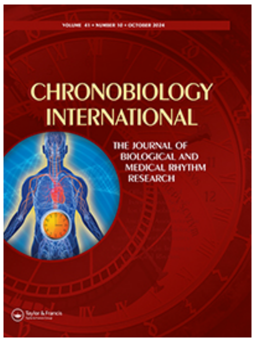


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# Assessing evidence in translational chronobiology: The cases of Daylight Saving Time and road safety, and of school start times and sleep duration

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**ABSTRACT**

One of the main challenges in translating chronobiology research into clinical practice is represented by differences in how basic scientists and clinicians evaluate evidence. The workshop "Assessing Evidence in Translational Chronobiology," which was held at the University of Surrey in June 2023, addressed this issue by bringing together basic scientists and clinicians to evaluate evidence on two specific topics: the impact of Daylight Saving Time (DST) on road traffic accidents and the relationship between delayed school start times (SSTs) and sleep duration in high school students. A comprehensive literature search was conducted for discussions during the workshop, which is presented in this review. The studies on both topics were analyzed from varying perspectives, including that of a chronobiologist and a transportation engineer for the DST-centered question, and that of a chronobiologist and an evidence-based medicine expert for the SSTs-centered question. The workshop audience, acting as a Delphi panel, attempted to produce statements/recommendations. It was concluded that most studies suggest that sleep duration benefits from delayed SSTs in high school, while less obvious results were obtained regarding the effect of DST on road safety.

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## Introduction

One of the challenges in translating Chronobiology research into practice is the difference in evaluating evidence between basic scientists and clinicians. This can result in some degree of disconnection between theoretical knowledge and practical applications, and in the assumption that what is reasonable from a pathophysiological view point can be translated into practice without the acquisition of the relevant evidence. This slows the translational process and also results in limited interest on the clinicians' part for topics and discoveries that scientists believe to be translationally relevant. Clinicians utilise formal pre-defined criteria to acquire and assess evidence to inform diagnosis and treatment, while scientists are more interested in uncovering general principles underlying physiology, and also pathophysiology and disease. Thus, in contexts such as DST and road safety, as well as school start times and academic performance, a partnership between "basic" and "translational" chronobiologists may aid and speed decision and policy-making. Engaging in open and collaborative discussions about the relative importance of the respective perspectives, and different contexts in which research is conducted, is probably a reasonable starting point. The aim of this narrative review is to present a large set of studies collected and analyzed for the workshop "Assessing evidence in Translational Chronobiology," that took place at the University of Surrey (UK) in June 2023, and to offer some insights and recommendations. The available evidence for two "hot topics" in Translational Chronobiology: Daylight Saving Time (DST) contributing to road traffic accidents and delayed school start times (SSTs) resulting in increased sleep duration in high school students was evaluated in a multidisciplinary setting.

The influence of transitions to and from DST on road traffic accidents is difficult to assess due to the complexity of the factors involved (Adams et al. 2005; Broughton and Stone 1998; Carey and Sarma 2017; Ferguson et al. 1995; Martín-Olalla and Mira 2023; Sullivan and Flannagan 2007). On one hand, DST modulates environmental light conditions, and this effect varies considerably in different geographical areas. On the other hand, transitions to and from DST may result in sleep deprivation and circadian disruption in drivers. Both factors could impinge on the incidence of road traffic accidents of different types. Studies on the topic have typically reported either short-term (up to 2 weeks) or longer term effects (usually 3–13 weeks around the clock shift). Previous attempts to summarize the studies investigating

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these effects on road traffic accidents have found inconsistent short-term findings and positive long-term effects of DST (Carey and Sarma 2017; Martín-Olalla and Mira 2023; Molina et al. 2023). However, such positive effects cannot be attributed solely to DST, as other risk factors for road traffic accidents, such as photoperiod and weather conditions may also vary over time, particularly when comparing different months like December/January to May/June. The amount of social jet-lag (i.e. the effect of time constraints largely derived from the social context on sleep-wake timing and sleep duration) may also significantly differ in such months. This can lead to different degrees of sleep curtailment and circadian disruption, especially in evening types, potentially impinging on the risk of road traffic accidents (Borisenkov et al. 2017).

Sleep has been studied extensively in adolescents (Bruce et al. 2017). It is well known that adolescents and young adults tend to exhibit delayed sleep onset/offset, which often results in sleep curtailment, especially during weekdays, due to early SSTs (Colrain and Baker 2011). This has also been associated with impaired academic performance (Curcio et al. 2006), and also with an increase in transport accidents (Flatley et al. 2004). In this context, there is growing interest in whether delaying SSTs may be a useful strategy to increase sleep duration in adolescents and, in turn, also health and performance (Afolabi-Brown et al. 2022; Minges and Redeker 2016).

The aim of this narrative review is to explore the above two topics with methods that are commonly utilized to produce clinically relevant statements, recommendations and guidelines (Cornberg et al. 2019).

## Methods

The literature was interrogated via two well-defined PICO [Population (P), Intervention (I), Comparator (C), Outcome (O)] questions (Huang et al. 2006) i.e.:

- *Do healthy individuals (P) have an increased risk of road traffic accidents (O) during the Daylight Saving Time months (April-October)(I) compared to the standard time months (November-March)(C)?*
- *Are delayed school start times (I) associated with longer sleep duration (O) in high school students (P)? (C: standard school times)*

The evidence was first examined and summarized in a comprehensive, detailed fashion by authors CM and GG, one with a clinical and one with a neurobiological background, and then double-checked by author EDD. The final set of data for both questions was analyzed from more specific perspectives: that of a chronobiologist and a transportation safety engineer for the DST-centred question, and that of a chronobiologist and an evidence-based medicine expert for the question on school starting times and sleep duration. The evidence was graded according to the Levels of Evidence (LoE) scale by the Oxford Centre for Evidence-based Medicine (Howick 2011); all papers for both questions were graded as LoE 3 or 4, which, in general, lead to weak or open statements and recommendations (Howick 2011). The audience of the meeting (a total of 30 participants), acting as a Delphi panel, discussed the overall evidence, and attempts were made to produce and vote statements/recommendations. A Delphi panel (i.e. the type of panel that generally reviews PICO-based clinical practice guidelines) consists of a diverse group of experts who have been chosen based on their knowledge and experience in the relevant topic and express written opinions at all stages of a guideline production (Nasa et al. 2021). In our case, a structured feedback process and iterative discussions between the panellists were chaired by the workshop organizers, with a view to achieve consensus during the workshop itself.

### *Search Strategies and Selection Criteria*

An extensive literature research was conducted using PubMed, Scopus, and Web of Science databases, without applying any filter/limitation. The final search was conducted on 11 May 2023; the descriptors for each topic are listed below. On first screening, which was performed through title and abstract evaluation, opinion pieces, book chapters, and newspaper/magazine articles in which no primary data were analyzed, together with papers written in languages other than English and clearly non-relevant records were excluded. The detailed processes are illustrated in the PRISMA flow diagrams (Page et al. 2021), (Figures 1 and 2). The full search strategy is available in the Supplementary Materials.

#### *DST and Road Traffic Accidents*

The final search included the following descriptors: “daylight saving time,” “DST,” “time change,” “road safety,” “road traffic,” “crash,” “accident.” Studies reporting a quantitative analysis using primary data on the effects of DST on road safety-related outcomes (e.g. road traffic accidents, casualties, and animal-vehicle accidents) and any type of road user were included. A second screening resulted in the exclusion of studies that artificially constructed a change in lighting conditions (e.g. in a laboratory experiment), studies in which potential effects of DST were discussed but not analyzed, studies that did not specifically focus on the impact of DST, and/or were related to time-zone changes rather than DST.

