping. This category was separate from the number of minutes spent lying in bed awake or tossing and turning. Our measure of sleep quantity was the self-reported number of minutes spent sleeping.

Control variables. Because people may sleep more on federal holidays than on other days, interviews were dummy coded 1 for holidays and 0 for all other days. Previous research indicates a negative correlation between time spent sleeping and time spent working (Basner et al., 2007). Accordingly, we entered number of minutes spent working as a control variable.

## Analysis

As discussed above, data from this sample were collected over several years from a large stratified random sample of Americans, and because we are interested in the impact of phase changes on sleep and work, our analyses include those who worked during the time period surveyed. In addition to holidays having an impact on the amount of sleep people might get on any particular day, we expect there to be daily patterns in sleep quantity. In other words,

social events might dictate that people tend to get differing amounts of sleep on weekends than they do on weekdays. Likewise, we expect to observe seasonal patterns in sleep quantity, as people may be more inclined to participate in social events during summer months or during months that tend to have a high number of social events (e.g., December). To account for this seasonality, we created an identification variable similar to that used in Study 1; this identification variable captured the week and day of the week for each of the dates included in the data set, We used this identification variable as a Level-2 grouping variable in HLM, thereby controlling for effects of day of the week and week of the year on sleep.

To test Hypotheses 1 and 2, that people would sleep less following phase advances and more following phase delays, we regressed minutes of sleep on variables indicating whether the day was a phase advance day, phase delay day, a holiday, and the amount of time the individual worked that day. Again, the Level-2 structure of the model allows us to account for differences due to the seasonal and daily influences. To test Hypothesis 3, that the negative effect of phase advances on sleep quantity is stronger than the positive effect of phase delays on sleep quantity, we compared the magnitudes of the beta coefficients from the tests described to test the first two hypotheses.

#### Results

Correlations among the variables in Study 2 are given in Table 4. Results from our regression analyses indicate that, on average, people tend to sleep 40 min less following phase advances as compared with all other non phase change days ( $p \le .05$ ; see Table 5). These results support Hypothesis 1. Results from our HLM analyses also indicate that there is no statistically significant difference in the amount of time that people tend to sleep following phase delays, failing to support Hypothesis 2. Although the relationship between phase advances and sleep was not significant, it is worth noting that the sign of the relationship is in the direction predicted. Finally, in Hypothesis 3 we suggested that the loss of sleep following phase advances would be larger than the gain in sleep following phase delays. Comparison of the coefficients, as suggested by Schwab (2005), suggests that this is indeed the case, with this difference being statistically significant (z' = 2.01, p <.05), offering support for Hypothesis 3.

## General Discussion

We hypothesized that the phase advance and phase delay time changes associated with Daylight Saving Time would influence

Table 4
Correlations Among Phase Change and Sleep for U.S. National Sample

			2.00		_		
Variable	М	SD	1	2	3	4	5
1. Sleep quantity	465,653	110.626	(4				
2. Phase delay	0.003	0.058	.014	_			
3. Phase advance	0.004	0.064	011	004	Committee of the Commit		
4. Time working	430.334	197.521	340**	021°	036**	_	
5. Holidays	0.010	0.097	.041**	006	006	077**	-

*Note.* N = 14,310 cases.

p < .05. p < .01 (two-tailed).

Table 5
Influence of Phase Delays and Phase Advances on
Sleep Quantity

Predictor	Sleep quantity	T value	
Intercept (B <sub>0</sub> )	546.22	245.64**	
Time working (β <sub>1</sub> )	-0.19	-41.53**	
Holiday (B <sub>2</sub> )	13.48	1.41	
Phase delay (hour gain) (B <sub>1</sub> )	12.39	0.65	
Phase advance (hour loss) (β <sub>4</sub> )	-40.41	-2,24°	

Note. Level-1 N=14.310 observations; Level-2 N=363 days. These values were estimated in hierarchical linear models that regressed sleep quantity on control variables and substantive predictors (phase advance and phase delay) at Level 1.

\*p < .05. \*\*p < .01 (two-tailed).

sleep quantity, frequency of workplace injuries, and severity of workplace injuries to a differential degree. Study 1 indicated that in comparison with non phase change days, there are 3.6 more American mining injuries each year on Mondays following phase advances, and that there are over 2,600 more days lost because of work injuries each year, suggesting higher levels of injury severity. Study 2 indicated that in comparison with non phase change days, phase advances (i.e., losing 1 hr in the spring) led a stratified random sample of Americans to sleep on average about 40 min less. This provides preliminary support for sleep as the likely mediator of the influence of time changes on workplace injuries.

In contrast, the effects of phase delays were not as powerful. In Study 2, we found that in comparison with non phase change days, phase delays ted a random sample of Americans to sleep on average 12.4 more minutes. However, this effect was not significant. Perhaps because there was no significant effect of phase delays on sleep, there were also no significant phase delay effects on injury frequency or injury severity. This is consistent with previous research that indicates that although people have difficulties adjusting their sleep schedules to phase advances, they are better able to adjust their sleep schedules to phase delays (Folkard & Barton, 1993; Monk & Folkard, 1976). Our data indicate that people tend to utilize the extra hour in phase delays for waking activity rather than for sleep.

Our exploratory hypotheses examined experience in the context of time phase changes. We hypothesized that employees with low levels of experience would be more susceptible to the effects of phase changes and, therefore, that the mean levels of experience of workers injured following phase changes would be lower following phase advances and higher following phase delays. Contrary to our expectations, in comparison with non phase change days, there was no significant difference in experience levels following phase advances. However, on phase delays, the mean level of experience was higher, indicating that fewer employees with low levels of experience were injured following phase delays. Given that our expectation that people would get more sleep following phase delays was not supported, it is unclear to us why phase delays would lead to this effect. This finding is a bit surprising and warrants further conceptual and empirical examination in future research. We speculate that there may be heterogeneity in which types of employees alter their sleep schedule to match phase delays. Although there is no overall effect of the phase delay on

sleep quantity, perhaps future research may find that employees with low levels of experience do get more sleep following phase delays.

There are several strengths in the design of this study. First, by conducting Study I in a mining setting in which workers tend to be in environments that are often isolated from daylight pattern changes, this study avoids the daylight confound that has been present in previous studies investigating Daylight Saving Time phase changes on injuries. Second, the external validity of our study is high because in Study 2 we examined a large nationwide random sample, and in Study 1 we examined actual workplace injuries. Third, the statistical power of our studies is considerably higher than previous studies examining Daylight Saving Time phase shifts. In Study 1, we examined 576,292 mining injuries across 8,766 days. In Study 2, we examined 14,310 sleep periods across 1,067 days.

There are three main limitations in the design of our study. First, we did not explicitly analyze the link between sleep and workplace injuries. The archival data sets that we examined did not allow for such tests, and the low base rate of workplace injuries makes it difficult to measure the relationship between sleep and workplace injuries. However, previous research examining sleep restriction and deprivation has clearly established the link between sleep restriction and difficulties with alertness and attention (Beaumont et al., 2001; Caldwell et al., 2004; Dijk et al., 1992; Falleti, Maruff, Collie, Darby, & McStephen, 2003; Flower et al., 2003; Jewett & Kronauer, 1999; Smith et al., 2002). Researchers have gone as far as to delineate the role of the prefrontal cortex in this process, and they measured the disproportionately negative effects of sleep deprivation on the prefrontal cortex in tightly controlled laboratory settings (Harrison & Horne, 2000b; Petiau et al., 1998; Wimmer et al., 1992). Moreover, previous research has already established the link between sleep quantity and workplace accidents (Legree et al., 2003). Finally, the patterns between phase changes and sleep match the patterns between phase changes and workplace injuries, with sleep effects preceding those accidents. Therefore, it seems reasonable that sleep restriction plays an important role in the influence of phase changes on workplace injuries.

A second limitation is that in Study 1 we relied on archival data reported to the National Institute for Occupational Safety and Health. Reporting of such workplace injuries is a legal requirement. However, it is possible that some injuries were not reported. Nevertheless, we have no reason to believe that the tendency to report or not to report injuries was different on phase change days than on other days. A third limitation is that the measure of work experience in Study I was the number of years that each worker has held the current job title. This does not take into account the fact that some employees may have gained similar experience in other job titles. We partly addressed this by controlling for age, which should be, on average, higher for individuals who have gained similar work experience under different job titles. However, unmeasured work experience may have weakened our ability to find effects in our exploratory analyses.

## Theoretical Implications

From the standpoint of entrainment theory, our research indicates the importance of considering multiple iterations of interaction between entrained systems. Previous research examining entrainment has suggested that when two or more cycles are entrained, influencing one cycle can influence the other (Ancona & Chong, 1996). Our study suggests that there may be more iterations of reciprocal influence than previously suggested. We found that changes to the scheduled waking activity cycles and work activity can influence sleep cycles, which can in turn influence waking activity cycles. Researchers applying entrainment theory to other contexts may similarly find that cyclically entrained systems that are disturbed may take several cycles of mutual influence to return to a state of equilibrium.

A second theoretical contribution is to further theory examining workplace injuries by noting the importance of work scheduling. We find that simply shifting a work schedule by 1 hr can increase the risk to employees. Whereas previous theory and research examining work scheduling has often focused on the pace of work, we find that changes to work schedules can also be important.

A third theoretical contribution of this article is to further extend theory examining sleep deprivation into the management and applied psychology literatures. Despite being a heavily researched topic in the fields of medicine and physiology, sleep deprivation has been a topic largely ignored by management and applied psychology. Perhaps this is due to the extreme nature of many studies examining sleep deprivation in the physiology literature, such as 37, 43, or 64 continuous hours of continuous sleep deprivation (Baranski, Cian, Esquivie, Pigeau, & Raphel, 1998; Beaumont et al., 2001; Blagrove, 1996; Caldwell et al., 2004). Such extreme contexts are rare in most organizations. However, the extremity of these studies belies the power that even small restrictions of sleep can have on employees. Researchers have found that periods of sleep deprivation and sleep restriction that are more common in organizations have important effects, such as losing I night of sleep (Harrison & Horne, 1999), losing as little as 5 hr of nocturnal sleep (Friedman, 1971), or restricting sleep to 4-5 hr per night for a week (Dinges et al., 1997). Even as little as a 6-min nap has been associated with improved memory (Lahl, Wispel, Willigens, & Pietrowsky, 2008). Our study indicates that phase advances associated with a 40-min decrement in sleep led to increased injury frequency and increased injury severity. This body of research suggests that sleep, a construct typically ignored by management and applied psychology researchers, has meaningful implications for organizations and employees.

## **Practical Implications**

Our findings also have important practical implications for managers and organizations. The ability to predict workplace injuries helps to enable managers and members of organizations to take preventative measures that can mitigate these effects. One manner in which organizations can attempt to avoid the increase in workplace injuries associated with the Daylight Saving Time phase advance is to schedule particularly dangerous work on other days, perhaps later in the week after employees have had more time to adjust their sleep schedules to the phase change. By moving dangerous activities to safer days, organizations can attempt to avoid the dangers of phase advances.

A second manner in which organizations could attempt to mitigate these effects would be to schedule extra safety monitors on days following phase advances. Such employees could be helpful

in anticipating potential workplace injuries before they occur. Multiple observers may partly offset the fact that on average employees will tend to be less observant of cues indicating impending injuries. Extra safety monitors may also be vulnerable to restricted sleep following phase advances, but they may contribute to workplace safety nonetheless,

A third strategy for mitigating these effects is suggested by Monk, Buysee, and Billy (2006). They found that the negative effects of a 6-hr phase advance were largely avoided by trickling in the phase change with daily 30-min phase advances. This suggests that breaking up a phase advance into smaller phase advances can aid phase adjustment. Perhaps managers could trickle phase advances into organizations in a similar manner, stretching out phase changes over smaller chunks by adjusting the starting times of employee work shifts.

#### Future Research

Because sleep is a topic largely ignored by the management and applied psychology literatures, there are many avenues for future research that remain unexplored at this time. One of the most promising such avenues is examining sleep restriction and deprivation in group and team contexts (cf. Barnes & Hollenbeck, 2009). To date, even in other research fields that have focused heavily on sleep restriction and deprivation, group and team contexts have largely gone unexplored. This is an important oversight given the importance of teams to contemporary organizations. Team behaviors, such as backing up behavior (Barnes et al., 2008; Porter et al., 2003) and team monitoring (Marks, Mathieu, & Zaccaro, 2001), could aid groups and teams in mitigating the effects of sleep in organizations.

Future research should consider other organizationally relevant variables that are influenced by phase changes and variance in sleep. To date, researchers have examined innovative decision making (Harrison & Horne, 1999), job satisfaction (Scott & Judge, 2006), and team performance (Barnes & Hollenbeck, 2009) in these contexts. However, there are potentially many other organizationally relevant variables that are influenced by phase changes and variance in sleep. Previous research indicates powerful effects of sleep on mood (Pilcher & Huffcutt, 1996). This suggests that mood may mediate the effects of sleep and phase changes on variables such as organizational citizenship behavior or goal setting.

Finally, future research should investigate moderators of the effects of phase changes on workplace injuries. Such research may find that phase changes are more likely to result in injuries for some types of tasks than others. For example, tasks that are stable over time and do not require novel thinking may be less vulnerable to the effects found in our article than are tasks that are dynamic and require higher levels of novel thinking.

## Conclusion

In summary, we found that time phase changes that are intended to better align waking activity with daylight periods have negative side effects on organizations. Following phase advances, employees slept 40 min less, had 5.7% more workplace injuries, and lost 67.6% more work days because of injuries than on non phase change days. Phase delays did not have any significant effects on

sleep, injury frequency, or injury severity. Thus, on balance, implementing Daylight Saving Time phase changes costs employees sleep and injuries. We therefore conclude that schedule changes, such as those involved in switches to and from Daylight Saving Time, place employees in clear and present danger. Such changes put employees in a position in which they are more likely to be injured—these injuries being especially severe, and perhaps resulting in death. It is not often that management and applied psychology researchers can highlight effects that can lead to death, but our research points in that direction. These findings beg for immediate attention given to employee schedules, sleep, and safety, because, as this study reveals, Daylight Saving Time may save daylight, but not without painful costs.

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Received September 8, 2008
Revision received January 19, 2009
Accepted January 22, 2009

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# Impact of Extended Daylight Saving Time on National Energy Consumption



# **Report to Congress**

**Energy Policy Act of 2005, Section 110** 

October 2008

U.S. Department of Energy Energy Efficiency and Renewable Energy

## Acknowledgements

The Department of Energy (DOE) acknowledges the important contributions made to this study by the principal investigators and primary authors—David B. Belzer, Ph.D (Pacific Northwest National Laboratory), Stanton W. Hadley (Oak Ridge National Laboratory), and Shih-Miao Chin, Ph.D (Oak Ridge National Laboratory). Jeff Dowd (DOE Office of Energy Efficiency and Renewable Energy) was the DOE project manager, and Margaret Mann (National Renewable Energy Laboratory) provided technical and project management assistance.

Two expert panels provided review comments on the study methodologies and made important and generous contributions.

- 1. Electricity and Daylight Saving Time Panel technical review of electricity econometric modeling:
  - Randy Barcus (Avista Corp)
  - Adrienne Kandel, Ph.D (California Energy Commission)
  - Hendrik Wolff, Ph.D (University of Washington)
- 2. Transportation Sector Panel technical review of analytical methods:
  - Harshad Desai (Federal Highway Administration)
  - Paul Leiby, Ph.D (Oak Ridge National Laboratory)
  - John Maples (DOE Energy Information Administration)
  - Art Rypinski (Department of Transportation)
  - Tom White (DOE Office of Policy and International Affairs)

The project team also thanks Darrell Beschen (DOE Office of Energy Efficiency and Renewable Energy), Doug Arent, Ph.D (National Renewable Energy Laboratory), and Bill Babiuch, Ph.D (National Renewable Energy Laboratory) for their helpful management review.