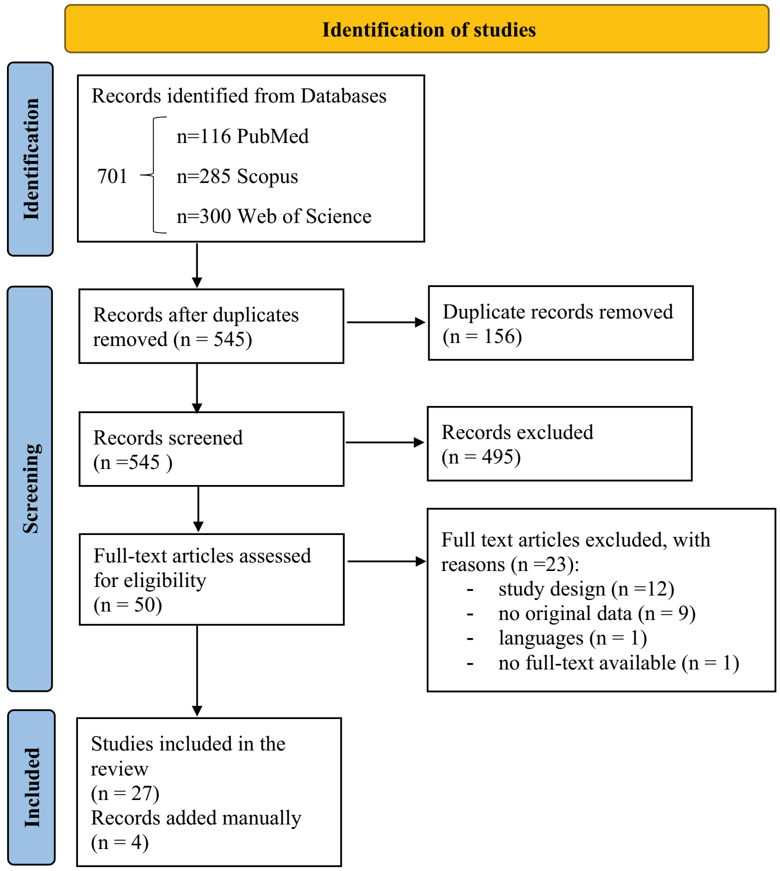


**Figure 1.** PRISMA flow diagram. Selection process for research question: "Do healthy individuals have an increased risk of road traffic accidents during the daylight saving time months (April-October) compared to the standard time months (November-March)?" Excluded records on first screening were: opinion pieces/book chapters/articles in which no primary data were analyzed/papers not in English/clearly non-relevant records.

### *SSTs and Sleep Duration in High School Students*

The final search was conducted using the following descriptors: "sleep duration," "sleep," "high school," "students," "adolescents," "school start time," "school start times," "school starting times," "school start delay," "start late," "start early." Studies reporting quantitative or semi-quantitative sleep assessment were included. On second screening, studies with endpoints other than sleep duration, populations other than high school students (e.g. elementary school students, university students, teachers), or no quantitative assessment of sleep duration were excluded.

## Results

### *Do Healthy Individuals Have an Increased Risk of Road Traffic Accidents During the Daylight Saving Time Months (April–October) Compared to the Standard Time Months (November–March)?*

#### *Characteristics of the Studies*

The final set included 31 original papers. Fourteen studies were from the USA (Coren 1996; Cunningham et al. 2022; Ferguson et al. 1995; Fritz et al. 2019, 2020; Hicks et al. 1983; Huang and Levinson 2010; Lahti et al. 2010; Molina et al. 2023; Prats-Uribe et al. 2018; Smith 2016; Sood and Ghosh 2007; Stevens and Lord 2006; Zhou and Li 2022), 12 from Europe (Abeyrathna and Langen 2021; Alsousou et al. 2009; Bunnings and Schiele 2021; Coate and Markowitz 2004; Ellis et al. 2016; Lambe and Cummings 2000; Nohl et al. 2021; Robb and Barnes 2018; Singh et al. 2022; Sullivan and Flannagan 2007; Varughese and Allen 2001; Whittaker 1996), one from Asia (Teke et al. 2021), one from Oceania (James 2023), and three studies with no specific location (Martín-Olalla and Mira 2023; Meyerhoff 1978; Vincent 1998), published from 1978 to 2023 (median year of publication: 2016). All studies were retrospective observational, and one was a meta-analysis. Most of the studies (77%) analyzed the short-term effects of clock shifts on the risk of road traffic accidents by assessing the period immediately (two weeks or less) before and/or after. In addition, 45% of the studies investigated the overall or longer term effects of clock shifts on road safety. The

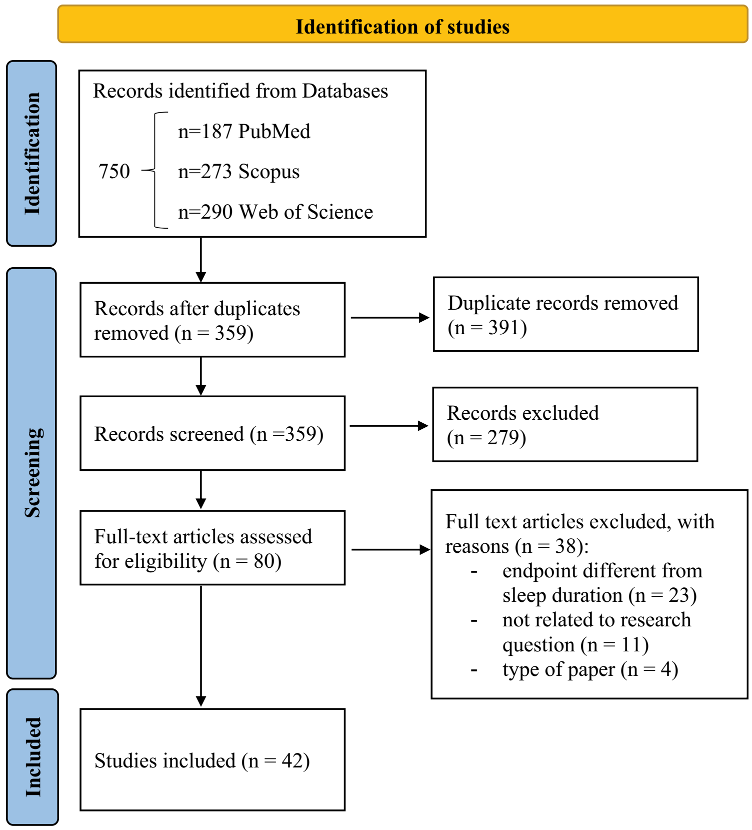


**Figure 2.** PRISMA flow diagram. Selection process for research question: "Are delayed school start times associated with longer sleep duration in high school students?" Excluded records on first screening were: opinion pieces/book chapters/articles in which no primary data were analyzed/papers not in English/clearly non-relevant records.

timeframes for the longer term effect studies ranged from 3 to 13 weeks. A single study conducted a comparative analysis of the two-weeks before and after transitioning to and from DST with equivalent intervals without the transition (Teke et al. 2021). Thirteen out of 31 papers focused the analysis on all types of road traffic accidents (41%), eight on fatal accidents (25%), two on hospital admissions due to road traffic accidents (6%), three on animal-vehicle accidents (9%), and five on motor vehicle accidents (16%).

## *The Short Term Effect*

The main findings are summarized in Table 1. Of the 24 studies analyzed, five reported an increase in the total number of road traffic accidents (Coren 1996; Hicks et al. 1983; Lahti et al. 2010; Robb and Barnes 2018; Stevens and Lord 2006) and five indicated an increase in fatal or severe injuries (Alsousou et al. 2009; Fritz et al. 2020; Prats-Uribe et al. 2018; Smith 2016; Varughese and Allen 2001). Eleven studies did not observe a difference after the clock shift to DST in Spring (Abeyrathna and Langen 2021; Bunnings and Schiele 2021; Cunningham et al. 2022; Fritz et al. 2019; James 2023; Lambe and Cummings 2000; Molina et al. 2023; Nohl et al. 2021; Sood and Ghosh 2007; Teke et al. 2021; Vincent 1998), with some exceptions when different types of road traffic accidents were taken into account (Bunnings and Schiele 2021; Molina et al. 2023; Nohl et al. 2021). Molina et al. documented a notable increase in fatal accidents and nighttime crashes, particularly from Sunday to Friday. However, no evident variations were reported within the broader sample (Molina et al. 2023). A few studies (three out of 24) suggested a potentially positive effect of the Spring transition to DST on road safety (Huang and Levinson 2010; Whittaker 1996; Zhou and Li 2022).

Considering the clock shift to standard time, 20 short-term studies provided relevant data, out of which seven reported an increase in the risk of all types of road traffic accidents, fatal accidents, and accidents involving animals after the transition from DST to standard time (Abeyrathna and Langen 2021; Cunningham et al. 2022; Molina et al. 2023; Prats-Uribe et al. 2018; Stevens and Lord 2006; Varughese and Allen 2001; Zhou and Li 2022). Eleven studies reported no difference after the DST to standard time clock shift (Bunnings and Schiele 2021; Fritz et al. 2019, 2020; Huang and Levinson 2010;

**Table 1.** Summary of the 24 studies on the short-term effects of time transitions (to/from DST) on road traffic accidents.

| Authors(year) | Analysis years | Timeframe | Key findings | Population | Sample size |
|---|---|---|---|---|---|
| Abeyrathna et al. (2021) | 2005–2007 | Up to 4 weeks before and 4 weeks after | Following the transition to DST, no change/slight decrease in the frequency of animal-vehicle accidents in the evening hours on weekdays. After the transition to standard time, the animal-vehicle accidents rate increased during evening hours and decreased in morning hours on weekdays | Animal-vehicle accidents | 35167 |
| Alsousou et al. (2009) | 1996–2006 | Up to 4 weeks before and 4 weeks after | Fatal accidents related to RTAs increased up to 14 days after the transition to DST | Fatal accidents | 282 |
| Bunnings and Schiele (2021) | 1997–2017 | n/a | No clear evidence. Fatal/serious accidents increased by 7.2% during the dark hours | All accidents | 4100000 |
| Coren (1996) | 1991–1992 | 1 week before, week of and 1 week after | RTAs increased by 8% after transition to DST and decreased by 8% after transition to standard time | All accidents | 21603 |
| Cunningham et al. (2022) | 1994–2021 | 1 week before and 1 week after | Animal-vehicle accidents were 14 times more likely shortly after dark. Night-time traffic and animal-vehicle accidents were more frequent during standard time. Animal-vehicle accidents increased by 16% in the week after transition to standard time | Animal-vehicle accidents | 1012465 |
| Fritz et al. (2019) | 1975–2018; 2012–2018; 2007–2018 | Saturdays, Sundays, and Mondays in the week before and after the DST spring transition. | No differences in fatal/non-fatal accident rates associated with the time transitions. This was not influenced by accident fatality, time-of-day, or geographical location | All accidents | 1874672 |
| Fritz et al. (2020) | 1996–2006; 2007–2017 | 1 week before and 1 week after | Fatal traffic accident risk increased by 6% after transition to DST, especially in the morning. West locations in time zone were more affected by transition to DST | Motor vehicle accidents | 732835 |
| Hicks et al. (1983) | 1976–1978 | 1 week before and 1 week after | Transitions to/from DST were associated with a significant increase in RTAs during the post-change weeks. The negative consequences of transitions may persist for more than one week | All accidents | 120111 (weekly-RTA database); 240222 (daily-RTA database) |
| Huang and Levinson (2010) | 2001–2007 | Up to 8 weeks before and after | DST is associated with fewer crashes for most dayparts; DST is also correlated with fewer fatal crashes than standard time | Motor vehicle accidents | n/a |
| James (2023) | 1989–2015 | According to day-of-week, month-of-year, year, and state fixed model | DST did not have an impact on fatal accidents. There was evidence of reallocation of accidents over the day due to ambient light | Fatal accidents | 41000 |
| Lahti et al. (2010) | 1981–2006 | 1 week before and after | Transitions to/from DST did not increase the number of crashes requiring hospitalization. DST transitions may increase the number of less severe accidents not requiring hospital treatment | Motor vehicle accidents | n/a |
| Lambe and Cummings (2000) | 1984–1995 | Monday before and after; 1 week after | Transition to/from DST did not have measurable effects on RTAs rates | All accidents | 6844 |
| Molina et al. (2023) | 1983–2019 | 1 week before and after | An increase in all crashes on the Sunday and Monday after transition from DST; other days were not significant | All accidents | n/a |
| Nohl et al. (2021) | 2002–2017 | 1 week before and after | Increased motorcycle accidents up to 52%, but no difference in overall RTAs after transition to DST. Decrease in motorcycle and bicycle accidents during time transition from DST to standard time | Number of traumas due to RTA | 30000 |

(*Continued*)

**Table 1.** (Continued).

| Authors(year) | Analysis years | Timeframe | Key findings | Population | Sample size |
|---|---|---|---|---|---|
| Prats-Uribe et al. (2018) | 1990–2014 | Day of the DST shift and up to 30 days after | Risk of fatal RTAs increased by 30% on the day of transition to/from DST and decreases after (the effect is similar but less pronounced after the transition to standard time) | Fatal accidents | n/a |
| Robb and Barnes (2018) | 2005–2016 | 1 week before and after | RTAs rates RTAs increased by 16% on the day of transition to DST and by 12% the following day | All accidents | 2256 |
| Smith (2016) | 2002–2011 | n/a | Fatal RTAs increased by 5-7% immediately after the transition to DST; no impact after the transition from DST | Fatal accidents | ˜40000 |
| Sood and Ghosh (2007) | 1976–2003 | Monday before, Monday of and Monday after | No short term effect | Fatal accidents | n/a |
| Stevens and Lord (2006) | 1998–2000 | 5 days before and after | A negative impact of the transition to/from DST is particularly marked for the transition from DST. Transition to DST results in a decrease in the number of pedestrian crashes | All accidents | 157290 |
| Teke et al. (2021) | 2014–2015 winter time; 2015–2016 summer time; 2016–2017 winter time; 2017–2018 summer time; | 2 weeks before and after ST shift (2014–2015) and DST shift (2015–2016); 2 weeks before and after the same period with permanent DST in 2016–2017 winter months and 2017–2018 summer months | No increase in the number of RTAs during the transition to/from DST. Gender, time of admission, week of admission, injury severity scores, and outcome are not affected by time transitions | Hospital admission after road traffic collisions | 710 |
| Varughese and Allen (2001) | 1975–1995 | 1 week before and after | Increase in vehicle accidents on Monday after transition to DST; increase accidents on the Sunday after transition to standard time | Fatal accidents | n/a |
| Vincent (1998) | 1984–1993 | Up to 8 days before and after | No peaks on Mondays after the transition to/from DST. No differences in motor vehicle accidents rates in the weeks before/after the transitions | Motor vehicle accidents | n/a |
| Whittaker (1996) | 1983–1993 | 1 week before and after | Accidents decreased by 6% in morning and 11% in evening after transition to DST, especially in the pedestrian (36%), cyclist (11%) and schoolchild (24%) subgroups. Transition from DST associated with a reduction (6%) in accidents in the morning. Evenings were associated with significant increases in accidents (4%), mainly involving vehicle (5%) and pedestrian (8%) | Fatal accidents | 4185 |
| Zhou and Li (2022) | 2014–2016 | Up to 8 week for the Spring time change and until 4 week for the Autumn time change | Decreased accidents after transition to DST, the highest reduction on Sundays (27%) and lowest on Fridays (14%). Nighttime accidents decreased by a third, while daytime had a mild reduction of 12%. Increased accidents after transition from DST, the highest on Mondays (14%) | All accidents | n/a |

RTAs=road traffic accidents, DST=Daylight Saving Time.

James 2023; Lahti et al. 2010; Lambe and Cummings 2000; Nohl et al. 2021; Sood and Ghosh 2007; Teke et al. 2021; Vincent 1998). However, while Nohl et al. reported no changes after the DST to standard time shift when the entire sample was analyzed, they found a decrease in motorcycle and bicycle road accidents (Nohl et al. 2021). Finally, two studies found a decrease in road traffic accidents after the clock shift to standard time (Coren 1996; Hicks et al. 1983).