## **Executive Summary**

The Energy Policy Act of 2005 (Pub. L. No. 109-58; EPAct 2005) amended the Uniform Time Act of 1966 (Pub. L. No. 89-387) to increase the portion of the year that is subject to Daylight Saving Time. (15 U.S.C. 260a note) EPAct 2005 extended the duration of Daylight Saving Time in the spring by changing its start date from the first Sunday in April to the second Sunday in March, and in the fall by changing its end date from the last Sunday in October to the first Sunday in November. (15 U.S.C. 260a note) EPAct 2005 also called for the Department of Energy to evaluate the impact of Extended Daylight Saving Time on energy consumption in the United States and to submit a report to Congress. (15 U.S.C. 260a note)

This report presents the results of impacts of Extended Daylight Saving Time on the national energy consumption in the United States. The key findings are:

- The total *electricity* savings of Extended Daylight Saving Time were about 1.3 Tera Watt-hour (TWh). This corresponds to 0.5 percent per each day of Extended Daylight Saving Time, or 0.03 percent of electricity consumption over the year. In reference, the total 2007 electricity consumption in the United States was 3,900 TWh.
- In terms of national *primary energy* consumption, the electricity savings translate to a reduction of 17 Trillion Btu (TBtu) over the spring and fall Extended Daylight Saving Time periods, or roughly 0.02 percent of total U.S. energy consumption during 2007 of 101,000 TBtu.
- During Extended Daylight Saving Time, electricity savings generally occurred over a
  three- to five-hour period in the evening with small increases in usage during the earlymorning hours. On a daily percentage basis, electricity savings were slightly greater
  during the March (spring) extension of Extended Daylight Saving Time than the
  November (fall) extension. On a regional basis, some southern portions of the United
  States exhibited slightly smaller impacts of Extended Daylight Saving Time on energy
  savings compared to the northern regions, a result possibly due to a small, offsetting
  increase in household air conditioning usage.
- Changes in national *traffic volume* and *motor gasoline consumption* for passenger vehicles in 2007 were determined to be statistically insignificant and therefore, could not be attributed to Extended Daylight Saving Time.

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## 1. Introduction

This report presents the results of impacts of Extended Daylight Saving Time on national energy consumption in the United States. It has been prepared by the Department of Energy (DOE) in response to the requirements set forth by section 110(c) of the Energy Policy Act of 2005 (Pub. L. No. 109-58; EPAct 2005).

Section 110 of EPAct 2005 amended the Uniform Time Act of 1966 (Pub. L. No. 89-387) to increase the portion of the year that is subject to Daylight Saving Time (DST). (15 U.S.C. 260a note) EPAct 2005 extended DST in the spring from the first Sunday in April to the second Sunday in March (three or four weeks earlier than the previous law), and in the fall from the last Sunday in October to the first Sunday in November (one week later than the previous law).

Previous analyses by the Federal Government of the impact of DST on energy consumption indicated that the largest effect was on lighting (Department of Transportation, 1975; DOE, 2006). Assuming that businesses and households maintain their daily schedules (with respect to clock time) after the transition to EDST, extra evening daylight hours may lower electricity consumption because of the delayed need for lighting. Morning electricity use could increase, as people awaken to darker homes and the need for electric lighting is greater. Some parts of the country enjoy cooler or warmer evening weather, and EDST could result in changes in the amount of electricity used for heating and air conditioning.

Daylight Saving Time also provides people with the opportunity to pursue more outdoor activities during the lighter (and warmer) late-afternoon/evening hours. Consequently, while reducing electricity consumption in homes, extra daylight might lead to more driving, which would likely translate into more miles of vehicular travel, thus resulting in higher motor gasoline consumption and higher energy use.

Section 2 of this report presents the key findings on changes in electricity use, motor gasoline use, and total energy. Section 3 summarizes the analytical approaches used in the study. The detail on the analysis methods is available in the separate Technical Documentation to this report (Belzer, et al., 2008).

The Technical Documentation can be found on the DOE Office of Energy Efficiency and Renewable Energy's website at <a href="http://www.eere.energy.gov/ba/pba/pdfs/epact-sec-110">http://www.eere.energy.gov/ba/pba/pdfs/epact-sec-110</a> edst technical documentation 2008.pdf

# 2. Key Findings: Changes in National Energy Consumption

# **Overall National Energy Consumption Findings**

Using both heuristic<sup>2</sup> and statistical analysis methods for measuring the national pattern of electricity changes, the study found:

- For the heuristic analysis, total savings of electricity during the four weeks of EDST time in 2007 was 1.3 TWh and the total primary energy saved associated with the changes in electricity consumption was 17 TBtu.
- For the statistical analysis, total savings of electricity during the four weeks of EDST in 2007 was 1.2 TWh. This also corresponds to a total primary energy savings of 17 TBtu. The statistical variation on this result is ±40 percent (at a 95 percent level of confidence).

The electricity savings are small compared to the national total for the year, representing about 0.03 percent of the total national electricity consumption of 3,900 TWh in 2007.<sup>3</sup> On a daily basis, the total electricity savings due to EDST was 0.46 to 0.48 percent per each day of EDST.

Electricity savings generally occurred over a period of three to five hours in the evening, offset slightly by small increases in energy consumption in several morning hours—typically the hours ending at 7:00 a.m. and 8:00 a.m. in the morning, and ending 5:00 p.m. through 9:00 p.m. in the evening. On a daily percentage basis, electricity savings were slightly greater during the March (spring) extension of DST (0.50 percent) than the November (fall) extension (0.38 percent).

Regionally, areas of the southern United States exhibited smaller impacts of EDST compared to areas of the North. The study found:

- Based on the heuristic analysis, electricity savings in the South as a percent per day were the same as in the North regions, 0.48 percent.
- Based on the statistical analysis, the average daily percent savings in electricity consumption for the North were 0.51 percent, while in the South the savings were 0.42 percent.

There is insufficient statistical evidence that the EDST period has had any measurable impact on motor gasoline consumption for passenger vehicles or traffic volume in 2007.

<sup>&</sup>lt;sup>2</sup> A pragmatic approach that compares the average changes in the pattern of electricity consumption between 2006 and 2007 during the periods of EDST in March and November without use of formal modeling.

<sup>&</sup>lt;sup>3</sup> Total net electric load for 2006 was 3,900 TWh as reported by the North American Electric Reliability Corporation (NERC). The DOE Energy Information Administration (EIA) has projected the national total net generation for 2007 at 3,990 TWh, while consumer demand was 3,900 TWh. The differences are due to electrical losses, generation for self-use, and imports.

# **Electricity Findings**

Summary of results using the heuristic method

Available hourly electricity consumption data for periods before and after EDST in 2007 and for comparable periods in 2006 made it possible to examine visually the effect of extended daylight saving time in 2007. The study compared hourly electricity consumption for comparable periods in 2006 and 2007 for 67 regionally-representative electric utilities across the country. As an illustration of this comparison, Figure 2-1 shows the hourly electricity consumption—over the 21 days of the spring EDST period in 2007 (March 11 through March 31)—for the area around Boston. Also shown is the electricity

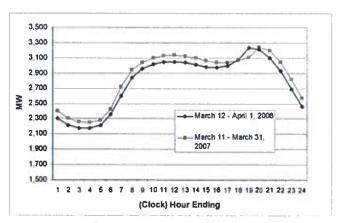


Figure 2-1. Average hourly electricity consumption, 2006 and 2007 spring EDST periods, Boston

consumption for the same period in March of 2006. Figure 2-1 shows the average hourly consumption levels for both years. Clearly, the evening consumption in hour 19 (hour ending at 7:00 p.m.) during 2007 is relatively lower than during 2006, and the peak evening consumption in 2007 is shifted during EDST from the hour ending at 7:00 p.m. to the following hour.

Even more revealing is the *ratio* of the 2007 to 2006 average consumption during corresponding morning and evening EDST hours. Figure 2-2 illustrates a brief but sharp increase in the ratio of average consumption in the morning hour 7 (6:00 a.m. - 7:00 a.m.) and a prolonged reduction in electricity usage during the evening hours 17 - 21 (5:00 p.m. - 9:00 p.m.). Viewed in this manner, the reduction in electricity consumption during the evening hours appears to more than offset the increase in use during the morning hours.

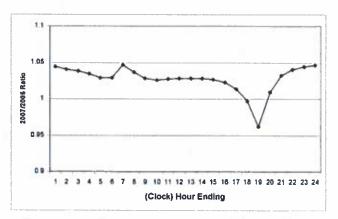


Figure 2-2. Ratio of 2007 average hourly electricity consumption to 2006 average hourly consumption, Boston

Although the ratios of electricity consumption for some utilities in this study were not as stable during the middle portion of the day as those in the Boston illustration, all of the electricity consumption curves demonstrated similar patterns.<sup>4</sup> Variations from the clear pattern illustrated in Figure 2-1 either showed increases in morning consumption that were not as distinct or in

<sup>&</sup>lt;sup>4</sup> Appendix D in the supporting Technical Documentation (Belzer, et al., 2008) provides additional examples of spring and fall hourly electricity consumption curves for 19 utilities across all regions of the country.

some southern regions, increased usage of air conditioning appeared to make the energy reductions during the evening occur later and with less intensity.

During the 2007 Extended Daylight Saving Time, the national average daily electricity savings, based on 16 representative regions of the North American Electric Reliability Corporation (NERC), was 0.48 percent per each day of EDST. This was the same average for the broadly aggregated Northern and Southern macro-regions. See Table 2-1. The lowest energy savings per day were in the Mid-South regions (0.27 percent, on average), while the greatest was in California (0.93 percent). The national daily average electricity savings were 0.48 percent per each day of EDST.

Table 2-1. Energy Savings by Region from Electricity Reductions Using the Heuristic Method<sup>5</sup>

NERC Region*	Location	Savings (GWH)	Avg. Savings per Day (%)	Primary Energy Savings (TBtu)
RFC	North	336	0.46%	5.3
NPCC-NY	North	49	0.41%	0.7
NPCC-NE	North	68	0.68%	0.7
MRO	North	58	0.37%	0.9
SERC-GAT	North	20	0.36%	0.3
WECC-NWP	North	111	0.64%	1.6
WECC-RMP	North	19	0.43%	0.3
North Subtotal		660	0.48%	9.9
FRCC	South	60	0.40%	0.7
SERC-DEL	South	25	0.26%	0.2
SERC-SE	South	111	0.67%	1.4
SERC-CEN	South	40	0.29%	0.5
SERC-VAC	South	114	0.52%	1.4
SPP	South	33	0.24%	0,5
TRE	South	54	0.29%	0.6
WECC-AZN	South	20	0.61%	0.2
WECC-CNV	South	172	0.93%	2.1
South Subtotal		629	0.48%	7.4
Total		1,290	0.48%	17.3

<sup>\*</sup>Note: Details on the NERC Regions listed are found in Appendix B-1 of the supporting Technical Documentation (Belzer, et al., 2008).

Summary of results using the statistical method

For the spring 2007 EDST, energy consumption data were collected and analyzed from a core 35 utilities. See Table 2-2. The resulting data were interpolated to calculate the average percentage change in energy consumption during a daily period of two hours in the morning and five hours in the evening—typically the hours ending at 7:00 a.m. and 8:00 a.m. in the morning, and ending 5:00 p.m. through 9:00 p.m. in the evening.

<sup>&</sup>lt;sup>5</sup> The national energy savings from electricity reduction are determined by the regional results, which are determined by scaling the individual utilities' results within each region. Appendix B of the supporting Technical Documentation describes the construction of the weighting factors and calculation of national energy savings.

Table 2-2. Morning and Evening Impacts by Utility, Spring EDST

	Morning		Evening	Evening	
	Average	Std.	Average	Std.	
Utility*	Hourly % Chg.	Error <sup>6</sup>	Hourly % Chg.	Error	
Indianapolis Power & Light	2.4%	0.9%	-3.8%	1.3%	
Louisville Gas & Elec	1.7%	1.0%	-2.6%	1.3%	
Dayton Hub - PJM	1.6%	0.7%	-3.4%	1.1%	
Duquesne Hub – PJM	0.6%	0.6%	-2.6%	0.9%	
No. Illinois Hub – PJM	1.9%	0.7%	-3.6%	0.8%	
ERCOT - Coast	0.4%	0.9%	-0.8%	1.0%	
ERCOT - S. Central	0.5%	1.3%	-1.7%	1.5%	
Con Ed - New York	0.9%	0.3%	-1.9%	0.5%	
ISO-NE - Connecticut	1.1%	0.6%	-3.3%	0.8%	
ISO-NE - NE Mass (Boston)	1.2%	0.5%	-2.9%	0.7%	
Lincoln Electric System	1.2%	0.8%	-3.2%	1.4%	
Madison Gas & Elec	1.8%	0.5%	-2.8%	0.7%	
Otter Tail Power Co.	4.0%	1.6%	-2.5%	1.6%	
City of Tallahassee	1.6%	1.4%	-2.1%	1.3%	
Gainesville Regional Utility	2.0%	1.3%	-1.8%	1.3%	
Jacksonville Energy Authority	1.4%	1.2%	-2.2%	1.5%	
Entergy Corp.	1.1%	0.8%	-1.9%	1.4%	
Alabama Electric Coop	-0.1%	1.9%	-1.2%	2.3%	
Oglethorpe Power Co.	0.7%	1.7%	-1.7%	1.8%	
Electric Power - Chattanooga	0.3%	1.2%	-2.8%	1.3%	
Memphis Light, Gas & Water	1.9%	0.9%	-2.2%	1.4%	
Dominion Hub - PJM	0.6%	1.3%	-3.1%	1.3%	
Ameren Control Area	1.7%	0.8%	-3.1%	1.1%	
Kansas City Public Utilities	1.2%	1.0%	-1.2%	1.3%	
Southwestern Public Service	0.6%	0.7%	-1.0%	1.1%	
Western Farmers Elec Coop	-0.2%	1.4%	-2.5%	1.7%	
El Paso Electric	2.6%	0.9%	-2.2%	1.0%	
Public Service of N. Mexico	2.2%	0.6%	-4.1%	0.6%	
California ISO	1.7%	0.5%	-4.0%	0.6%	
Los Angeles DWP	2.4%	0.6%	-3.7%	0.9%	
Avista Corp	1.1%	0.7%	-2.8%	0.9%	
Portland General Electric	0.6%	0.8%	-1.9%	0.9%	
Chelan County PUD	2.1%	0.8%	-1.0%	0.8%	
Black Hills Corporation	1.0%	1.1%	-3.5%	1.5%	
WAPA - Rocky Mountain	1.9%	0.7%	-3.3%	0.8%	

<sup>\*</sup> Note: The utilities listed are a combination of individual utilities (investor-owned or consumer-owned) and regional entities -- Independent System Operators, or ISOs. Details are provided in Appendix B.1 of the supporting Technical Documentation (Belzer, et al., 2008).

The national average reduction in daily electricity consumption in the spring EDST period was 0.50 percent. There were substantial variations reported among utilities for both the morning and evening hours. Morning impacts ranged from a usage reduction of 0.2 percent to an increase of 4.0 percent, while reductions during the evening hours generally were within the range of 1.0 to

<sup>&</sup>lt;sup>6</sup> "Std Error" is the standard deviation associated with the estimated change in electricity use, based upon the results of the statistical model. It is a statistical measure that reflects the uncertainty of the estimated change with respect to its expected (or average) value (as shown in the highlighted columns of Tables 2-2 and 2-3).

<sup>&</sup>lt;sup>7</sup> The morning increases in usage reflect the compounding impact of factors other than lighting.

4.0 percent. Table 2-2 summarizes the spring results from the statistical model.

The study collected and analyzed energy consumption data from a core 29 utilities for EDST in the fall of 2007. The fall EDST national average reduction in daily electricity consumption was 0.38 percent. Table 2-3 summarizes the fall EDST results from the statistical model.

Table 2-3. Morning and Evening Impacts by Utility, Fall EDST

	Morni	ng	Evening		
	Average		Average	1	
Utility*	Hourly % Chg.	Std. Error	Hourly % Chg.	Std. Erro	
Indianapolis Power & Light	2.3%	1.1%	-3.4%	1.9%	
Louisville Gas & Elec	1.4%	1.6%	-3.9%	1.4%	
Dayton Hub – PJM	0.5%	1.1%	-3.6%	1.4%	
Duquesne Hub - PJM	0.5%	1.0%	-3.1%	1.3%	
No. Illinois Hub - PJM	2.0%	0.6%	-3.2%	1.0%	
ERCOT - Coast	2.9%	1.1%	-1.1%	1.3%	
ERCOT - S. Central	3.3%	2.4%	-1.7%	2.5%	
Con Ed - New York	1.3%	0.7%	-1.4%	0.7%	
ISO-NE - Connecticut	0.5%	1.0%	-3.5%	1.2%	
ISO-NE - NE Mass (Boston)	1.0%	0.8%	-2.8%	1.1%	
Lincoln Electric System	2.9%	0.8%	-2.5%	1.3%	
Madison Gas & Elec	1.0%	0.6%	-2.6%	1.2%	
Otter Tail Power Co.	0.9%	2.4%	-2.5%	2.5%	
City of Tallahassee	-0.2%	1.6%	-1.0%	1.4%	
Gainesville Regional Utility	1.1%	1.5%	-1.3%	1.9%	
Jacksonville Energy Authority	NA	NA	0.0%	0.0%	
Progress Energy (Florida)	0.6%	1.5%	-1.5%	1.8%	
Entergy Corp.	1.8%	1.0%	-1.7%	1.1%	
Alabama Electric Coop	NA	NA	0.0%	0.0%	
Oglethorpe Power Co.	NC	NC	-1.4%	2.0%	
Electric Power - Chattanooga	1.3%	1.4%	-3.1%	1.7%	
Memphis Light, Gas & Water	0.7%	1.1%	-3.5%	1.6%	
Dominion Hub - PJM	0.3%	1.8%	-3.7%	1.3%	
Ameren Control Area	NA	NA	0.0%	0.0%	
Kansas City Public Utilities	1.7%	1.3%	-1.3%	1.3%	
Southwestern Public Serv.	NA	NA	0.0%	0.0%	
Western Farmers Elec Coop	NA	NA	0.0%	0.0%	
El Paso Electric	1.8%	1.7%	-3.2%	1.2%	
Public Service of N. Mexico	1.8%	0.7%	-3.3%	0.9%	
California ISO	1.2%	0.8%	-3.8%	1.4%	
Los Angeles DWP	2.5%	0.5%	-3.6%	0.9%	
Avista Corp	1.0%	1.0%	-3.0%	1.2%	
Portland General Electric	NA	NA	0.0%	0.0%	
Chelan County PUD	1.4%	1.3%	-1.5%	1.2%	
Black Hills Corporation	NA	NA	0.0%	0.0%	
WAPA - Rocky Mountain	2.0%	1.0%	-3.7%	0.9%	
Note: NA = Fall data unavailable NC = Not calculated	9				

<sup>\*</sup> Note: The utilities listed are a combination of individual utilities (investor-owned or consumer-owned) and regional entities -- Independent System Operators, or ISOs. Details are provided in Appendix B.1 of the supporting Technical Documentation (Belzer, et al., 2008).

An examination of the impact in both the morning and evening indicates that the impacts (both positive and negative) were generally smaller in the fall than in the spring. The national average reduction in daily electricity consumption in the fall EDST period was 0.38 percent as compared to the 0.50 percent for the spring.

# **Transportation Energy Findings**

Changes in national traffic volume and motor gasoline consumption for passenger vehicles in 2007 could not be attributed to EDST. This finding was based on a comparison of the 2007 two-week average national motor gasoline consumption during the weeks before and after DST and EDST. It was also based on an analysis of daily traffic volume for the late-afternoon/evening hours, 3:00 p.m. to 9:00 p.m. — when EDST was expected to have the greatest influence on gasoline use.

Results from analysis of changes in motor gasoline consumption

The changes in motor gasoline consumption due to daylight hours were small. The differences in mean values (averages) of "motor gasoline supplied" information were determined to be statistically insignificant for both the spring and fall over a 10-year period ranging from 1998 to 2007. "Motor gasoline supplied" is used as a proxy for motor gasoline consumption. <sup>10</sup>

Tables 2-4, 2-5, and 2-6 show the motor gasoline consumption before and after periods of Daylight Saving Time. Changes in motor gasoline consumption ranged from -3.85 percent to 3.79 percent in the spring to -3.39 percent to 3.33 percent in the fall. The 10-year average was 0.83 percent for the spring and 0.25 percent for the fall. Table 2-6 reports the results from the statistical comparison of means for motor gasoline consumption, and it indicates the change in means is not statistically significant.

This finding may result from two factors. First, even under standard time, some portion of the morning hours during which many people prepare for work or school is already dark at the end of October. Thus, the extension of daylight time, which provides later sunrises in terms of clock time, is expected to have a smaller effect on lighting use than in March. Second, the cooler (colder) temperatures at the end of October are less conducive to outdoor activities (e.g., gardening, youth sports activities, etc.) regardless of daylight conditions. Thus, a smaller impact on energy use for lighting in the evening during the fall EDST period, as compared to the spring, is not unexpected.

<sup>9</sup> Small compared to the seasonal variations and long-term growth rate in "motor gasoline supplied."

<sup>&</sup>lt;sup>10</sup> In a longer timeframe, "gasoline supplied" equals gasoline consumption, provided that the motor gasoline rolling stock remains constant. DOE's EIA states: "Products supplied approximately represent consumption of petroleum products because it measures the disappearance of these products from primary sources, i.e., refineries, natural gas processing plants, blending plants, pipelines, and bulk terminals. In general, the product supplied value of each product in any given period is computed as follows: field production, plus refinery production, plus imports, plus unaccounted for crude oil, (plus net receipts when calculated on a Petroleum Administration for Defense (PAD) District basis), minus stock change, minus crude oil losses, minus refinery inputs, minus exports." [EIA Weekly Petroleum Status Report, 2008]

Table 2-4. Two-Week Average Motor Gasoline Consumption before and after DST and EDST for Spring, 1998 to 2007

Two-Week Ave	age Before	Two-Week Ave		
Two-Week Period	Thousand Barrels per Day	Two-Week Period	Thousand Barrels per Day	Percent Change
21-Mar-98 to 3-Apr-98	8,494	4-Apr-98 to 17-Apr-98	8,167	-3.85%
20-Mar-99 to 2-Apr-99	8,148	4-Apr-99 to 16-Apr-99	7,972	-2.16%
18-Mar-00 to 31-Mar-00	8,140	1-Apr-00 to 14-Apr-00	8,606	5.72%
17-Mar-01 to 30-Mar-01	8,491	31-Mar-01 to 13-Apr-01	8,372	-1.40%
23-Mar-02 to 5-Apr-02	8,626	6-Apr-02 to 19-Apr-02	8,762	1.58%
22-Mar-03 to 4-Apr-03	8,371	5-Apr-03 to 18-Apr-03	8,689	3.79%
20-Mar-04 to 2-Apr-04	8,990	3-Apr-04 to 16-Apr-04	9,156	1.84%
19-Mar-05 to 1-Apr-05	9,085	2-Apr-05 to 15-Apr-05	9,130	0.49%
18-Mar-06 to 31-Mar-06	9,059	1-Apr-06 to 14-Apr-06	9,199	1.55%
24-Feb-07 to 9-Mar-07	9,175	10-Mar-07 to 23-Mar-07	9,245	0.77%
Average	8,658	1 100 - 4010	8,730	0.83%

Table 2-5. Two-Week Average Motor Gasoline Consumption before and after DST and EDST for Fall, 1998 to 2007

Two-Week Aver	age Before	Two-Week Aver		
Two-Week Period	Thousand Barrels per Day	Two-Week Period	Thousand Barrels per Day	Percent Change
10-Oct-98 to 23-Oct-98	8,074	24-Oct-98 to 6-Nov-98	8,278	-3.85%
16-Oct-99 to 29-Oct-99	8,527	30-Oct-99 to 12-Nov-99	8,375	-2.16%
14-Oct-00 to 27-Oct-00	8,773	28-Oct-00 to 10-Nov-00	8,498	5.72%
13-Oct-01 to 26-Oct-01	8,661	27-Oct-01 to 9-Nov-01	8,784	-1.40%
12-Oct-02 to 25-Oct-02	8,838	26-Oct-02 to 8-Nov-02	9,042	1.58%
11-Oct-03 to 24-Oct-03	9,084	25-Oct-03 to 7-Nov-03	9,156	3.79%
16-Oct-04 to 29-Oct-04	8,930	30-Oct-04 to 12-Nov-04	9,227	1.84%
15-Oct-05 to 28-Oct-05	9,013	29-Oct-05 to 11-Nov-05	9,199	0.49%
14-Oct-06 to 27-Oct-06	9,505	28-Oct-06 to 10-Nov-06	9,183	1.55%
20-Oct-07 to 2-Nov-07	9,361	3-Nov-07 to 16-Nov-07	9,205	0.77%
Average	8,877		8,895	0.25%

Table 2-6. Results from Statistical Comparison of Means

	Mean of Changes in Two-Week Average Motor Gasoline Consumption*	Standard Error of the Mean Change	Change in Means: Statistically Significant (Yes/No)
Spring	72	74	No
Fall	18	71	No

<sup>\*</sup> Note: Unit of measurement is thousand barrels per day.

# Results for changes in late-afternoon/evening traffic volume

A statistical analysis of daily traffic volume for the late-afternoon/evening hours (3:00 p.m. to 9:00 p.m.) when EDST is expected to have the greatest influence on gasoline use shows a statistically significant, but small 0.17 percent increase in traffic volume during those hours for the week of "March 11 – March 17" (the first week of EDST) relative to "March 4 – March 10." This is shown in Table 2-7.

Table 2-7. Summary Results for Traffic from 3:00 p.m. to 9:00 p.m., Spring

Year	Region*	Week-to-Week Comparison for Two Weeks Before and Two Weeks After EDST	Mean Change in Traffic Volume	Standard Error of the Mean Change	Percent Change	Difference in Means, Statistically Significant (Yes/No)
	United	Week of "Feb 25 – Mar 3" compared to "Mar 4 – Mar 10"	157	6	1.68%	Yes
2007	States 2007 (exclude AZ, DC,	Week of "Mar 4 – Mar 10" compared to "Mar 11 – Mar 17"	16	7	0.17%	Yes
HI, WY)	Week of "Mar 11 - Mar 17" compared to "Mar 18-Mar 24"	-7	6	-0.08%	No	
	United	Week of "Feb 25 – Mar 3" compared to "Mar 4 – Mar 10"	32	5	0.34%	Yes
States 2006 (exclude AZ, DC, HI, WY)	Week of "Mar 4 – Mar 10" compared to "Mar 11 – Mar 17"	89	5	0.91%	Yes	
	Week of "Mar 11 – Mar 17" compared to "Mar 18-Mar 24"	-50	5	-0.51%	Yes	

<sup>\*</sup>Note: Arizona (AZ) and Hawaii (HI) are two states that do not observe Daylight Saving Time. Traffic volume data was not available for the District of Columbia (DC) and Wyoming (WY).

Because the late-afternoon/evening traffic accounts for about 37 percent of total traffic, the 0.17 percent increase in traffic is equivalent to a 0.06 percent increase of the daily total traffic. This 0.06 percent increase in daily traffic translates to a "maximum possible" motor gasoline consumption increase of about 5.5 thousand barrels per day for each day of EDST. The United States consumed an average of 8,800 thousand barrels of motor gasoline per day for passenger vehicles from 1998 to 2007.

However, the small increase (0.17 percent) in traffic, before and after the EDST in 2007, could not directly be attributed to EDST in 2007 for the following reasons:

<sup>&</sup>lt;sup>11</sup> Based on the traffic information by hours of the day for some 4000 traffic counters, the traffic from 3:00 p.m. to 9:00 p.m. was about 37 percent of the total daily traffic for 24 hours for all counters during the week of March 4 to March 10, 2007. Thirty-seven percent of 0.17 percent equals 0.06 percent.

More traffic volume will yield more motor gasoline consumption, provided the traffic volume increases are uniform among roadway segments, and the roadway segment lengths and average gasoline consumption rate are constant. The daily total traffic increase is assumed to be uniformly distributed. Weekly "motor gasoline supplied" was 9,158 thousand barrels per day for the week ending just before the start of EDST on March 11, 2007. Therefore, 0.06 percent of 9,158 thousand barrels is 5.5 thousand barrels per day.

- Other factors may have influenced the changes in daily traffic volume during those hours (e.g., weather conditions, roadway construction, traffic accidents/incidents, and special events/festivals).<sup>13</sup>
- As shown in Table 2-7, there is a statistically noticeable change in traffic the week prior to EDST, when traffic increased by 1.68 percent from the week of "February 25 March 3" compared to "March 4 March 10." In addition, there is no statistically significant difference from the week of "March 11 March 17" to "March 18 March 24" (the second week after EDST).
- Table 2-7 also shows that the week-to-week traffic differences are statistically noticeable for the same time frame in 2006—the February 25 to March 24 period. Although these four weeks of traffic in 2006 were not under the influence of EDST, the week to week traffic differences ranged from -0.51 percent to 0.91 percent. This further supports the evidence that observed traffic variations in 2007 were the result of an array of traffic influencing factors and cannot be attributed to EDST.

Changes in national traffic volume and motor gasoline for the fall EDST

This study did not examine national traffic data for the fall of 2007. However, the miles of vehicular travel information from *Traffic Volume Trends* by the Federal Highway Administration shows a steady pattern of annual miles of vehicular travel for 2005, 2006, and 2007. Based on this information and expert opinion, EDST-induced traffic and associated motor gasoline consumption for the fall, if any, would likely be similar to results found in the spring.

<sup>&</sup>lt;sup>13</sup> Gasoline prices did not appear to have been one of the factors. The average retail gasoline price was determined to not have had an influence on the week-to-week differences in traffic volume in the spring of 2007 (February 26 to March 19) and in the spring of 2006 (February 27 to March 20). During those 2007 and 2006 periods, the national weighted average retail price for all grades and all formulations of gasoline ranged from 2.43 to 2.62 dollars per gallon (February 26 to March 19, 2007) and from 2.30 to 2.55 dollars per gallon (February 27 to March 20, 2006). There was no statistical relationship between traffic volume and retail gasoline price, as measured by the correlation coefficient of 0.005. Therefore, gasoline price was not a factor in explaining the short-term changes in traffic from February 26 to March 19 of 2007.

# 3. Analysis Approach

Due to the complex interaction between additional DST hours, hourly temperature, weather, and other factors, there is no single best method for analyzing EDST impacts on electricity and motor gasoline consumption. Therefore, the study used multiple methods to evaluate the impact of EDST on changes in energy consumption, each with different strengths and limitations. Taken together, their findings provide greater insight into EDST energy impacts than would be possible by application of only a single method. The supporting Technical Documentation to this report provides details on the data and analysis methods used in the study.