Some studies also focused on the immediate effect of the transition (Harrison 2013; Lahti et al. 2010). Following DST, a significant increase in road traffic accidents was observed on Monday, and a corresponding reduction was observed after the DST to standard time shift in Autumn (Coren 1996). Varughese and Allen found an increase in fatalities immediately following the clock shifts in both Spring and Autumn (Varughese and Allen 2001). By contrast, Lambe and Cummings showed no significant differences in accident frequency on the Monday before, the Monday immediately after, and the second Monday after the Spring and Autumn transitions (Lambe and Cummings 2000). Vincent reported no peaks or troughs on Mondays after the transition to DST or the return to standard time (Vincent 1998). Molina et al. only observed an increase in all crashes immediately after the end of the DST in Autumn (Molina et al. 2023).

### The Longer Term Effect

Fourteen studies examined the longer term impact of DST on road safety (Table 2). Two studies reported an increase in accidents and casualties after the Spring transition (Alsousou et al. 2009; Smith 2016); three studies did not report changes associated with DST months in accidents, injuries, and fatalities (Coate and Markowitz 2004; Prats-Uribe et al. 2018; Sullivan and Flannagan 2007). However, factors such as light conditions and the type of road users impacted the results when taken into consideration (Coate and Markowitz 2004; Sullivan and Flannagan 2007). In this regard, although Coate and Markowitz did not report any significant differences in accident rates, they observed an increase in morning pedestrian fatalities when sunrise and sunset were later (Coate and Markowitz 2004). Six studies reported a reduction in accidents during DST months, although the overall magnitude of this effect is difficult to estimate due to the variability of approaches and analyses in such studies (Ferguson et al. 1995; Huang and Levinson 2010; Meyerhoff 1978; Singh et al. 2022; Sood and Ghosh 2007; Zhou and Li

**Table 2.** Summary of the 14 studies on the long-term effects of DST vs standard time on road traffic accidents.

| Authors(year) | Analysis years | Timeframe | Key findings | Population | Sample size |
|---|---|---|---|---|---|
| Abeyrathna et al. (2021) | 2005-2007 | 4 weeks before and 4 weeks after | Animal-vehicle accidents significantly increased after the transition from DST for the first three weeks. Accident rates increased steadily for six weeks before transition and peaked in the second week after | Animal-vehicle accidents | 35167 |
| Alsousou et al. (2009) | 1996-2006 | 4 weeks before and 4 weeks after | Overall, there were more accidents both after transition to/from DST (34%/65%) | Fatal accidents | 282 |
| Coate and Markowitz (2004) | 1998-1999 | 1 month before and 1 month after | Full year DST would reduce all pedestrian fatalities by 13% in the 5:00-10:00 a.m. and 4:00-9:00 p.m. time periods. Motor vehicle occupant fatalities would be reduced by 3% per year. Overall, no difference in fatal accidents | Fatal accidents | 14360 |
| Cunningham et al. (2022) | 1994-2021 | Over the year | Permanent DST would prevent 36 550 deer-vehicle collisions and save $1.2 billion in collision costs annually. Permanent standard time would lead to 74 000 additional deaths annually | Animal-vehicle accidents | 1012465 |
| Ellis et al. (2016) | 2009-2010; 2010-2011 | April to Sept – Oct to March | DST decreased accidents involving koalas by 8% on weekdays and 11% on weekends in the DST months. Implementing DST could prevent many koala deaths each year | Animal-vehicle accidents | 1348 |
| Ferguson et al. (1995) | 1987-1991 | 22 weeks before and 22 weeks after | Reduced pedestrian and vehicle occupant fatalities due to DST implementation. Reported inverse relationship between light level and fatal crashes. Controlled for geographic variation by calculating actual sunrise/sunset times | Fatal accidents | 74811 |
| Huang and Levinson (2010) | 2001-2007 | 8 weeks before and after | Overall DST associated with fewer accidents than standard time in the long run | Motor vehicle accidents | n/a |
| Meyerhoff (1978) | 1973 -1974 | n/a | DST reduces fatal RTAs by approximately 1%, during several weeks after the transition to/from DST | Motor vehicle accidents | n/a |
| Prats-Uribe et al. (2018) | 1990-2014 | Day of the DST and up to 30 days | DST changes associated with lower road safety, with a cost of 1.5 lives every year due to RTAs | Fatal accidents | n/a |
| Singh et al. (2022) | 2005-218 | 3 weeks before and 3 weeks after | DST transitions have a minor positive impact on road accidents and fatalities. The estimated reduction in fatalities is 0.75 per year on average. The estimated reduction in total accidents is 4.73 per year on average | All accidents and fatalities | ~700000 |
| Smith and Austin (2016) | 2002-2011 | n/a | Overall DST increased the fatal vehicle accidents but the results are limited | Fatal accidents | ~40000 |
| Sood and Ghosh (2007) | 1976-2003 | Monday before, Monday of and Mondays after | Having controlled for collision trends within and across years, 8-11% decrease in fatal accidents involving pedestrians and 6-10% decrease for vehicular occupants during DST | Fatal accidents | n/a |
| Sullivan and Flannagan (2007) | 1987–2004; 1991–1999 | 5 weeks before and after | No effect reported, while risk for fatal accidents involving pedestrians, animals and other motor vehicles was increased in low light levels | All accidents | 56266 |
| Zhou and Li (2022) | 2014-2016 | Up to 8 week for the spring time change and up to 4 week for the Autumn time change | Transition to DST led to an 18% reduction in accidents over an eight-week period, while transition from DST resulted in a 6% increase in accidents over a four-week period | All accidents | n/a |

RTAs=road traffic accidents, DST=Daylight Saving Time.

2022). Nevertheless, when accidents involving pedestrians were considered, the decrease clearly tended to be larger for pedestrians than for vehicle occupants (Ferguson et al. 1995; Sood and Ghosh 2007). Moreover, three studies showed a decrease in road traffic accidents involving animals during DST months and an increase during standard time months (Abeyrathna and Langen 2021; Cunningham et al. 2022; Ellis et al. 2016).

Most literature has predominantly relied on actual data to explore the longer term consequences of DST on road traffic safety, assessing a specific time period within a given range of weeks (between 3 and 13 weeks) in the Spring and/or Autumn. However, it is worth mentioning that five studies utilized models developed from real data to estimate the effect as a year-round DST ("long-term effect"), generally as a secondary study aim (Bunnings and Schiele 2021; Coate and Markowitz 2004; Cunningham et al. 2022; Ferguson et al. 1995; Stevens and Lord 2006). Some models considered various relevant factors (e.g. light conditions, state speed limits, seat belt and vehicle inspection regulations, alcohol control policies and weather) but did not account for the longer-term effects of clock shifts and later sunrises and sunsets on sleep patterns. While some of these studies showed a larger reduction in accidents involving pedestrians rather than vehicles with a year-round DST (Coate and Markowitz 2004; Ferguson et al. 1995), others reported that a year-round standard time would reduce motor vehicle accidents and, to a lesser extent, accidents involving pedestrians (Stevens and Lord 2006). Additionally, Bunnings and Schiele compared simulated accident counts under different time regimes, suggesting that road safety is somewhat higher under an all-year DST than under an all-year standard time (Bunnings and Schiele 2021).

Finally, in what is a unique study, Teke and co-authors compared emergency room admissions resulting from road traffic accidents during the two weeks around DST, before and after the implementation of permanent DST in Turkey, reporting no impact on road traffic accidents during these weeks (Teke et al. 2021).

## Are Delayed School Start Times Associated with Longer Sleep Duration in High School Students?

### Characteristics of the Studies

The final database included 42 original papers (Table 3) from different geographical areas: 25 from USA/Canada (Berry et al. 2021; Boergers et al. 2014; Carskadon et al. 1998; Danner and Phillips 2008; Dunster et al. 2018; Fuller and Bastian 2022; Gariépy et al. 2017; Meltzer, Saletin, et al. 2021, Meltzer, Wahlstrom, et al. 2021; Meltzer 2022; Nahmod et al. 2017; Ming et al. 2011; Neuroth et al. 2021; Owens et al. 2010, 2017; Nahmod et al. 2019; Paksarian et al. 2015; Patte et al. 2017, 2019; Peltz et al. 2017; Short et al. 2013; Thacher and Onyper 2016; Wahistrom 2002; Weingart et al. 2021; Widome et al. 2020), 7 from Europe (Alfonsi et al. 2020; Das-Friebel et al. 2020; Evanger et al. 2023; Koscec Bjelajac et al. 2020; Perkinson-Gloor et al. 2013; Vedaa et al. 2012; Winnebeck et al. 2020), 6 from Asia (Borisenkov et al. 2022; Chan et al. 2017, 2018; Kim 2022; Lo et al. 2018; Rhie et al. 2018), three from South America (Alves et al. 2020; De Araújo et al. 2022; Estevan et al. 2022), and one from Oceania (Borlase et al. 2013), published between 1998 and 2023 (median year of publication: 2018). Twenty-two studies were longitudinal, whereas the others were observational (Table 3).

The final database comprised ~ 340000 high school students from grades 9$^{th}$ to 12$^{th}$, age 13–18 y; in 10 studies, grades 6$^{th}$ to 8$^{th}$ were also considered (Borisenkov et al. 2022; Gariépy et al. 2017; Kim 2022; Koscec Bjelajac et al. 2020; Lo et al. 2018; Meltzer et al. 2021, 2022; Owens et al. 2017; Patte et al. 2017; Weingart et al. 2021). The median cumulative population was ~ 1150 participants. When grouping students by population size, five studies (12%) included < 100 students, 12 (29%) 100–500 students, three (7%) 501–1000 students, 14 (31%) 1001–10000 students, and eight (21%) >10000 students (Table 3).

Sleep duration was assessed with questionnaires in most studies ($n = 32$); actigraphy was used in 8 studies, either alone (3 studies) or together with another method (sleep diaries in 3 studies, sleep diaries and melatonin profiles in 1 study, surveys in 1 study); sleep diaries were also used alone in 2 studies and together with surveys in other 2 studies, while 1 study assessed sleep duration with face-to-face interviews and surveys (Table 3). Actigraphy and sleep diaries were used when the population size was smaller, whereas questionnaires/surveys were preferred in studies with a larger population size (Figure 3).

### Main Findings

Despite the large variety of study designs, delayed SSTs were associated with longer sleep duration in 39 out of 42 studies, with a mean±SD sleep time extension of 36 ± 16 min. Both longitudinal and observational studies found an increase in sleep duration with later SSTs. SSTs at baseline varied considerably, from as early as 07:15 h to 09:00 h (mean±SD SST at baseline 07:51 ± 00:27 h), and SST delay also varied, with a mean of 50 ±

**Table 3.** Summary of the 42 studies on the effect of delaying School Start Time (SST) on sleep duration in high school students.

| Authors(year) | Population | Methods | Intervention/Exposure | Outcomes/key findings | Secondary outcomes |
|---|---|---|---|---|---|
| Studies that met the primary outcome – intervention | | | | | |
| Estevan et al. (2022) | grades 9-12 high school students (15) | actigraphy | 60 min SST delay due to irregular SSTs during pandemics | 34 ± 5 min increase in sleep duration | |
| de Araújo et al. (2022) | high school students (48) | actigraphy sleep diaries | 60 min SST delay for 1 week | increase in sleep duration | mental health |
| Winnebeck et al. (2020) | grades 10-12 high school students (65) | actigraphy | 60 min optional SST delay for 9 weeks | 65 min increase in sleep duration | sleep quality |
| Dunster et al. (2018) | grade 10 high school students (100) | actigraphy surveys | 50 min SST delay | 34 min increase in sleep duration | academic performance |
| Vedaa et al. (2012) | grade 10 students (106) | questionnaires reaction time tests | 60 min SST delay on Mondays | 60 min increase in sleep duration on Sunday nights | sleep quality |
| Boergers et al. (2014) | grades 9-12 boarding school students (197) | surveys | 25 min SST delay | 29 min increase in sleep duration | mental health |
| Owens et al. (2010) | grades 9-12 high school students (201) | surveys | 30 min SST delay | 45 min increase in sleep duration | mental health |
| Borlase et al. (2013) | grades 9-12 high school students (212) | surveys | 90 min SST delay | increase in sleep duration | sleep quality |
| Chan et al. (2018) | grade 11 high school students (228) | questionnaires | 60 min SST delay | increase in sleep duration | mental health |
| Lo et al. (2018) | grades 7-10 students (375) | actigraphy sleep diaries | 45 min SST delay | 23.2 min increase in time in bed | mental health |
| Widome et al. (2020) | grades 9-11 high school students (455) | actigraphy | 50 min SST delay | 42 min increase in sleep duration | |
| Meltzer et al. (2022) | grades 6-12 students (1152) | surveys | 50 min SST delay | 31 min increase in sleep duration | sleep quality |
| Chan et al. (2017) | students (1173) | surveys | 15 min SST delay | increase in time in bed | mental health |
| Wahistrom (2002) | grades 9-12 high school students (~1200) | surveys school reports | 85 min SST delay | increase in sleep duration | mental health |
| Kim (2022) | grades 7-12 students (2351) | surveys | 60 min later SST | increase in sleep duration | academic performance |
| Berry et al. (2021) | grades 9-11 high school students (2414) | surveys | 50 min SST delay | increase in sleep duration | sleep quality |
| Owens et al. (2017) | grades 7-12 students (2416) | questionnaires | 50 min SST delay | 30.1 min increase in sleep duration | sleep quality |
| Danner et al. (2008) | grades 9-12 high school students (9966) | questionnaires | 60 min SST delay | increase in sleep duration | car crash |
| Patte et al. (2019) | grades 9-12 high school students (27930) | questionnaires | 10 min SST delay | 23.7 min increase in sleep duration | |
| Meltzer, Wahlstrom, et al. (2021) (2) | grades 6-12 students (~28000) | surveys | 70 min SST delay | 45 min increase in sleep duration | sleep quality |
| Rhie et al. (2018) | grades 9-12 high school students (42517) | surveys | 60 min SST delay | increase in sleep duration | academic performance |
| Fuller et al. (2022) | grades 9-12 high school students (62873) | surveys school reports | 90 min SST delay | 46 min increase in sleep duration | academic performance |
| Studies that met the primary outcome – exposure | | | | | |
| Carskadon et al. (1998) | grades 9-10 high school students (40) | actigraphy sleep diaries melatonin | 65 min SST advance due to transition from 9 to 10 grade | decreased sleep duration and delay in DLMO phase in 10th grade | |
| Alfonsi et al. (2020) | students (51) | sleep diaries | early vs late (≥8:30 a.m.) SST | 34 min increase in sleep duration across the academic year | academic performance |
| Nahmod et al. (2019) | adolescents (383) | actigraphy sleep diaries | very early (<7.30 a.m.) vs early vs late (>8.30 a.m.) SST | 21-34 min increase in sleep duration | |
| Nahmod et al. (2017) | students (413) | sleep diaries | early vs late (>8.30 a.m.) SST | 27-57 min increase in sleep duration | |
| Weingart et al. (2021) | grades 6-12 teens (590) | surveys | irregular SSTs in home-schooling | increase in sleep duration | |
| Short et al. (2013) | grades 9-12 high school students (687) | sleep diaries surveys | earlier vs later SST difference (45 min) | 47 min increase in sleep duration | |
| Ming et al. (2011) | grades 9-12 high school students (1941) | surveys | early vs late SST | earlier SSTs associated with shorter sleep duration | sleep quality |
| Koscec Bjelajac et al. (2020) | grades 6-12 students (2033) | surveys | weekly SST alternation 08:00 a.m./14:00 p.m. | increase in sleep duration in 14:00 a.m. SST | mental health |
| Perkinson-Gloor et al. (2013) | grades 8-9 students (2716) | questionnaires | earlier vs later SST difference (20 min) | increase in sleep duration | mental health |
| Evanger et al. (2023) | grades 10-11 high school students (4010) | surveys | earlier vs later SST (15 min) | increase in sleep duration | circadian preference predictor |
| Meltzer, Saletin, et al. (2021) | students (5245) | surveys | irregular SSTs during pandemics | increase in sleep duration | |

(*Continued*)