# Analysis of Changes in Electricity Use across Extended Daylight Saving Time Transitions

The study used two methods to calculate changes in national energy consumption associated with electricity consumption.

- A "heuristic" method compared the average changes in the pattern of electricity consumption between 2006 and 2007 during the periods of EDST in March and November.
- A statistical method applied regression models to daily and hourly consumption for a sample of utilities.<sup>14</sup>

The electricity analysis portion of the study used 2006 and 2007 consumption data from as many as 67 electric utilities. <sup>15</sup> The utilities (and regional ISOs) included in this report represent 66 percent of U.S. electricity consumption in the heuristic analysis and 32 percent of consumption in the statistical analysis. Figure 3-1 shows the 67 utilities overlaid on a climate zone map. Utilities are located in all the climate zones except for Zone one, the southern tip of Florida.

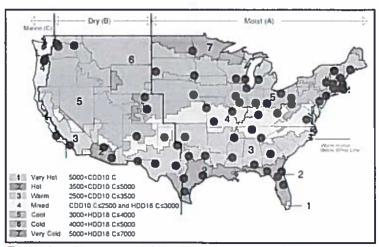


Figure 3-1. Sixty-seven utilities with 2007 data overlaid on Climate Zone map

Heuristic analysis of electricity consumption curves

The heuristic method examined the hourly electricity consumption patterns for 67 electric utilities in 2007 relative to 2006, and used 21-day averages for each hour of the day in the spring

<sup>&</sup>lt;sup>14</sup> The selection of electric utilities for this study aimed to result in a regionally representative collection of utilities, although they were not randomly selected.

<sup>&</sup>lt;sup>15</sup> Data was obtained from Federal Energy Regulatory Commission reports, independent system operator (ISO) web sites, and directly from utilities.

and seven-day averages for the fall. <sup>16</sup> This approach is heuristic in the sense that it seeks to predict the 2007 pattern of the average electricity consumption profile that would have occurred without EDST. The observed deviations from a smooth pattern of ratios (in defined ranges of morning and evening hours) are evidence of the impact of EDST. By interpolating between hours deemed to be unaffected by EDST, the average changes in consumption over the EDST periods for spring and fall were calculated.

Figure 3-2 provides an illustration of this approach for Boston's electricity consumption curve. 17 It shows the ratio, over 21 days, of average hourly electricity consumption in a 24-hour period during both the 2007 spring EDST period and the same period for 2006. Looking at the ratio of 2007/2006 consumption, it is possible to see that for Boston. EDST was likely responsible for the sharp morning increase at around 7:00 a.m. and a substantial reduction during several evening hours. The lines with squares are

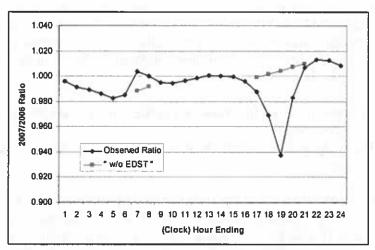


Figure 3-2. Illustration of heuristic approach to estimating impacts, Boston

the linearly inserted values of the ratios of consumption for the morning and evening periods. In the morning period, the ratios were interpolated between the hours ending at 6:00 a.m. and 9:00 a.m. In the evening, the interpolation was performed between the hours ending at 4:00 p.m. and 10:00 p.m.

Statistical models: focus on lighting and appliance use

A statistical approach was developed, using detailed regression models of daily and hourly electricity consumption for as many as 35 utilities located across the United States. <sup>18</sup> The statistical models account for:

- Electricity consumption growth between 2006 and 2007;
- Seasonal change;
- Day of week (Saturday, Sunday, weekday) and holidays;

<sup>&</sup>lt;sup>16</sup> The spring extension of DST moved the date from the first Sunday in April to the second Sunday in March. For 2007, that totaled 21 days. The fall extension was from the last Sunday in October to the first Sunday in November, seven days.

<sup>&</sup>lt;sup>17</sup> The data used in the Boston illustrative example comes from the Northeast Massachusetts-Boston sub-region of the New England ISO. As a shorthand descriptor, the study refers to this area as Boston.

<sup>&</sup>lt;sup>18</sup> Thirty-five utilities, for which data was available, for the spring analysis, and 29 for the fall analysis.

- Temperature (degree-days for both heating and cooling)<sup>19</sup>; and
- Indicator variables to distinguish between the (March and November) EDST and (April and October) DST time periods in 2007 and 2006.

A statistical measure of confidence was determined for the calculated impacts.

The analysis focused on the specific hours where electricity usage was expected to be most influenced by EDST. The morning hours were assumed to be the hours ending in the range between 7:00 a.m. and 8:00 a.m. inclusive. In the evening, the influenced hours were assumed to extend from 5:00 p.m. through 9:00 p.m. inclusive in the spring and from 5:00 p.m. through 8:00 p.m. inclusive in the fall.

# Approaches Used to Examine Traffic Volume and Motor Gasoline Consumption

The study used two methods of analysis to calculate the impact of EDST on motor gasoline consumption.

One method involved the examination of the two-week averages of motor gasoline consumption for periods before and after DST and EDST. Using weekly data for "motor gasoline supplied" over a 10-year period (1998 to 2007) for both the spring and fall seasons, an analysis was conducted on the impact of daylight time on motor gasoline consumption. A statistical comparison of the mean values of average gasoline consumption for two weeks before and two weeks after DST and EDST was conducted. The statistical testing evaluates the hypothesis that the mean values of weekly "motor gasoline supplied" are the same (at the 95 percent confidence level) across the transition to or from standard time to DST and EDST. Energy savings were determined by calculating the week-to-week percentage change between the two-week average of before and after weekly "motor gasoline supplied" information.

The second method was a comparison of differences in average week-to-week national traffic volume to determine if there are statistically significant differences in the averages. Daily traffic volume data for the spring was analyzed during the hours most likely to be influenced by EDST. Statistical tests were performed to determine if the mean values of the spring traffic volume changed (at the 95 percent level of confidence) in the weeks before, during, and after EDST. The traffic volume analysis relied upon traffic data that is collected at more than 4,000 continuous traffic-counting locations nationwide. The study used traffic information during the two weeks<sup>22</sup> before and after Daylight Saving Time in the spring of 2007 and for the same period in 2006.

<sup>&</sup>lt;sup>19</sup> A "degree-day" is a measure of heating or cooling. For example, if the actual temperature is above 65 degrees, the number of heating degrees for that day is zero.

<sup>&</sup>lt;sup>20</sup> In about one-third of the utilities analyzed, the morning hours displaying the most influence from EDST were those ending at 8:00 a.m. and 9:00 a.m.

<sup>&</sup>lt;sup>21</sup> "Motor gasoline supplied" information is used as a proxy for gasoline consumption. The Technical Documentation for this study provides details.

<sup>&</sup>lt;sup>22</sup> Using only two weeks of traffic data before and after the Daylight Saving Time minimizes potential influences from long-term trends and seasonal variations within the traffic data series.

# Other Considerations

In addition to the changes in electricity use, motor gasoline use, and primary energy presented in this report, there are other potential energy-related impacts from EDST such as changes in fuel oil and natural gas used for heating in buildings. The previous DST studies that examined fuel oil and natural gas, most notably the 1975 Department of Transportation study, found that DST had less impact on changes in fuel oil and natural gas use in buildings than the changes in electricity consumption. This study did not further examine the fuel oil and natural gas impacts on buildings due to the limited availability of supporting data for analysis of these factors.

In addition, this study did not include an economic analysis of EDST, which compares the relative costs and outcomes, such as cost-benefit or cost-effectiveness. Section 110 of EPAct 2005 directed the Department of Energy to focus only on the impact of EDST on "energy consumption in the United States." (42 U.S.C. 260a note)

Finally, this study did not analyze any non-energy impacts that might result from EDST, as the focus of Section 110 of the Energy Policy Act of 2005 is only on energy consumption. Potential non-energy impacts include children traveling to school during darkness, traffic accident rates, crime rates, electronics changeover to new EDST dates, airline schedule changes, and agricultural work scheduling.

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# Daylight saving time as a potential public health intervention: an observational study of evening daylight and objectively-measured physical activity among 23,000 children from 9 countries

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International Journal of Behavioral Nutrition and Physical Activity201411:84

DOI: 10.1186/1479-5868-11-84

Goodman et al.; licensee BioMed Central Ltd. 2014

Received: 6 January 2014

Published: 23 October 2014

# **Abstract**

### Background

It has been proposed that introducing daylight saving measures could increase children's physical activity, but there exists little research on this issue. This study therefore examined associations between time of sunset and activity levels, including using the bi-annual 'changing of the clocks' as a natural experiment.

### Methods

23,188 children aged 5-16 years from 15 studies in nine countries were brought together in the International Children's Accelerometry Database. 439 of these children were of particular interest for our analyses as they contributed data both immediately before and after the clocks changed. All children provided objectively-measured physical activity data from Actigraph accelerometers, and we used their average physical activity level (accelerometer counts per minute) as our primary outcome. Date of accelerometer data collection was matched to time of sunset, and to weather characteristics including daily precipitation, humidity, wind speed and temperature.

### Results

Adjusting for child and weather covariates, we found that longer evening daylight was independently associated with a small increase in daily physical activity. Consistent with a causal interpretation, the magnitude of these associations was largest in the late afternoon and early evening and these associations were also evident when comparing the same child just before and just after the clocks changed. These associations were, however, only consistently observed in the five mainland European, four English and two Australian samples (adjusted, pooled effect sizes 0.03-0.07 standard deviations per hour of additional evening daylight). In some settings there was some evidence of larger associations between daylength and physical activity in boys. There was no evidence of interactions with weight status or maternal education, and inconsistent findings for interactions with age.

### **Conclusions**

In Europe and Australia, evening daylight seems to play a causal role in increasing children's activity in a relatively equitable manner. Although the average increase in activity is small in absolute terms, these increases apply across all children in a population. Moreover, these small effect sizes actually compare relatively favourably with the typical effect of intensive, individual-level interventions. We therefore conclude that, by shifting the physical activity mean of the entire population, the introduction of additional daylight saving measures could yield worthwhile public health benefits.

# Keywords

Child Adolescent Physical activity Day length Seasons

# **Background**

Physical activity confers substantial physical and mental health benefits in children [1, 2, 3, 4, 5], but most children around the world do not meet current activity guidelines [6]. For children as for adults, successfully promoting physical activity is likely to require both individual-level and population-level interventions [7]. The latter are important because, following the insights of Geoffrey Rose [8], even a small shift in a population mean can yield important public health benefits.

One potential population-level measure which has received some policy attention in recent years concerns the introduction of additional daylight saving measures [9]. Although the total number of hours of daylight in the day is fixed, many countries modify when those hours fall by 'changing the clocks' – for example, putting the clocks forward in the summer to shift daylight hours from the very early morning to the evening. Recent decades have seen recurrent political debates surrounding daylight saving measures in several countries. For example, several Australian states have held repeated referenda on the topic, and the issue even spawned the creation in 2008 of the single-issue political party 'Daylight Saving for South East Queensland'. Similarly a Bill was debated in the British Parliament between 2010 and 2012 which proposed to shift the clocks forward by an additional hour year round. This change would have given British children an estimated average of 200 extra waking daylight hours per year [10], and the logo of the associated civil society campaign depicted children playing outdoors in the evening sunlight. The Bill's accompanying research paper listed "increased opportunities for outdoor activity" alongside other potential health and environmental benefits, such as reducing road traffic crashes and cutting domestic energy use [11]. A similar argument about leisure-time activity has featured in the Australian debate [12].

The British Bill's research paper did not, however, cite any evidence to support its claims about physical activity, and nor does much evidence exist regarding likely impacts on children. Many studies have certainly reported that children's physical activity is generally higher in the summer than in the winter, as reviewed in [13, 14, 15]. Very few studies, however, examine whether seasonal differences persist after adjustment for weather conditions, or whether the seasonal patterning of physical activity across the day is consistent with a causal effect of evening daylight. One study which did examine these issues in detail found that seasonal differences in physical activity were greatest in the late afternoon and early evening, which is what one would expect if time of sunset did play a causal role [16]. This study had some major limitations, however, including its small sample size (N = 325), its restriction to a single setting in south-east England, and its failure to adjust for temperature.

This paper therefore revisited this question in a much larger, international sample. Our first broad aim was to test the hypotheses that (i) longer evening daylight is associated with higher total physical activity, even after adjusting for weather conditions; and (ii) these overall differences in physical activity are greatest in the late afternoon and early evening. Given our uniquely large sample size, we were also able to use countries' bi-annual changing of the clocks as a natural experiment, i.e., as an event or intervention not designed for research purposes but which can nevertheless provide valuable research opportunities [17]. Specifically, we tested the hypothesis that the same child measured immediately before and immediately after the clocks changed would be more active on the days where sunset had been moved an hour later. Our second broad aim was to examine whether any associations between evening daylight and activity levels differed by study setting, sex, age, weight status or socio-economic position.

# **Methods**

# Study design

The International Children's Accelerometry Database (<a href="https://www.mrc.epid.cam.ac.uk/research/studies/icad/">https://www.mrc.epid.cam.ac.uk/research/studies/icad/</a>) was established to pool objectively-measured physical activity data from studies using the Actigraph accelerometer in children worldwide. The aims, design and methods of ICAD have been described in detail elsewhere [18]. Formal data sharing agreements were established and all partners consulted their individual research board to confirm that sufficient ethical approval had been attained for contributing data.

### **Participants**

The full ICAD database pools accelerometer data from 20 studies conducted in ten countries between 1997 and 2009 [18]. In this paper, we excluded four studies which focussed on pre-school children and one study for which date of measurement was not available. We used baseline data from all of the 15 remaining studies, plus follow-up measurements in the seven longitudinal studies and one natural experimental study (Additional file 1: Table A1). We also used follow-up measurements from the control group of one of the two randomised controlled trials, as for this study it was possible to distinguish intervention and control groups.

Among 23,354 individuals aged 5-16 years old in the 15 eligible studies, we excluded 1.7% of measurement days (0.7% of individuals) because of missing data on age, sex, weight status or weather conditions. Our resulting study population consisted of 23,188 participants who between them provided 158,784 days of valid data across 31,378 time points (Table 1). Although our full study population included children providing data from any part of the year, one of our analyses was limited to 439 children who were sampled during a week which spanned the clock change (51% female, age range 5-16, 1830 measurement days).

Table 1

Descriptive characteristics of study participants

į.	1 38 =	N (%) participants	N (%) valid days
Full sample		23,188 (100%)	158,784 (100%)
Sex	Male	8819 (38%)	62,745 (40%)

	Female	14,369 (62%)†	96,039 (60%)
Age	5-6 years	1800 (8%)	7855 (5%)
	7-8 years	711 (3%)	4963 (3%)
	9-10 years	5769 (25%)	30,702 (19%)
	11-12 years	9616 (41%)	61,352 (39%)
	13-14 years	4206 (18%)	46,530 (29%)
	15-16 years	1086 (5%)	7382 (5%)
	Australia  N = 2	2459 (11%)	18,679 (12%)
	Brazil  N = 1	453 (2%)	1577 (1%)
	Denmark [N = 2]	2031 (9%)	11,030 (7%)
	England [N = 4]	10,284 (44%)	83,420 (53%)
Country [No. studies	Estonia (N = 1)	656 (3%)	2537 (2%)
	Madeira [N = I]	1214 (5%)	4899 (3%)
	Norway [N = 1]	384 (2%)	1459 (1%)
	Switzerland [N = 1]	404 (2%)	2569 (2%)
	United States [N = 2]	5303 (23%)	32,614 (21%)
	Normal/underweight	17,573 (76%)	121,350 (76%)
Weight status	Overweight	4116 (18%)	27,967 (18%)
	Obese	1499 (6%)	9467 (6%)
	Up to high school	7422 (48%)	54,547 (48%)
Mother's education	College/vocational	2656 (17%)	19,352 (17%)
	University level	5251 (34%)	38,723 (34%)

For individuals measured more than once, the first column gives age and weight status at baseline while the second column gives age and weight status during the measurement period in question. Numbers add up to less than the total for mother's education because this variable was only collected in 11 of the 15 studies, and was also subject to some missing data within those 11 studies (see Additional file 1: Tables A1 and A2). Proportion of girls 52% after excluding one large American study that measured girls only.