**Table 3.** (Continued).

| Authors(year) | Population | Methods | Intervention/Exposure | Outcomes/key findings | Secondary outcomes |
|---|---|---|---|---|---|
| Borisenkov et al. (2022) | grades 6–11 students (6571) | questionnaires | earlier vs later SST difference (60 min) | increase in sleep duration | academic performance |
| Paksarian et al. (2015) | grades 9–12 high school students (7308) | interviews school reports | early vs late SST | increase in sleep duration | |
| Alves et al. (2020) | grades 9–11 high school students (11525) | questionnaires | morning vs afternoon school shifts | increase in sleep duration in afternoon shifts | |
| Gariépy et al. (2017) | grades 6–12 students (29635) | surveys | earlier vs later SST difference (10 min) | 3.2 min increase in sleep duration every 10 min delay in SST | |
| Patte et al. (2017) | grades 9–12 high school students (35821) | surveys | earlier vs later SST difference (60 min) | 7 min increase in sleep duration | health recommendations |
| Neuroth et al. (2021) | grades 9–12 high school students (46537) | surveys | early vs late (≥8:30 a.m.) SST | increase in sleep duration | mental health |
| Studies that did not met the primary outcome | | | | | |
| Peltz et al. (2017) | grades 9–11 high school students (197) | sleep diaries surveys | early (<8.30 a.m.) vs late (≥8:30 a.m.) SST | baseline better sleep hygiene improved mental health | mental health |
| Thacher et al. (2016) | grades 9–12 high school students (410) | surveys school reports | 45 min SST delay | delay in sleep period | academic performance |
| Das-Friebel et al. (2020) | grades 9–12 high school students (663) | surveys | 20 min SST delay | delay in sleep period | |

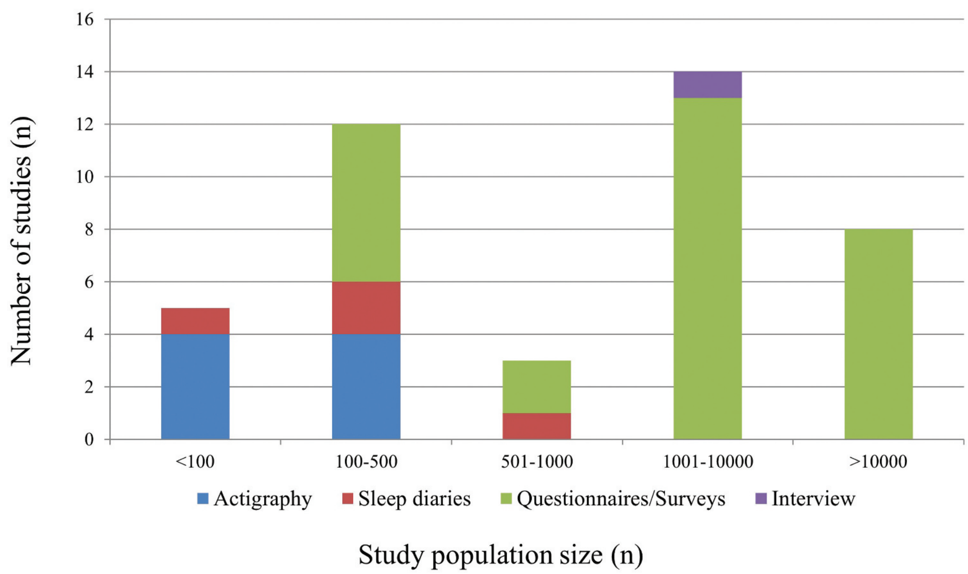


**Figure 3.** Sleep duration measurement methods. Number of studies (out of a total of 42) using actigraphy (blue), sleep diaries (red), questionnaires/surveys (grey) or interviews (violet) as the main method for sleep measurement, grouped by study population size (x-axis). In small population size studies ($n$ = <100), actigraphy and sleep diaries were the preferred method, whereas questionnaires/surveys were preferred in larger studies.

21 min and a median of 60 min (mean±SD SST after the delay: 08:42 ± 00:32 h). Even short delays of 30 min or less resulted in longer sleep duration (Boergers et al. 2014; Chan et al. 2017; Evanger et al. 2023; Gariépy et al. 2017; Neuroth et al. 2021; Owens et al. 2010; Patte et al. 2019; Perkinson-Gloor et al. 2013). The methods, study population and main findings of all studies included are summarized in Table 3, divided by outcome and intervention/exposure. Of interest, Carskadon et al. studied the effect of a 65-min earlier SST in 10$^{th}$ grade compared to the later 9$^{th}$ grade SST in a total 40 students; earlier SST was associated with a decrease in sleep duration, as measured by actigraphy (Carskadon et al. 1998).

Of the 39 studied that met the outcome of prolonging sleep duration, 27 also included and met different secondary outcomes (Table 3), that were positively associated with the main finding: 11 studies showed an improvement in mental health issues (e.g. symptoms of depression/anxiety), eight studies showed an increase in sleep quality, six found an improvement in academic performance, and finally longer sleep duration was associated with circadian preference predictors, general health improvement, and car crash incidence decrease in one study each (Table 3).

Of three studies in which delayed SSTs did not result in longer sleep duration, Das-Friebel et al. analyzed surveys of 663 high school students before and after a 20-min delay of SST: a significant delay in bed and wake up times (but not in sleep duration) was observed; moreover, daytime sleepiness and mood did not improve (Das-Friebel et al. 2020). In Peltz et al., early *versus* late SST did not show a difference in sleep duration in 197 adolescents, using surveys and sleep diaries, although a better sleep hygiene was associated with improvement in mental health in this study (Peltz et al. 2017). Finally, Thacher et al. analyzed a 45 min delay in SST at two follow-up (after six and 12 months) of 410 high school students via surveys, and found that, after a transient longer sleep duration at first follow-up time, this was not confirmed at second follow-up; nevertheless, a significant reduction in daytime sleepiness at both follow up times was recorded (Thacher and Onyper 2016).

## Discussion

### DST and Road Traffic Accidents

Although numerous studies have explored the impact of DST on road safety – mostly the short term impact of transitions to and from DST – findings have been inconsistent, with some studies indicating that clock adjustment can have either a positive or negative influence on road safety, and others documenting no impact. These disparate outcomes may be due to the opposing effects of DST, as previously suggested (Carey and Sarma 2017). Although DST increases ambient light in the late afternoon, when traffic volumes are typically high, thus increasing road safety, it also negatively affects drivers by causing sleep curtailment, which can adversely affect driving ability (Orsini et al. 2022, 2023). Sleep curtailment can be especially problematic for adolescents and young adults, who are also more susceptible to social jet-lag and to high-risk behaviours such as speeding, texting while driving, and substance misuse. The adverse effects of sleep curtailment and circadian misalignment may be more prominent during midwinter's limited daylight hours and midsummer's late sunsets. Consequently, studies conducted over 3–13 weeks during Spring or Autumn transitions could underestimate the longer-term impact of DST on road safety. Moreover, due to the retrospective nature of the studies, it is difficult to isolate the effect of DST *per se*, especially when considering the confounding effects of factors such as traffic volumes, road conditions, weather (and their combination, such as icy stretches), or road users involved. Finally, most of the research conducted thus far has focused on examining the impact of changes between standard time and DST, and on distinguishing between the effects of the Autumn and Spring transitions. Fewer studies have attempted to compare the consequences of DST *versus* standard time in general.

By contrast, the majority of longer term data and models suggested a decrease in road traffic accidents despite the wide range in time frames, ranging from 3 to 13 weeks, although inconsistency remained. Moreover, it is important to note that DST is different from permanent DST. This, which is not necessarily widespread perception, would result in work/school starting long before dawn, depending on geographical location and photoperiod (Antle 2023). In addition, the loss of morning light and late evening light exposure in the summer would result in further circadian delay, making it harder to fall asleep at night and to wake up in the morning. This is most likely the reason why experiments with permanent DST (for example in Russia, the USA, and the United Kingdom) have all been rapidly abandoned (Borisenkov et al. 2017; Gray and Jenkins 2019; UK Time Zone History). Considering this, some theoretical models suggest that maintaining either DST or standard time year-round is preferable to transitioning, even though it is difficult to imagine how to conduct actual research on this to produce meaningful comparisons of the two options. Some information in this respect can be gauged by use of position within a time zone as a surrogate marker of the impact of time adjustment. These types of studies, which we did not include in our assessments, seem to indicate that there are more fatal accidents throughout the year when sunrises/sunsets occur later (Gentry et al. 2022).