# Measurement of physical activity

All physical activity measurements were made with uniaxial, waist-worn Actigraph accelerometers (models 7164, 71256 and GT1M); these are a family of accelerometers that have been shown to provide reliable and valid measurement of physical activity in children and adolescents [19, 20, 21]. All raw accelerometer data files were re-analysed to provide physical activity outcome variables that could be directly compared across studies (see [18] for details). Data files were reintegrated to a 60 second epoch where necessary and processed using commercially available software (KineSoft v3.3.20, Saskatchewan, Canada). Non-wear time was defined as 60 minutes of consecutive zeros allowing for 2 minutes of non-zero interruptions [22].

We restricted our analysis of activity data to the time period 07:00 and 22:59, and defined a valid measurement day as one recording at least 500 minutes of wear time during this time period (18% days excluded as invalid). When examining the pattern of physical activity across the day, we only included hours with at least 30 minutes of measured wear time. Each participating child provided an average of 5.1 days across the week in which they were measured (range 1–7); we did not require a minimum number of valid days of accelerometer data per child because days, not children, were our primary units of analysis.

Although we sought to limit our analyses to activity during waking hours, we unfortunately lacked reliable data on the time children went to sleep or woke up. While most children took their accelerometers off to sleep, on 6% of days there was evidence of overnight wear, defined as ≥5 minutes of weartime between 1:00 and 04:59. On these days, we assumed the child was in fact sleeping during any hour between 21:00 and 07:59 for which the mean accelerometer counts per minute (cpm) was below 50. Mean cpm values of under 50 were observed for 90% of hours recorded between 03:00 and 03:59 but only 3% of hours recorded between 19:00 and 19:59, suggesting this cut-point provided a reasonable proxy for sleeping time among children for whom we had reason to suspect overnight wear. Our findings were unchanged in sensitivity analyses which instead used thresholds of 30 cpm or 100 cpm to exclude suspected sleeping time, or which excluded altogether the 6% of days with suspected overnight wear.

Our pre-specified primary outcome measure was the child's average counts per minute. Substantive findings were similar in sensitivity analyses which instead used percent time spent in moderate-to-vigorous physical activity (MVPA), defined either as ≥3000 cpm [23] or ≥2296 cpm [24]. For our key findings, we present these MVPA results (using the ≥3000 cpm cut-off) alongside the results for mean cpm. In order to facilitate interpretation of these MVPA results, we additionally convert the observed percentage times into approximate absolute minutes on the assumption of a 14-hour average waking day [25].

### Time of sunset and covariates

For each day of accelerometer wear, we used <a href="http://www.timean.tkate.com">http://www.timean.tkate.com</a> to assign time of sunset on that specific date in the city in which, or nearest which, data collection took place. We also used the date and the city of data collection to assign six weather variables to each day; total precipitation across the day, mean humidity across the day, maximum daily wind speed, mean daily temperature, maximum departure of temperature above the daily mean, and maximum departure of temperature below the daily mean. We accessed these data using Mathematica 9 (Wolfram Research), which compiles daily information from a wide range of weather stations run by states, international bodies or public-private partnerships [26]. The correlation between hour of sunset and mean temperature was moderately but not prohibitively high (r = 0.59), while correlations with other weather covariates were modest (r < 0.30).

The child's height and weight were measured in the original studies using standardized clinical procedures, and we used these to calculate body mass index (kg/m²). Participants were categorized as underweight/normal weight, overweight or obese according to age and sex-specific cut points [27]. Maternal education was assessed in 11/15 studies, and was re-coded to distinguish between 'high school or lower' education versus 'college or university' education (Additional file 1: Table A2).

### Statistical analyses

Both time of sunset and weather vary between individual days, and we therefore used days not children as our units of analysis. We adjusted for the clustering of days within children using robust standard errors. All analyses used Stata [3,].

To address our first aim, we fit linear regression models with the outcome being daily or hourly activity epm. Time of sunset was the primary explanatory variable of interest, with adjustment for study population, age, sex, weight status, day of the week and the six weather covariates. When using the changing of the clocks as a natural experiment, we restricted our analyses to the 439 children with at least one valid school day measurement both in the week before and in the week after the clocks changed (e.g. Wednesday, Thursday and Friday before the clocks changed and Monday and Tuesday afterwards).

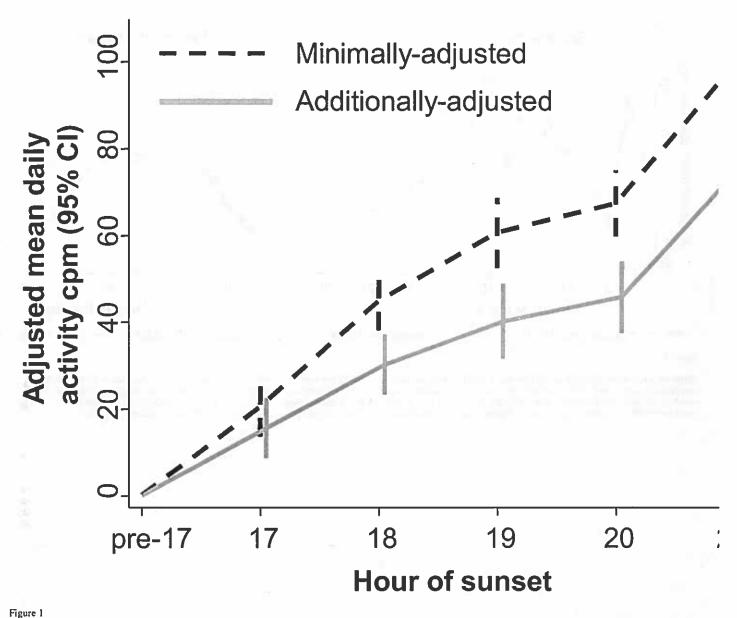
To address our second aim, we calculated the adjusted effect size of evening daylight separately for each study population. We used forest plots to present the fifteen resulting effect sizes, together with an 1<sup>2</sup> value representing between study heterogeneity and with an overall pooled effect size estimated using random effects meta-analysis |28|. We sometimes converted pooled estimates into standardised effect sizes by dividing by the standard deviation of activity cpm for the population in question. We then proceeded to fit interaction terms between evening daylight and the four pre-specified characteristics of sex, age, weight status and maternal education. These four characteristics were selected a priori as characteristics that we felt to be of interest and that were relatively consistently measured across the ICAD studies. We fit these interaction terms after stratifying by study population, and calculated 1<sup>2</sup> values and pooled effect sizes. When examining interactions with age, we restricted our analyses to children aged 9–15 as most measurement days (91%) were of children between these ages.

# Results

The characteristics of the participants are summarised in Table 1. Of the measurement days, 66% were schooldays and 38% of days had no precipitation. The average daily temperature was 12°C (range -21 to 33°C, inter-quartile range 7 to 16°C). Mean daily weartime was 773 minutes (12.9 hours), and this was similar regardless of time of sunset (e.g. regression coefficient +1.40 minutes for days with sunset 18:00–19:59 versus pre-18:00 after adjusting for study population, age and sex; and -2.5 minutes for days with sunset post-20:00 versus pre-18:00).

### Evening daylight and overall activity levels

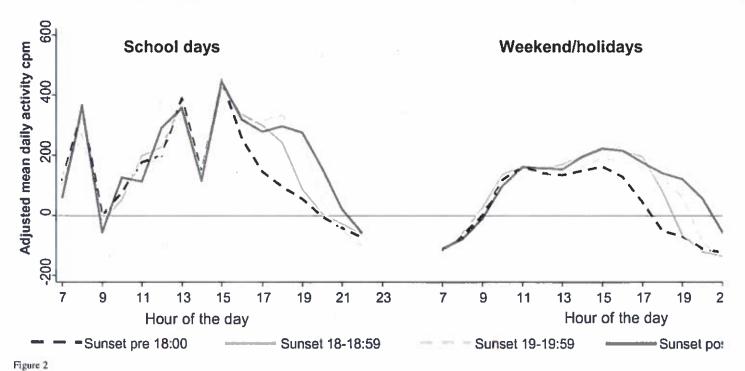
A later hour of sunset (i.e. extended evening daylight) was associated with increased daily activity across the full range of time of sunset, and this association was only partly attenuated after adjusting for the six weather covariates (Figure 1). Here and for all findings reported subsequently, substantive findings were similar in sensitivity analyses which instead used percent time spent in MVPA. The adjusted difference in overall daily activity between days with sunset after 21:00 vs. before 17:00 was 75 cpm (95% CI 67, 84). The equivalent difference for percent daily time in MVPA was 0.72% (95% CI 0.60, 0.84) using the ≥3000 cpm cut-point, which translates into around 6 minutes. To put the values on the y-axis in context, participants had a mean daily activity count of 560 cpm (649 in boys, 503 in girls), and spent an average of 4.0% of their day, or 33 minutes, in MVPA (5.2%/43 minutes in boys, 3.1%/26 minutes in girls). The adjusted differences between the days with more versus less evening daylight are therefore modest but not trivial in relation to children's overall activity levels.



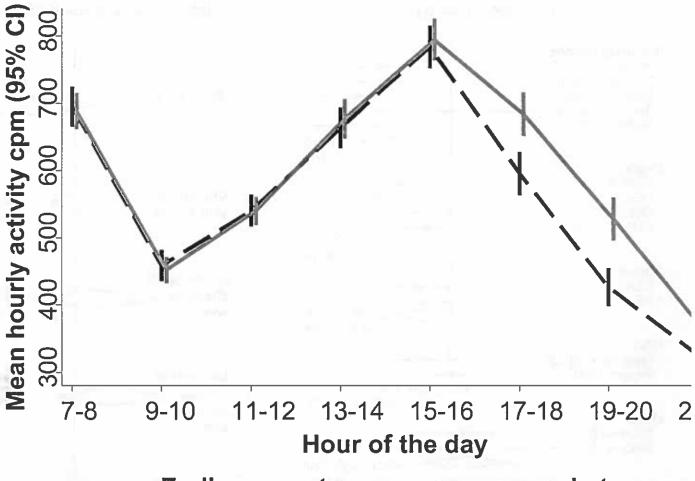
Association between time of sunset and total daily activity. CI = confidence interval, cpm = counts per minute. Analysis based on 158,784 measurement days from 23,188 children from 15 studies in 9 countries. Minimally-adjusted analyses adjust for age, sex and study population; additionally-adjusted analyses also include day of the week, weight status and (most importantly) the six weather covariates. Hour of sunset is rounded down, e.g. '18' covers '18:00–18:59', and the reference group is sunset before 17:00.

# Evening daylight and the patterning of activity across the day

Consistent with a causal interpretation, hour-by-hour analyses indicated that it was in the late afternoon and evening that the duration of evening daylight was most strongly associated with hourly physical activity levels (Figure 2). This was true on both schooldays and weekend/holiday days, with the period of the day when physical activity fell fastest corresponding to the timing of sunset (e.g. falling fastest between 18:00 and 19:00 on days when the sun also set between those hours). Similarly, when comparing the subsample of 439 children who were measured on schooldays immediately before and immediately after the changing of the clocks, there was strong evidence that children were more active during the evening of the days with later sunset (Figure 3). Between 17:00 and 20:59 the mean increase in physical activity on the days with later sunset was 94 cpm per hour (95% CI 62, 125); the equivalent increase in percent of time spent in MVPA was 0.84% (95% CI 0.40%, 1.28%) or 2.0 minutes.



Adjusted mean activity counts per minute across the hours of the day, according to the time of sunset. cpm = counts per minute. Analysis based on 158,784 measurement days from 23,188 children from 15 studies in 9 countries. Analyses adjust for study population, age, sex, day of the week, weight status and the six weather variables, with a reference group of 09:00 on days with sunset before 18:00. Hours are rounded down, e.g. '18' covers '18:00–18:59'. Confidence intervals not presented as they are generally too narrow to be clearly visible: Additional file 1: Figure A1 includes a version of this graph with confidence intervals.



(before clocks moved forward or after they moved back)

(after clocks moved forwa or before they moved back

Figure 3

Mean physical activity across the hours of the day, comparing children either side of the changing of the clocks. CI = confidence interval, cpm = counts per minute. Analysis based on 1830 schooldays from 439 children from 11 studies in 9 countries. Analyses restricted to children with at least one valid schoolday measurement day both before and after the clocks changed; to increase power, data from across the spring and autumn clock changes are pooled. Hours are grouped into two-hour time periods to increase power and are rounded down, e.g. '7-8' covers '07:00-08:59'. Adjustment was not essential as each child serves as his or her own control, but the results were similar in adjusted analyses.

Importantly, Figure 2 and Figure 3 show no association between hour of sunset and activity levels in the morning, and generally no association in the early afternoon (with the exception of a modest effect on weekend/holiday days as early as 14:00 in Figure 2). This suggests that the association between evening daylight and physical activity cannot readily be explained by residual confounding by weather conditions, since any effects of weather would generally be expected to operate more evenly across the day [16]. These findings also provide no suggestion that later sunrise is associated with reduced activity in the morning, including on days when the sun set before 18:00 and on which the average time of sunrise was not until 07:27 (inter-quartile range 07:05 to 07:54).

# Examining differences by place, sex, age, weight and maternal education

As shown in Figure 1, there was strong evidence that the association between evening daylight and physical activity varied systematically between settings (1² = 75%, p < 0.001, for overall heterogeneity between the 15 studies). Specifically there was relatively consistent evidence that evening daylight was associated with higher average physical activity in mainland Europe, England and (to a lesser extent) Australia. The pooled point estimates of the increase in daily mean activity in these three settings were 20.2 cpm, 15.7 cpm and 8.2 cpm per additional hour of evening daylight; these changes translate into standardised effect sizes of 0.07, 0.06 and 0.03, respectively. The equivalent effect sizes in terms of percent of daily time spent in MVPA were 0.19%, 0.20% and 0.05% per additional hour of evening daylight, corresponding to around 1.6 minutes, 1.7 minutes and 0.4 minutes respectively. By contrast, there was little or no consistent evidence of associations with evening daylight in the American samples or in the Madeiran and Brazilian samples, with standardised effect sizes ranging from -0.02 to +0.01 and in all cases non-significant. A post-hoc univariable meta-regression analysis provided some evidence that the smaller magnitude of the associations in these latter settings might reflect their higher maximum temperatures (adjusted R² = 51%, p = 0.01; see Additional file 1; Figure A2 and accompanying text).