Further research is necessary to explore the intricate relationship between DST and road safety, taking into account of variables such as geography (and thus photoperiod), weather, season and population characteristics. Studies from different regions have shown different outcomes, which suggests that local factors, such as latitude, habits, and traffic infrastructure may all play a role, making the effects of DST on road safety difficult to generalize.

The currently available evidence is of low-moderate quality and the results extremely variable. The Delphi panel agreed that no statement or recommendation could be formulated.

### SSTs and Sleep Duration in High School Students

This review demonstrates that delaying SSTs, even for less than 60 min, was associated with an increase in sleep duration in high school students; the evidence was confirmed in different contexts, considering SSTs at baseline, minutes of delay, timeframe of the change in SST, as well as total amount of hours spent at school, extra-school activities, and home-school distance. Most studies considered a set of secondary outcomes, mainly regarding adolescents' mental health issues and academic performance, which were related to sleep duration in these studies, but that could also be consequences of diverse situations, e.g. the use of social media (van den Eijnden et al. 2021). A longer sleep duration has been linked to better sleep quality (Berry et al. 2021; Borlase et al. 2013; Meltzer et al. 2021, 2022; Ming et al. 2011; Owens et al. 2017; Vedaa et al. 2012; Winnebeck et al. 2020), mental health (Boergers et al. 2014; Chan et al. 2017, 2018; De Araújo et al. 2022; Koscec Bjelajac et al. 2020; Lo et al. 2018; Neuroth et al. 2021; Owens et al. 2010; Peltz et al. 2017; Perkinson-Gloor et al. 2013; Wahistrom 2002), and academic performance (Alfonsi et al. 2020; Borisenkov et al. 2022; Dunster et al. 2018; Fuller and Bastian 2022; Kim 2022; Rhie et al. 2018), thus underlining the crucial role of sleep hygiene during adolescence (Berry et al. 2021; Kansagra 2020); this is in line with similar data found in university students (Albqoor and Shaheen 2021; Yeo et al. 2023), teachers (Wahlstrom et al. 2023), and the general population (Chaput et al. 2020). In conclusion, there is evidence to indicate a benefit of delaying SST in high school, even for delays of less than 60 min, and there is a need to raise awareness on the concept of "making time for sleep" for students, especially during school days.

The currently available evidence is of low-moderate quality, but the results are homogeneous. The Delphi panel formulated the following statement: delayed SSTs, as short as 20 minutes, are associated with longer sleep duration in high school students.

## Conclusions

With respect to both subjects and both statements, it is obvious that the lack of randomized controlled trials (RCTs), which represent the best type of evidence in medical terms, is, to an extent and especially in relation to DST, a feasibility issue. The lack of RCTs does not impinge on either the need for formal evaluation of the available evidence, or the usefulness of its actual rating.

Feedback from the workshop participants emphasised the usefulness of discussions based on diverse competence and the involvement of experts with different backgrounds to include, for example, transportation engineering and economics. The literature on DST and road safety is ambiguous, as already mentioned above. Discussions on the impact of delayed SSTs on sleep duration among adolescents were easier and generated a more widely agreed-upon statement. However, factors affecting implementation on any deriving policy (for example a delay in SST) were highlighted, to include parental influence, logistics etc.

Also in relation to implementation, the importance of effective communication as a means to facilitate knowledge exchange, rather than simply disseminating evidence, was underscored. Further, it was highlighted that transparency regarding the limitations in knowledge/evidence and attempts at identifying "winners and losers" of any policy change will also be crucial. Aligning scientific evidence with the objectives of policy-making and considering alliances involving different stakeholders will also help driving change.

Finally, informed and possibly compelling risk/benefit and economic arguments will be essential to help transform scientific findings into effective public health initiatives or changes in policy on a wider scale. In summary, participants felt that the application of methods for evidence assessment borrowed from clinical medicine seems useful to ease collaborations and to identify well-defined and pragmatic research questions within the context of translational Chronobiology.

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## References

Abeyrathna WANU, Langen TA. 2021. Effect of daylight saving time clock shifts on white-tailed deer-vehicle collision rates. J Environ Manag. 292:112774. doi: 10.1016/j.jenvman.2021.112774

Adams J, White M, Heywood P. 2005. Year-round daylight saving and serious or fatal road traffic injuries in children in the north-east of England. J Public Health. 27:316–317. doi: 10.1093/pubmed/fdi047

Afolabi-Brown O, Moore ME, Tapia IE. 2022. Sleep deficiency in adolescents: the school start time debate. Clin Chest Med. 43:239–247. doi: 10.1016/j.ccm.2022.02.008

Albqoor MA, Shaheen AM. 2021. Sleep quality, sleep latency, and sleep duration: a national comparative study of university students in Jordan. Sleep Breath. 25:1147–1154. doi: 10.1007/s11325-020-02188-w

Alfonsi V, Palmizio R, Rubino A, Scarpelli S, Gorgoni M, D'Atri A, Pazzaglia M, Ferrara M, Giuliano S, De

Gennaro L. 2020. The association between school start time and sleep duration, sustained attention, and academic performance. NSS. 12:1161–1172. doi: 10.2147/NSS.S273875

Alsousou J, Jenks T, Bouamra O, Lecky F, Willett K. 2009. Daylight Savings Time (DST) transition: the effect on serious or fatal road traffic collision related injuries. Inj Extra. 40:211–212. doi: 10.1016/j.injury.2009.06.241

Alves FR, De Souza EA, De França Ferreira LG, De Oliveira Vilar Neto J, De Bruin VMS, De Bruin PFC. 2020. Sleep duration and daytime sleepiness in a large sample of Brazilian high school adolescents. Sleep Med. 66:207–215. doi: 10.1016/j.sleep.2019.08.019

Antle MC. 2023. The controversy over daylight saving time: evidence for and against. Curr Opin Pulm Med. 29:574–579. doi: 10.1097/MCP.0000000000001003

Berry KM, Erickson DJ, Berger AT, Wahlstrom K, Iber C, Full KM, Redline S, Widome R. 2021. Association of delaying school start time with sleep–wake behaviors among adolescents. J Adolesc Health. 69:831–837. doi: 10.1016/j.jadohealth.2021.04.030

Boergers J, Gable CJ, Owens JA. 2014. Later school start time is associated with improved sleep and daytime functioning in adolescents. J Dev Behav Pediatr. 35:11–17. doi: 10.1097/DBP.0000000000000018

Borisenkov MF, Popov SV, Smirnov VV, Dorogina OI, Pecherkina AA, Symaniuk EE. 2022. Later school start time is associated with better academic performance, sleep-wake rhythm characteristics, and eating behavior. Chronobiol Int. 39:1444–1453. doi: 10.1080/07420528.2022.2117050

Borisenkov MF, Tserne TA, Panev AS, Kuznetsova ES, Petrova NB, Timonin VD, Kolomeichuk SN, Vinogradova IA, Kovyazina MS, Khokhlov NA, et al. 2017. Seven-year survey of sleep timing in Russian children and adolescents: chronic 1-h forward transition of social clock is associated with increased social jetlag and winter pattern of mood seasonality. Biol Rhythm Res. 48:3–12. doi: 10.1080/09291016.2016.1223778

Borlase BJ, Gander PH, Gibson RH. 2013. Effects of school start times and technology use on teenagers' sleep: 1999–2008: teen sleep: school timimg and technology. Sleep And Biol Rhythms. 11:46–54. doi: 10.1111/sbr.12003

Broughton J, Stone M 1998. A new assessment of the likely effects on road accidents of adopting SDST. TRL REPORT 368 [Internet]. [accessed 2024 Feb 6]. https://trid.trb.org/View/541596

Bruce ES, Lunt L, McDonagh JE. 2017. Sleep in adolescents and young adults. Clin Med. 17:424–428. doi: 10.7861/clinmedicine.17-5-424

Bunnings C, Schiele V. 2021. Spring forward, don't fall back: the effect of daylight saving time on road safety. Rev Econ Stat. 103:165–176. doi: 10.1162/rest_a_00873