# Interactions, pooled effect size

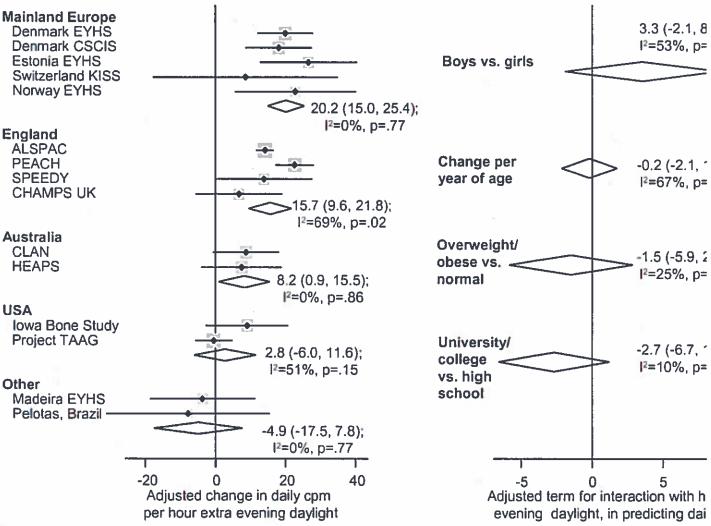


Figure 4

Association between evening daylight and physical activity across study populations, and pooled effect sizes for interactions by sex, age, weight status and maternal education. cpm = counts per minute. Analysis based on 23,188 children from 15 studies in 9 countries, except for the comparison of maternal education which is based on 15,563 children in 11 studies in 8 countries (see Additional file 1: Tables A1 and A2 for details of studies providing maternal education data). On the left, random-effects pooled estimates are presented by country/region, together with 95% confidence intervals. Points to the right of the line indicate that longer evening daylight is associated with increased mean daily cpm, points to the left indicate the reverse. On the right, pooled effect sizes and 95% confidence intervals are shown following tests for interaction, with the adjusted interaction term representing the difference that the interaction variable (e.g. sex) makes to the effect size for evening daylight upon total daily activity measured in cpm. For interaction terms stratified by study population see the Additional file 1: Figures A3 and A4.

Although associations with evening daylight varied markedly between settings, there was less convincing evidence for interactions with the child's characteristics (Figure 4, plus Additional file 1: Figures A3-A4). This lack of an interaction was clearest for weight status and maternal education, with neither variable showing any significant interaction in any of the five study settings, and with the overall pooled effect sizes also non-significant. By contrast, the non-significant pooled interaction terms for sex and age were harder to interpret as in both cases there was some evidence of between-study heterogeneity (0.01 stp store). With respect to sex, this heterogeneity reflected the fact that the association between evening daylight and physical activity tended to be stronger in boys than in girls in some European and English samples, but this was not the case in the other settings (Additional file 1: Figure A3). With respect to age, there was no very obvious pattern; the magnitude of the association with evening daylight was greater among younger children in Denmark, was greater among older children in Australia, and did not differ according to age in the remaining three settings for which sufficient data were available.

# **Discussion**

Among 23,000 school-age children from 9 countries, we found strong evidence that longer evening daylight was associated with a small increase in daily physical activity, even after adjusting for weather conditions. Consistent with a causal interpretation, the magnitude of this associations was largest in the late afternoon and early evening, including when the same child was measured immediately before and after the clocks went forward or back. These associations were, however, only consistently observed in the European and Australian samples. There was inconsistent evidence that the magnitude of the association with evening daylight was greater in boys; no evidence of any differences in the magnitude of the association according to weight status or maternal education; and inconsistent findings for interactions with age.

### Limitations and directions for future research

This study substantially extends previous analyses of some subsets of this data, which have at most only provided a relatively brief examination of physical activity differences by season [29, 30]. It also addresses several recognised limitations of the existing literature [14], including small sample sizes, inconsistent accelerometer protocols and little or no examination of interactions with factors such as age, sex or weight status. In addition, our large sample size allowed us to use the bi-annual changing of the clocks as a natural experiment, and to show significant differences in children's activity levels either side of the clock change. This observation considerably strengthens the case for a causal interpretation of the association between evening daylight and physical activity, as does the fact that the fastest decrease in children's evening physical activity coincided with sunset throughout the year.

This study does, however, also have several important limitations. First, our data were largely cross-sectional rather than longitudinal: although we could follow the same child across the week when the clocks changed, we could not follow children across a full year. We have, however, no reason to believe that children sampled at different times of the year differed systematically within or between studies.

A second set of limitations involves data not available to us. For one thing, although we adjusted for observed weather conditions on each day of measurement, the timing of some physically active events may instead reflect expected weather conditions (e.g. some schools may routinely schedule sports days on summer afternoons in the hope that it will be warm and dry). Failing to adjust for such social expectations may mean that our effect estimates are still subject to some residual confounding by weather, and this may partly account for why small differences in activity levels were seen as early as 14:00 on weekend/holidays. In addition, we lacked any data on the behavioural mediators of the observed activity differences. As such, we cannot examine how far one can generalise the findings of one previous, small English study which found that associations between day length and activity levels were largely mediated by outdoor play [16]. This is one useful direction for future research, perhaps particularly as it becomes increasingly possible to substitute or complement detailed activity diaries with data from global positioning systems (GPS) monitors [31]. We also lacked systematic information on area-level factors such as neighbourhood safety or the availability of green space which might plausibly moderate the effect of evening daylight upon physical activity; again, this would be one useful direction for future research. Also of interest would be an examination of how a wider range of behaviours vary with daylength; these were largely beyond the scope of what is possible in the ICAD database, although the lack of any association between time of sunset and accelerometer weartime provides some indirect evidence against an effect of evening daylight on children's duration of sleep.

Finally, most of our study populations came from Europe and almost all came from high-income settings, meaning that more research would be needed to establish how far the observed associations apply across other settings. Our data do, however, give some hints that daylight saving measures might not increase activity in hot settings, perhaps because high temperatures may inhibit summertime activity.

# Implications for policy and practice

The British parliament recently debated a Bill proposing new daylight saving measures which would shift the clocks forward by one additional hour year round [10]. If the adjusted, pooled effect size we observed in this study were fully causal, one would expect the proposed daylight savings measures to generate a 0.06 standard deviation increase in the total physical activity of English children, corresponding to an estimated 1.7 extra minutes of MVPA per day. The equivalent standardised effect sizes in mainland Europe and in Australia were 0.07 and 0.03, respectively. As such, introducing additional daylight saving measures in any of these settings would be likely only to have a small-to-very-small average effect upon each child. Such measures would, however, have far greater reach than most other potential policy initiatives, with these small average effects applying every day to each and every child in the country. This is important because even small changes to the population mean can have important public health consequences [8]. Moreover, although these population-level effect sizes are small in absolute terms, the English and mainland European effect estimates actually compare relatively favourably to individual-level approaches, despite the latter generally being much more intensive (and expensive). For example, one recent meta-analysis of 22 randomised controlled comparisons reported a standardised pooled effect size of 0.12 (95% Cl 0.04, 0.20) for interventions seeking to promote child or adolescent physical activity [32].

Notably, the association between longer evening daylight and higher physical activity was observed irrespective of weight status or maternal education. This contrasts with one previous Australian survey in which daylight savings measures seemed to have the largest effects among normal weight adults from socio-economically advantaged groups [33]. Further research in adults would be useful to confirm this finding, ideally using objectively-measured activity data. Speculatively, however, a relatively wide range of children may respond to longer evening daylight by playing more outdoors whereas among adults the effect may primarily be confined to the groups with the highest propensity to exercise.

# **Conclusions**

This study provides the strongest evidence to date that, in European and Australian settings, evening daylight plays a causal role in increasing physical activity in the late afternoon and early evening – a period which has been described as the 'critical hours' for children's physical activity [34]. In these settings, it seems possible that additional daylight saving measures could shift mean population child physical activity levels by an amount which, although small in absolute terms, would not be trivial relative to what can feasibly be achieved through other approaches. Moreover, our findings also suggest that this effect might operate in a relatively equitable way. As such, while daylight savings proposals such as those recently considered in Britain would not solve the problem of inadequate levels of child physical activity, this paper indicates that they could represent a small step in the right direction.

# **Abbreviations**

CI:

Confidence intervals

cpm:

Counts per minute

ICAD:

International Children's Accelerometry Database

MVPA:

Moderate-to-vigorous physical activity.

# **Declarations**

# **Funding**

Funding for the ICAD study was provided by the UK National Prevention Research Initiative (NPRI; http://www.npri.org.uk). Funding partners are: British Heart Foundation; Cancer Research UK; Department of Health; Diabetes UK; Economic and Social Research Council; Medical Research Council; Research and Development Office for the Northern Ireland Health and Social Services; Chief Scientist Office, Scottish Executive Health Department; The Stroke Association; Welsh Assembly Government and World Cancer Research Fund, AG contributed to this project while funded by a post-doctoral fellowship from the National Institute of Health Research (NIHR). AC is supported by the NIHR Bristol Nutrition Biomedical Research Unit based at University Hospitals Bristol NHS Foundation Trust and the University of Bristol. The views expressed in this paper are those of the authors and not necessarily those of the NHS, the NIHR, Department of Health or of the other study funders. The members of the ICAD steering committee are Prof. A. R. Cooper, Prof. U. Ekelund, Dr. L. Sherar, Dr D. Esliger, Dr A. S. Page and Dr E. van Sluijs, Contributors of data to the International Children's Accelerometry Database (ICAD) studies used in this paper are: Dr. K. Kordas, Avon Longitudinal Study of Parents and Children (ALSPAC) (kasia kordas@bristol.ac.uk); Dr. R. Davey, Children's Health and Activity Monitoring for Schools (CHAMPS UK) (rachef.davey@canberra.edu.au); Prof. R.R. Pate, Physical Activity in Pre-school Children; Trial of Activity for Adolescent Girls (TAAG) (rpate@mailbox.sc.edu); Prof. J. Salmon, Children Living in Active Neighbourhoods (CLAN) (jo.salmon@deakin.edu.au); Prof. L. B. Andersen, Copenhagen School Child Intervention Study (CSCIS) (Iboandersen@health.sdu.dk); Dr. K. Froberg, European Youth Heart Study (EYHS), Denmark, Estonia (kfroberg@health.sdu.dk); Prof. L. Sardinha, EYHS, Portugal (Isardinha@fmh.utl.pt); Prof. S. Anderssen, EYHS, Norway (s.a.anderssen@nih.no); Dr. A. Timperio, Healthy Eating and Play Study (HEAPS) (anna.timperio@deakin.edu.au); Prof. K.F. Janz, Iowa Bone Development Study (kathleen-janz@uiowa.edu); Dr. S. Kreimler, Kinder-Sportstudie (KISS) (susi kriemler@unibas.ch); Prof. A.R. Cooper, Personal and Environmental Associations with Children's Health (PEACH) (ashley.cooper@bristol.ac.uk); Dr. P. Hallal, 1993 Pelotas Birth Cohort (prchallal@gmail.com), Dr E. van Sluijs, Sport, Physical activity and Eating behaviour: Environmental Determinants in Young people (SPEEDY) (esther, vansluijs@mrc-epid.cam.ac.uk). Many thanks to Dr. G. P. Sutton for help with using Mathematica, and to Prof. U. Ekelund, Dr. L. Sherar, Prof. J. Salmon and Dr. E. van Sluijs for comments on draft versions of this paper.

### Electronic supplementary material

12966 2014 940 MOESMI ESM.pdf Additional file 1: Additional methods and results; presentation of fuller details on the studies included in the analyses, and additional results.(PDF 759 KB)

Below are the links to the authors' original submitted files for images.

12966 2014 940 MOESM2 ESM.pdf Authors' original file for figure 1

12966 2014 940 MOESM3 ESM.pdf Authors' original file for figure 2

12066 2014 940 MOESM4 ESM.pdf Authors' original file for figure 3

12966 2014 940 MOESM5 ESM.pdf Authors' original file for figure 4

### Competing interests

The authors declare that they have no competing interests.

### Authors' contributions

AG conceived the study and led the analysis and the writing, with input from AP and AC. All authors contributed to data interpretation, and all approve the final version.

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# Day Length and Weather Effects on Children's Physical Activity and Participation in Play, Sports, and Active Travel

Anna Goodman, James Paskins, and Roger Mackett

# Abstract

# Background

Children in primary school are more physically active in the spring/summer. Little is known about the relative contributions of day length and weather, however, or about the underlying behavioral mediators.

### Methods

325 British children aged 8 to 11 wore accelerometers as an objective measure of physical activity, measured in terms of mean activity counts. Children simultaneously completed diaries in which we identified episodes of out-of-home play, structured sports, and active travel. Our main exposure measures were day length, temperature, rainfall, cloud cover, and wind speed.

### Results

Overall physical activity was higher on long days (≥ 14 hours daylight), but there was no difference between short (< 9.5 hours) and medium days (10.2–12.6 hours). The effect of long day length was largest between 5 PM and 8 PM, and persisted after adjusting for rainfall, cloud cover, and wind. Up to half this effect was explained by a greater duration and intensity of out-of-home play on long days; structured sports and active travel were less affected by day length.

# Conclusions

At least above a certain threshold, longer afternoon/evening daylight may have a causal role in increasing child physical activity. This strengthens the public health arguments for daylight saving measures such as those recently under consideration in Britain.

Keywords: youth, seasonal variation, public health, daylight

Promoting physical activity in childhood has become a policy priority, reflecting its potential to confer substantial benefits to physical and mental health. 1-4 Understanding when and why children are active is an important step in designing effective public health interventions to achieve this goal. This includes understanding how children's physical activity varies across the day, week, and year—and ideally also the interrelationship between variation at these different levels.

Such temporal variation has generally received less research attention than the relationship between overall physical activity and relatively fixed characteristics of the child or their environment.<sup>5-7</sup> Nevertheless, several large (N > 100) population-based studies have examined the effects of season or day length in the US, <sup>8,9</sup> Canada, <sup>10</sup> the UK, <sup>11,12</sup> Denmark, <sup>13</sup> Norway, <sup>14</sup> Sweden, <sup>15</sup> Cyprus, <sup>16</sup> and New Zealand. <sup>17</sup> These studies collected objective measures of physical activity from a total of 11,476 children aged 4 to 13, approximately 90% of whom were aged 9 to 11. All but one <sup>10</sup> reported higher activity levels in the spring and/or summer than in the autumn and/or winter, with moderate to substantial effect sizes. Likewise a recent, broader review (including smaller studies and studies with nonobjective measurement of physical activity) reported seasonal differences in 29 out of 35 studies of 2- to 19-year-olds. <sup>18</sup> This included 6 out of 7 studies from the UK, <sup>11,12,19-22</sup> the exception being one very small study (N = 34).<sup>23</sup>

There is therefore consistent evidence of seasonal differences in the overall physical activity of children in primary school in Europe, North America, and New Zealand. Almost nothing, however, is known about the timing and causes of these differences. Only 2 studies examined

when in the day or week seasonal effects were greatest, reporting larger effects during the weekend in Norway and during after school hours in Norway and Cyprus. <sup>14</sup>, <sup>16</sup> No study investigated the behavioral mediators underlying the observed seasonal differences, although several discuss changes in the amount of outdoor play as a plausible candidate. This hypothesis is indirectly supported by one study of British 11-year-olds which reports a spring/summer increase in both the duration and the activity intensity of time spent outdoors after school. <sup>24</sup> Finally, very little is known about the relative contribution of day length and different aspects of the weather in generating seasonal differences, a research gap highlighted in recent studies and reviews. <sup>9,11,14,18,25</sup> To our knowledge, only 1 study of 5- to 12-year-olds in New Zealand has examined this issue, reporting that rainfall and temperature had larger effects upon step-counts in than day length, wind or hours of sunshine. <sup>17</sup>

These research uncertainties matter because of their policy implications. Although season and day length are nonmodifiable factors, many countries use daylight saving measures ('changing the clocks') to shift the extra hours of summertime daylight from the very early morning (when most people are asleep) to the evening (when most people are awake). The UK currently changes the clocks forward by 1 hour during summertime ('Single Summer Time'), but the past decade has seen several proposals to extend this by changing the clocks forward by 1 extra hour year round ('Single/Double Summer Time'). The most recent of these proposals was a Daylight Saving Bill which in 2011 was under debate in the House of Commons.

The proposed change to Single/Double Summer Time would give British children an estimated average of 200 extra waking daylight hours per year. <sup>26</sup> The Bill's accompanying research paper listed "increase[d] opportunities for outdoor activity" <sup>27, p.12</sup> as one potential benefit, alongside other public health benefits, such as reduced child and adult injuries from road traffic crashes and reduced greenhouse gas emissions. <sup>27,28</sup> This predicted increase in children's physical activity would be considerably strengthened if evening daylight were an important, independent contributor to seasonal differences. By contrast, if (nonmodifiable) aspects of the weather were more important, then it might be more effective to target the downstream behavioral mediators—a process facilitated by knowing precisely which aspects of behavior are most affected by season.

The aims of this paper are therefore to test the hypotheses 1) that longer day length predicts increased child physical activity in the late afternoon and early evening, independent of weather conditions; and 2) that any day length effects upon physical activity are partially mediated by effects on children's participation in play, sport, and active travel.

### Methods

# **Participants**

This paper brings together 2 observational studies, both of which used the same methodology to study physical activity and behavior among 8- to 11-year-olds in Hertfordshire, South-East England. <sup>29,30</sup> Nine primary schools were selected on the basis of their willingness to cooperate (out of 27 approached), and children and parents provided written informed assent/consent. The first study collected valid data from 115 children in Year 6 (age 10–11, 50% participation rate), conducting fieldwork between February 2002 and July 2003. The second study collected valid data from 210 children from Years 4, 5, and 6 (age 8 to 11, 55% participation rate), between July 2005 and March 2006. Our total sample therefore consists of 325 children (170 girls), with a mean age of 9.8 years and a 25% prevalence of overweight/obesity <sup>31</sup> (see Table 1).



Table 1

Demographic Characteristics of Study Participants and Distribution of Weather Conditions Across Study Days

These studies were approved by the University College London ethics committee for non-NHS human research.

# **Physical Activity**

We measured physical activity using RT3 triaxial accelerometers (Stayhealthy Inc, USA). These measure body acceleration in 3 planes, giving an overall activity count which provides a valid measure of physical activity in children. Accelerometers were worn around the waist on the hip from Wednesday to Monday, giving 4 full days of data (Thursday to Sunday). Movement was recorded each minute and periods and, in line with common practice in epidemiological studies, 33,34 we considered 10 continuous minutes of zero counts as \*nonworn time.\* We measured physical activity as the percentage time spent in moderate-to-vigorous physical activity (MVPA) with a cut-point of 970 counts per minute. As a sensitivity analysis we repeated our analyses using mean overall volume of physical activity (mean counts per minute).

# Participation in Out-of-Home Play, Structured Sports, and Active Travel

Children completed travel and activity diaries for 4 days, adapted from National Travel Survey diaries<sup>35</sup> and simplified during piloting to ensure children could easily understand them (example extract in the supplementary material). After the monitoring phase a researcher went through the diary with the child to clarify parts which were unclear or incomplete.<sup>29</sup> This included cross-checking the timings in the diaries against the timings from the accelerometer traces, resolving any apparent discrepancies in discussion with the child. Diary timings were also cross-checked against the Global Positioning Systems (GPS) monitors worn by a subsample of our participants (N = 111) for behaviors involving spatial changes (eg, leaving a building, starting a journey).

The events in the diary were recorded as free text by the children, 16,428 out of 16,664 (98.5%) of which could subsequently be coded according to a hierarchical typology previously described.<sup>29</sup> In this paper we focus upon 3 behaviors which we have shown were particularly physically active.<sup>36</sup> out-of-home unstructured play (eg. informal football games, 'playing'); structured sport (eg. sports lessons or training); and active travel (eg. walking, cycling). Within these, we also singled out 'cycling' and 'swimming' events because accelerometers underestimate physical activity from cycling and cannot be worn in water.<sup>37</sup> As such, if short days/bad weather were associated with increased swimming or cycling, this could create the spurious impression of a decrease in overall physical activity.

For each behavior we calculated its duration (minutes in behavior/total minutes), activity intensity (MVPA minutes in behavior/total minutes in behavior/, and activity contribution (duration × intensity, or MVPA minutes in behavior/total minutes).

# Day Length and Weather

We calculated day length in hours using sunrise and sunset times for London, <sup>38</sup> which borders Hertfordshire. As fieldwork was constrained by school term times, day lengths formed 3 clusters: 'short' days (7.9–9.5 hours, November to early February), 'medium' days (10.2–12.6 hours: October, late February, and March), and 'long' days (14.1–16.6 hours, mid-April to July). The Royston weather station in north Hertfordshire <sup>39</sup> provided day-by-day data for 4 weather variables: mean temperature in degrees centigrade; total rainfall in millimeters; cloud cover at 9:00 AM in oktas (one okta indicates clouds covering one-eighth of the sky); and mean wind speed in miles per hour.

# **Analysis**

We used linear regression to examine day length and weather effects upon a) proportion time in MVPA and b) duration and intensity of participation in play/sport/active travel. We also fitted the model shown in Figure 1 to examine how far effects on MVPA were mediated by the activity contribution from play, sport or active travel. To test our hypothesis that day length effects would be strongest in the afternoon/evening, we fitted these models separately for the 'pre-3 PM' vs. 'post-3 PM' periods of the day (cut-off chosen as the end of the school day). We also ran these models separately for each hour of the day to pin-point further the timing of any effects.



Figure

Mediation model to examine how far participation in 3 physically active behaviors can explain day length or weather effects upon overall physical activity. Activity contribution = duration (proportion of day spent in behavior) × intensity

(proportion ...

Although the correlations between day length, temperature, rainfall cloud, and wind were generally low (Pearson's rho  $\leq 0.3$ ), day length and temperature were highly collinear (rho = 0.75). We therefore entered only day length into multivariable models, selecting day length because it was always at least a strong a predictor as temperature. We entered day length as a categorical variable (and report p-values for heterogeneity) because visual inspection sometimes indicated nonlinear associations.

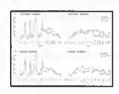
All analyses were restricted to days with at least 8 hours of valid, overlapping diary and accelerometer data between 6:00 AM and 11:00 PM (N = 491 weekdays, N = 326 weekend days). We used days not children as our units of analysis because weather varies from day to day. All regression models adjusted for gender, school year, and weight status (as categorical variables), and used robust standard errors to account for clustering of days within children. Substantive findings regarding total effects were unchanged when we used 3-level random intercepts to additionally allow for clustering of children within schools: we do not present these 3-level models because they could not readily be used to estimate direct vs. indirect effects in our mediation analysis. All analyses were conducted in Statal 1.1 except the mediation analyses which used MPlus5.

### Results

Across the 817 days with valid data, children spent 18% of their time in MVPA. This was higher on weekdays (19% vs. 17% on weekend days) and in boys (20% vs. 16% in girls): study, age, and weight status were not associated with MVPA (see Table 1). These and all other associations presented below were similar or identical for boys and girls (all P > .01 for interaction with gender), or when repeated using overall volume of physical activity

# Effect of Day Length and Weather on Physical Activity

Physical activity was associated with day length on both week and weekend days, an association driven by higher levels of physical activity on long days post-3 PM than on short or medium days post-3 PM (P < .002 for heterogeneity, see Table 2). This association was little changed after adjusting for cloud cover, rainfall, and wind speed, suggesting the day length effect could not be explained by these aspects of the weather. As hypothesized, the effect was particularly large in the late afternoon and early evening: between 5 PM and 8 PM children spent 22% time in MVPA on long days vs. 13% on short/medium days (24% vs. 15% on weekdays, 20% vs. 11% on weekends: see Figure 2). By contrast, long day length had smaller effects upon physical activity in the early afternoon, and there was no evidence of an effect on weekday or weekend mornings (see Figure 2). There was also very little difference between short and medium days in physical activity at any time.



Physical activity across the day, by day length and rainfall. \*  $P \le .05$ , \*\*  $P \le .01$ ; \*\*\*  $P \le .001$  in hour-by-hour analyses, after adjusting for gender, school year, and weight status P-values calculated using tests for heterogeneity ...



Table 2 Effect of Day Length and Weather on Children's Overall Physical Activity

As for the weather variables, temperature showed a very similar pattern to day length (see Table 1)—an unsurprising finding given their

collinearity. A different pattern was seen for rainfall, which was associated with lower physical activity during the middle part of the day. On weekdays this effect was particularly pronounced during morning break and lunch break (Figure 2, second and third peaks), although interestingly activity levels were little changed on the journey to and from school (first and fourth peaks). There was no evidence that cloud cover or wind independently predicted physical activity.

Mediating Role of Out-of-Home Play, Structured Sport, and Active Travel

As shown in Table 3, out-of-home play seemed to mediate part of the effect of long day length upon physical activity post-3 PM. This was true on weekdays and weekends alike, and the magnitude of the indirect (ie, mediated) path was 40% to 50% of the total effect. This mediation primarily reflected the substantially greater duration of play during the afternoons and evenings of long days (Figure 3). For example, in the period 4 PM to 8 PM, out-of-home play accounted for 3%, 7%, and 13% of children's time on short, medium, and long weekdays; and 7%, 5%, and 14% on weekend days (both P < .001 for heterogeneity). There was also evidence that the intensity of children's play was greater post-3 PM (but not pre-3 PM) on long week and weekend days (45% time in MVPA on long days vs. 32% on medium days and 20% on short days, P < .001 for heterogeneity; see also Appendix). Exploratory post hoc analyses suggested that this greater intensity reflected a higher proportion of unstructured ball games, one of the most active forms of play: these accounted for 24% (27/111) of all play events initiated post-3 PM on long days, vs. 2% (2/83) on short or medium days.



Figure 3

Percentage of time spent participating in physically active behaviors, by day length. \*  $P \le .05$ , \*\*  $P \le .01$ , \*\*\*  $P \le .001$  in hour-by-hour analyses, after adjusting for gender, school year, and weight status. P-values calculated ...



Table 3

The Contribution of Out-of-Home Play, Structured Sport, and Active Travel in Mediating the Effects of Day Length and Weather on Children's Overall Physical Activity

By contrast, there was a trend for longer day length to be associated with a shorter duration of structured sport (Figure 3), leading to an indirect path in the opposite direction on weekdays post-3 PM and also on weekends pre-3 PM (Table 3). In no time period was there strong evidence that active travel formed an indirect path between day length and physical activity (Table 3), despite a trend toward a slightly longer duration of active travel on long days (Figure 3). There was likewise little or no evidence that rainfall, cloud or wind predicted the duration or intensity of participation in any physically active behavior (see Appendix), and no evidence that these weather variables were mediated by play, sport or active travel (Table 3).

Finally, duration of swimming and cycling were generally not associated with day length or weather and the trend was for higher duration on longer days with better weather (eg. 0.5%, 0.6%, and 0.7% time swimming on short, medium, and long days; 0.3%, 0.4%, and 0.8% time cycling). There was thus no suggestion of information bias such that physical activity was missed or underestimated more often on short or rainy days.

### Discussion

This study of 325 8-11 year-olds found higher overall physical activity on long week and weekend days, but no difference between short and medium days. The effect of long day length was largest between 5 PM and 8 PM, and persisted after adjusting for rainfall, cloud cover, and

wind. Up to half the effect was mediated by a substantially greater duration and intensity of out-of-home play on long days. Participation in structured sports and active travel showed less variation by day length, but in some time periods the effect of long day length was partly offset by a reduced activity contribution from sports. Rainfall independently predicted lower physical activity in the morning and early afternoon, an effect not explained by participation in play, sport or active travel. There was no evidence for independent effects of cloud cover or wind, and temperature was too collinear with day length to examine separately.

The specificity of the day length effect in the late afternoon/early evening is consistent with previous studies showing larger seasonal differences after school hours <sup>14</sup>, <sup>16</sup> and extends previous research by showing that this also applies at weekends. This specificity supports the hypothesis that daylight itself has a causal effect on child physical activity in northern climates, a hypothesis further strengthened by our novel demonstration that the day length effect was little changed after adjusting for rainfall, cloud cover, and wind. This therefore supports claims that (alongside other benefits) postponing sunset through daylight saving measures would promote child physical activity. <sup>28</sup> This is particularly the case given that the after-school period has been described as the 'critical hours' for children's physical activity, <sup>40,41</sup> and given that the absence of any day length effects in the morning suggests that afternoon activity gains would not be counterbalanced by earlier decreases. On the other hand, we did not observe a dose response effect: while physical activity was higher on long days (sunset post-8 PM), there was no difference between medium days (sunset around 6 PM) and short days (sunset pre-5 PM). If replicated in other datasets, this may indicate that the benefits of daylight saving measures would be concentrated in the spring/autumn transitions between medium and long days.

The key mediating role of out-of-home play confirms the importance of play for child physical activity 5,6,36,41 and is consistent with parents' identification of darkness as a barrier to permitting unsupervised play outdoors. 42 It replicates recent evidence that the duration and/or intensity of children's outdoor activity increases in spring/summer, 24,41 and extends this by highlighting play (perhaps particularly informal ball games) as the activities most affected. This central role of play arguably undermines somewhat recommendations to counter seasonal variation by building infrastructure for indoor sports. 25,43 Insofar as such policies seem unlikely to facilitate informal play (much of which occurs very near the home 44), they may reduce seasonal differences less than daylight saving measures. Nevertheless, some benefit is plausible given the potential hinted at in our data for increased structured sports on short and medium days to offset in part the effect of reduced play. This offsetting effect may stem from the fact that organized activities such as football leagues run primarily in the autumn/winter months, and supports the importance of such activities in months where out-of-home play is less attractive or not permitted by parents. Moreover, the smaller role of sports and active travel in explaining seasonal differences does not lessen their importance as targets for physical activity interventions in general. 36 Indeed, this importance is in some ways enhanced by their relative imperviousness to day length and weather, a 'weather-resistance' particularly notable for active commuting to school. This contrasted with markedly lower physical activity during school hours on rainy days, suggesting that schools may need to do more to provide alternative options for indoor activity.

Besides these substantive issues, our findings also have methodological implications. The importance of day length confirms the difficulty of comparing data collected at different times of year, 8,9,18 while the independent influence of rainfall indicates that analogous weather effects may operate over even shorter timescales. This complicates between-study comparisons, could create within-study bias, and at a minimum may introduce 'noise' which decreases power and precision. We therefore recommend that future studies of child physical activity consider adjusting for day length and rainfall.

We hope future studies will also address the limitations of this research, 3 of which may have lead to underestimation of the effects we support. First our use of accelerometer data recorded on a minute-by-minute basis is longer than the ideal epoch length of ≤ 15 seconds <sup>37</sup> and may have lead us to miss brief sporadic MVPA. Second, we may have underestimated the importance of our behavioral mediators because of inaccuracies in children's reporting of the timing of events and because children did not always record garden play separately. One potential resolution would be to enhance diary data by using global positioning systems (GPS) monitors to identify when children were outside. <sup>24</sup> Third, only day-by-day weather data were available to us and, in the case of cloud cover, this was only available at one point in time; this may have diluted the magnitude of the weather effects which would be seen using hour-by-hour data.

A further limitation is that high collinearity and relatively small sample size prevented us from distinguishing day length and temperature

effects. Day length had stronger minimally-adjusted effects which, in combination with the specificity of the effect to the afternoon/evening, lead us to believe that day length played a greater causal role. It would, however, be valuable to examine this directly in more informative datasets, particularly as one New Zealand study found temperature was more important than day length. Finally, further research is also needed before it can be assumed that these findings generalize to settings with more extreme weather (eg. extreme heat 45), or to preschool children (who may not show seasonal differences in physical activity 18).

To conclude, these findings suggest that primary school children in South-East England are more physically active on long days, partly because they spend more time playing outside the home. This represents the most direct evidence yet that (at least at some points of the year) redistributing daylight hours to the afternoon might prove an effective population-level intervention to promote child physical activity. In combination with the evidence that such measures would avert road traffic crashes and reduce greenhouse gas emissions, <sup>27</sup> this study therefore bolsters the public health arguments in favor of daylight saving measures such as those recently under consideration in the UK.

# Supplementary Material

Supplementary material Click here to view (229K, doc)

# Acknowledgments

Many thanks to the children who took part in these studies, and to their parents and teachers. We are grateful to the Environment Department of Hertfordshire County Council, a non-academic partner which facilitated much of the fieldwork. We also greatly appreciate the work of Belinda Brown, Yi Gong, Kay Kitazawa, Lindsey Lucas, and Jill Turbin, who assisted in carrying out the fieldwork, and Laurel Edmunds, Ruth Sullivan, and Kate Westgate for providing advice on the use and analysis of accelerometers. Funding for the first study ('Reducing children's car use: the health and potential car dependency impacts") was provided by UK Engineering and Physical Sciences Research Council, grant GR/N33638. Funding for the second study ('Children's Activities Perceptions and Behavior in the Local Environment (CAPABLE)') was provided by UK Engineering and Physical Sciences Research Council, grant GR/T09378/01. AG completed this report during a Post-Doctoral Research Fellowship supported by the National Institute for Health Research or the Department of Health.

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# Article information

J Phys Act Health. Author manuscript; available in PMC 2013 Feb 28.

Published in final edited form as:

J Phys Act Health. 2012 Nov; 9(8): 1105–1116.

Published online 2011 Nov 8.

PMCID: PMC3584676 EMSID: EMS52057 Anna Goodman, James Paskins, and Roger Mackett

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# Switch to daylight saving time leads to cyberloafing at the office

Date: March 7, 2012

Source: Penn State

Summary: The annual shift to daylight saving time and its accompanying loss of sleep cause em-

ployees to spend more time than normal surfing the Web for content unrelated to their work, resulting in potentially massive productivity losses, according to researchers.

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#### **FULL STORY**

The annual shift to daylight saving time and its accompanying loss of sleep cause employees to spend more time than normal surfing the Web for content unrelated to their work, resulting in potentially massive productivity losses, according to researchers.

Web searches related to entertainment rise sharply the Monday after the shift to daylight saving time when compared to the preceding and subsequent Mondays, according to D. Lance Ferris, assistant professor of management and organization in Penn State's Smeal College of Business, and his colleagues David T. Wagner, Singapore Management University; Christopher M. Barnes, Virginia Tech University; and Vivien K. G. Lim, National University of Singapore. They based their findings on an examination of six years worth of data from Google.

Using existing data that shows that people exhibit poorer self-control when they're tired, the researchers said that the lost sleep due to the time change -- an average of 40 minutes that Sunday night -- makes employees less likely to self-regulate their behavior and more inclined to spend time cyberloafing, or surfing the Internet for personal pursuits while on the clock.

Ferris and his colleagues also conducted a lab experiment in which they monitored subjects' sleep the night before they were required to watch a boring lecture online. The less sleep the sub-

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jects received the night before, the more time they spent surfing the Web when they were supposed to be watching the lecture.

Interruptions in sleep had the same effect. In fact, the subjects on average engaged in 8.4 minutes more of cyberloafing (or 20 percent of the assigned task time) for every hour of interrupted sleep the night before.

While a few minutes of personal Web surfing now and then may seem harmless, given that about one-third of the world's countries participate in some form of daylight saving time, the researchers write in the Journal of Applied Psychology that "global productivity losses from a spike in employee cyberloafing are potentially staggering." In light of their discovery and other research on the true energy-saving effects of daylight saving time, the authors encourage policymakers to revisit the costs and benefits of the time change policy.

They said their findings have implications for managers, who in the current economy, are squeezing more and more work out of fewer employees.

\*In the push for high productivity, managers and organizations may cut into the sleep of employees by requiring longer work hours," the researchers write. "This may promote vicious cycles of lost sleep, resulting in less time spent working, which could result In more frantic pushes for extended work time. Managers may find that by avoiding infringement on employee sleep, they will get more productivity out of their employees."

The researchers said that employers can facilitate more self-requlation of their employees' cyberloafing if they encourage their employees to get a sufficient amount of sleep. Outside of that, they recommend turning computer screens so that colleagues can see them or even providing designated break times when personal internet use would be permissible.

#### Story Source:

Materials provided by Penn State. Note: Content may be edited for style and length.

<www.sciencedaily.com/releases/2012/03/120307112618.htm>.

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Lost sleep and cyberloafing: Evidence from the laboratory and a daylight saving time quasi-experiment.

By Wagner, David T.; Barnes, Christopher M.; Lim, Vivien K. G.; Ferris, D. Lance Journal of Applied Psychology, Vol 97(5), Sep 2012, 1068-1076.

#### **Abstract**

The Internet is a powerful tool that has changed the way people work. However, the ubiquity of the Internet has led to a new workplace threat to productivity—cyberloafing. Building on the ego depletion model of self-regulation, we examine how lost and low-quality sleep influence employee cyberloafing behaviors and how individual differences in conscientiousness moderate these effects. We also demonstrate that the shift to Daylight Saving Time (DST) results in a dramatic increase in cyberloafing behavior at the national level. We first tested the DST-cyberloafing relation through a national quasi-experiment, then directly tested the relation between sleep and cyberloafing in a closely controlled laboratory setting. We discuss the implications of our findings for theory, practice, and future research. (PsycINFO Database Record (c) 2016 APA, all rights reserved)

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J Air Waste Manag Assoc. 2012 Jun;62(6):642-50.

Relative roles of emissions and meteorology in the diurnal pattern of urban PM10: analysis of the daylight saving time effect.

Muñoz RC<sup>1</sup>.

#### Author information

#### **Abstract**

Daylight saving time (DST) is a common practice in many countries, in which Official Time (OT) is abruptly shifted 1 hour with respect to solar time on two occasions every year (in fall and spring). All anthropogenic emitting processes tied to OT like job and school commuting traffic, abruptly change in this moment their timing with respect to solar time, inducing a sudden shift between emissions and the meteorological factors that control the dispersion and transport of air pollutants. Analyzing 13 years of hourly particulate matter (PM10) concentrations measured in Santiago, Chile, we demonstrate that the DST practice has observable non-trivial effects in the PM10 diurnal cycle. The clearest impact is in the morning peak of PM10 during the fall DST change, which occurs later and has on average a significant smaller magnitude in the days after the DST change as compared to the days before it. This decrease in magnitude is most remarkable because it occurs in a period of the year when overall PM10 concentrations increase due to generally worsening of the dispersion conditions. Results are shown for seven monitoring stations around the city, and for the fall and spring DST changes. They show clearly the interplay of emissions and meteorology in conditioning urban air pollution problems, highlighting the role of the morning and evening transitions of the atmospheric boundary layer in shaping the diurnal pattern of urban air pollutant concentrations.

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Psychology & Psychiatry December 14, 2016

## Switching to daylight saving time may lead to harsher legal sentences

December 14, 2016



Credit: Association for Psychological Science

Judges in the United States tend to give defendants longer sentences the day after switching to daylight saving time compared with other days of the year, according to research published in Psychological Science, a journal of the Association for Psychological Science.



Previous research has shown that people tend to sacrifice, on average, about 40 minutes of sleep when they "spring forward" to daylight saving time, and even this small amount of lost sleep can have negative consequences, including an increase in workplace injuries, slacking off at work, and auto accidents. The results of this new research suggest that shortened sleep associated with the change to daylight saving time might also affect the severity of sentences doled out by judges.

"We find that the sentences given to those convicted of crimes may be partially polluted by the sleep of those giving the punishments," says researcher Kyoungmin Cho of the

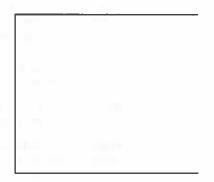
University of Washington, first author on the study. "Sleep is a factor that should not play a role in their sentences, but does."

Cho conducted the research with co-authors Christopher M. Barnes (University of Washington) and Cristiano L. Guanara (University of Virginia).

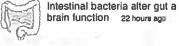
Evidence for the detrimental effects of sleep is abundant; Studies have shown that sleepdeprived people have more difficulty weighing risks, they are more sensitive to potentially negative or threatening stimuli, they have more difficulty regulating emotions, and they are more impulsive.

The annual shift in sleeping patterns due to daylight saving time led Cho, Barnes, and Guanara to wonder: Could losing an hour affect consequential legal decisions the next day?

To answer this question, the researchers tapped into data on legal sentences handed down



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between 1992 and 2003, collected by the US Sentencing Commission. The researchers examined data within each judicial district to account for variation across districts and they looked at the length of the sentence given, not including any other types of sentences including community confinement or probation.

To isolate the unique impact of daylight saving time, Cho and colleagues took other potential influences into account, including the yearly trend in sentencing decisions and various characteristics related to both the trial and the offender.

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Across multiple analyses, the researchers found a consistent trend: Sentences given on the Monday after the switch to daylight saving time were longer than those given on other days.

Specifically, Cho and colleagues found that sentences on the so-catted "Sleepy Monday" were about 5% longer than those given on the previous Monday and the following Monday.

Additional analyses showed that legal sentences handed out on Sleepy Monday were longer than those given on all other Mondays combined, and they were also longer than those doled out on all other days of the year combined.

Importantly, the effect was specific to Steepy Monday: Sentences given on the other weekdays following the transition to daylight saving time did not differ from sentences given one week before or one week after. Cho and colleagues found that the return to standard time in the fall, when people gain an hour, had no effect on legal sentencing.

To be sure, there are many variables that influence a judge's sentencing decisions and the average amount of sleep lost due to daylight saving time is less than an hour. And yet, the data still showed a clear relationship between the time change and sentencing:

"We were surprised at how clearly we were able to detect the hypothesized effect," says Cho. "Across many alternative analyses and robustness checks, the effect was still quite clear and meaningful."

The findings have clear implications for those involved in the legal system, but may also extend to the many other contexts in which people give or receive punishment.

"Bosses punish employees who break work rules, parents punish children who engage in bad behavior, teachers punish students who disrupt the classroom environment, and sports referees punish players and athletes who violate the rules of the game," Cho notes. "Many of the people making these punishment decisions will do so while short on sleep, and the same logic explored in our research will likely apply in those contexts, as well."

In future research, Cho hopes to investigate the causal mechanisms that link steep and punishment decisions, as well as potential strategies for mitigating these effects.

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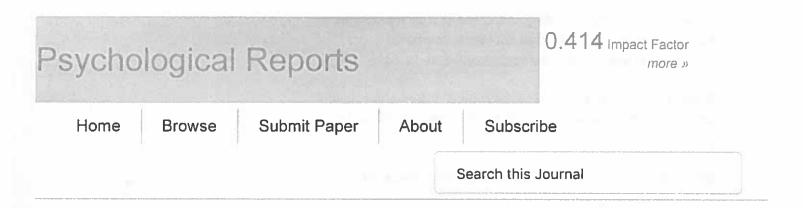
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## **Effects of Daylight Saving Time Changes on** Stock Market Volatility: A Reply

Hakan Berument, Nukhet Dogan First Published December 1, 2011 | research-article







#### Abstract

There is a rich array of evidence that suggests that changes in sleeping patterns affect an individual's decision-making processes. A nationwide sleepingpattern change happens twice a year when the Daylight Saving Time (DST) change occurs. Kamstra, Kramer, and Levi argued in 2000 that a DST change lowers stock market returns. This study presents evidence that DST

changes affect the relationship between stock market return and volatility. Empirical evidence suggests that the positive relationship between return and volatility becomes negative on the Mondays following DST changes.

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ISSN: 0033-2941

Online ISSN: 1558-691X

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Published 23 November 2016, DOI: 10.1098/rsbl 2016.0632

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#### Abstract

Daylight saving time (DST) could reduce collisions with wildlife by changing the timing of commuter traffic relative to the behaviour of nocturnal animals. To test this idea, we tracked wild koalas (Phascolarctos cinereus) in southeast Queensland, where koalas have declined by 80% in the last 20 years, and compared their movements with traffic patterns along roads where they are often killed. Using a simple model, we found that DST could decrease collisions with koalas by 8% on weekdays and 11% at weekends, simply by shifting the timing of traffic relative to darkness. Wildlife conservation and road safety should become part of the debate on DST.

#### Footnotes

· Electronic supplementary material is available online at https://dx.doi.org/10.6084/m9.figshare.c.3573249,

Received August 11, 2016.

Accepted October 31, 2016

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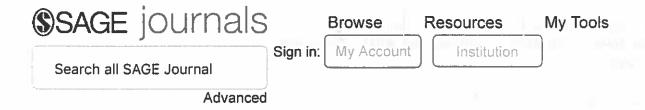
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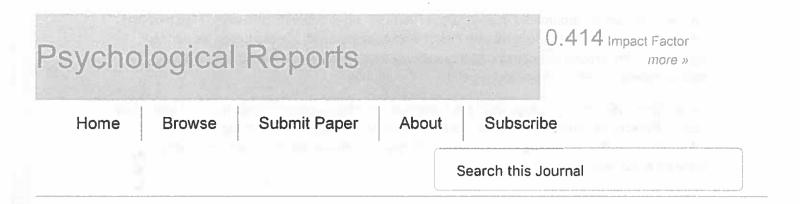
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Authors' contributions

Competing interests





# Effects of Daylight Saving Time Changes on Stock Market Volatility: A Reply

Hakan Berument, Nukhet Dogan

First Published December 1, 2011 | research-article





#### **Abstract**

There is a rich array of evidence that suggests that changes in sleeping patterns affect an individual's decision-making processes. A nationwide sleeping-pattern change happens twice a year when the Daylight Saving Time (DST) change occurs. Kamstra, Kramer, and Levi argued in 2000 that a DST change lowers stock market returns. This study presents evidence that DST

Testimony regarding LB309 - Eliminate Daylight Saving Time Before the Government, Military and Veterans Affairs Committee March 3, 2017

By Scott C. Yates

To the members of the committee, thank you very much for allowing me to testify today, especially as a resident not of Nebraska, but of your neighbor state of Colorado.

I follow bills from all around the country since I've taken up this cause, and when I learned that Senator Brasch had introduced this bill here, I was quite pleased. I wrote to her, as I do to legislators from around the country, and I must say that her response was the most thoughtful and complete I've gotten from any legislator in the country.

I'm a former CEO of technology startups. I just recently hired a new CEO for my third startup so I could focus more time on this issue. My second company was involved in legislative information, so I've always been fascinated with the unicameral approach, so I'm doubly pleased to be here today.

I'd like to speak today in three general areas: research, good government, and politics.

Before I get to that, a very short bit of history.

I've been a leader on this issue for a couple of years now, having appeared on CNN, a bunch of radio stations and newspapers, and I've talked to legislators and citizens all over the country.

If you ask someone why we change the clocks twice per year, most will say it has something to do with agriculture. Let me just clear that up here and now, especially knowing how important agriculture is to Nebraska.

The farmers were always against clock-changing. Always. The Boston Chamber of Commerce issued press releases saying that farmers liked it, but farmers never liked it, and that bit of "fake news" has endured for about 100 years now.

Why we have it now is really something of a mystery, as it was actually just the U.S. following the example set by the Germans in World War I. They thought it would help them save fuel oil, but there's a theory that it was just a distraction to take people's minds off the facts that they only had turnips to eat one winter during the war.

Anyway, Great Britain followed suit, and the U.S. after that, and now we're stuck with showing up to work all bleary-eyed and figure out the damn DVD player settings twice a year.

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