Carey RN, Sarma KM. 2017. Impact of daylight saving time on road traffic collision risk: a systematic review. BMJ Open. 7: e014319. doi: 10.1136/bmjopen-2016-014319

Carskadon MA, Wolfson AR, Acebo C, Tzischinsky O, Seifer R. 1998. Adolescent sleep patterns, circadian timing, and sleepiness at a transition to early school days. Sleep. 21:871–881. doi: 10.1093/sleep/21.8.871

Chan CS, Poon CYS, Leung JCY, Lau KNT, Lau EYY. 2018. Delayed school start time is associated with better sleep, daytime functioning, and life satisfaction in residential high-school students ☆. J Adolescence. 66:49–54. doi: 10.1016/j.adolescence.2018.05.002

Chan NY, Zhang J, Mwm Y, Lam SP, Li SX, Kong APS, Li AM, Wing YK. 2017. Impact of a modest delay in school start time in Hong Kong school adolescents. Sleep Med. 30:164–170. doi: 10.1016/j.sleep.2016.09.018

Chaput J-P, Dutil C, Featherstone R, Ross R, Giangregorio L, Saunders TJ, Janssen I, Poitras VJ, Kho ME, Ross-White A, et al. 2020. Sleep duration and health in adults: an overview of systematic reviews. Appl Physiol Nutr Metab. 45:S218–S231. doi: 10.1139/apnm-2020-0034

Coate D, Markowitz S. 2004. The effects of daylight and daylight saving time on US pedestrian fatalities and motor vehicle occupant fatalities. Accid Anal Prev. 36:351–357. doi: 10.1016/S0001-4575(03)00015-0

Colrain IM, Baker FC. 2011. Changes in sleep as a function of adolescent development. Neuropsychol Rev. 21:5–21. doi: 10.1007/s11065-010-9155-5

Coren S. 1996. Daylight savings time and traffic accidents. N Engl J Med. 334:924–925. doi: 10.1056/NEJM199604043341416

Cornberg M, Tacke F, Karlsen TH, European Association for the Study of the Liver. 2019. Clinical practice guidelines of the european association for the study of the liver - advancing methodology but preserving practicability. J Hepatol. 70:5–7. doi: 10.1016/j.jhep.2018.10.011

Cunningham CX, Nuñez TA, Hentati Y, Sullender B, Breen C, Ganz TR, Kreling SES, Shively KA, Reese E, Miles J, et al. 2022. Permanent daylight saving time would reduce deer-vehicle collisions. Curr Biol. 32:4982–4988.e4. doi: 10.1016/j.cub.2022.10.007

Curcio G, Ferrara M, De Gennaro L. 2006. Sleep loss, learning capacity and academic performance. Sleep Med Rev. 10:323–337. doi: 10.1016/j.smrv.2005.11.001

Danner F, Phillips B. 2008. Adolescent sleep, school start times, and teen motor vehicle crashes. J Clin Sleep Med. 4:533–535. doi: 10.5664/jcsm.27345

Das-Friebel A, Gkiouleka A, Grob A, Lemola S. 2020. Effects of a 20 minutes delay in school start time on bed and wake up times, daytime tiredness, behavioral persistence, and positive attitude towards life in adolescents. Sleep Med. 66:103–109. doi: 10.1016/j.sleep.2019.07.025

De Araújo LBG, Bianchin S, Pedrazzoli M, Louzada FM, Beijamini F. 2022. Multiple positive outcomes of a later school starting time for adolescents. Sleep Health. 8:451–457. doi: 10.1016/j.sleh.2022.04.002

Dunster GP, De La Iglesia L, Ben-Hamo M, Nave C, Fleischer JG, Panda S, De La Iglesia HO. 2018. Sleepmore in Seattle: later school start times are associated with more sleep and better performance in high school students. Sci Adv. 4:eaau6200. doi: 10.1126/sciadv.aau6200

Ellis WA, FitzGibbon SI, Barth BJ, Niehaus AC, David GK, Taylor BD, Matsushige H, Melzer A, Bercovitch FB, Carrick F, et al. 2016. Daylight saving time can decrease the frequency of wildlife–vehicle collisions. Biol Lett. 12:20160632.

Estevan I, Tassino B, Vetter C, Silva A. 2022. Challenged by extremely irregular school schedules, Uruguayan adolescents only set their waking time. J Adoles. 94:488–492. doi: 10.1002/jad.12036

Evanger LN, Bjorvatn B, Pallesen S, Hysing M, Sivertsen B, Saxvig IW. 2023. Later school start time is associated with longer school day sleep duration and less social jetlag among Norwegian high school students: results from a large-scale, cross-sectional study. J Sleep Res. 32:e13840. doi: 10.1111/jsr.13840

Ferguson SA, Preusser DF, Lund AK, Zador PL, Ulmer RG. 1995. Daylight saving time and motor vehicle crashes: the reduction in pedestrian and vehicle occupant fatalities. Am J Public Health. 85:92–95. doi: 10.2105/AJPH.85.1.92

Flatley D, Reyner LA, Horne JA. 2004. Sleep-related crashes on sections of different road types in the UK (1995-2001).

Fritz J, VoPham T, Wright KP, Vetter C. 2020. A chronobiological evaluation of the acute effects of daylight saving time on traffic accident risk. Curr Biol. 30:729–735.e2. doi: 10.1016/j.cub.2019.12.045

Fritz J, Wright KP, Vetter C. 2019. 0192 a Re-appraisal of the link between daylight saving time and traffic accidents in the US. Sleep. 42:A78–A79. doi: 10.1093/sleep/zsz067.191

Fuller SC, Bastian KC. 2022. Saved by the bell schedule? The effects of a later school start time on high schoolers in an urban district. Urban Educ. 59:1552–1585. doi: 10.1177/00420859211073889

Gariépy G, Janssen I, Sentenac M, Elgar FJ. 2017. School start time and sleep in Canadian adolescents. J Sleep Res. 26:195–201. doi: 10.1111/jsr.12475

Gentry J, Evaniuck J, Suriyamongkol T, Mali I. 2022. Living in the wrong time zone: elevated risk of traffic fatalities in eccentric time localities. Time Soc. 31:457–479. doi: 10.1177/0961463X221104675

Gray TR, Jenkins JA. 2019. Congress and the political economy of daylight saving time, 1918–1985. Soc Sci Q. 100:1664–1684. doi: 10.1111/ssqu.12656

Harrison Y. 2013. The impact of daylight saving time on sleep and related behaviours. Sleep Med Rev. 17:285–292. doi: 10.1016/j.smrv.2012.10.001

Hicks RA, Lindseth K, Hawkins J. 1983. Daylight saving-time changes increase traffic accidents. Percept Mot Skills. 56:64–66. doi: 10.2466/pms.1983.56.1.64

Howick J 2011. OCEBM levels of evidence working Group*. The Oxford 2011 levels of evidence. Oxford Centre for Evidence-Based Medicine. [Internet]. https://www.cebm.net/wp-content/uploads/2014/06/CEBM-Levels-of-Evidence-2.1.pdf

Huang A, Levinson D. 2010. The effects of daylight saving time on vehicle crashes in Minnesota. J Saf Res. 41:513–520. doi: 10.1016/j.jsr.2010.10.006

Huang X, Lin J, Demner-Fushman D. 2006. Evaluation of PICO as a knowledge representation for clinical questions. AMIA Annu Symp Proc. 2006:359.

James J. 2023. Let there be light: daylight saving time and road traffic collisions. Econ Inq. 61:523–545. doi: 10.1111/ecin.13130

Kansagra S. 2020. Sleep disorders in adolescents. Pediatrics. 145:S204–S209. doi: 10.1542/peds.2019-2056I

Kim T. 2022. The effects of school start time on educational outcomes: evidence from the 9 O'clock attendance policy in South Korea. BE J Econ Anal Policy. 22:439–474. doi: 10.1515/bejeap-2020-0194

Koscec Bjelajac A, Bakotic M, Ross B. 2020. Weekly alternation of morning and afternoon school start times: implications for sleep and daytime functioning of adolescents. Sleep. 43:zsaa030. doi: 10.1093/sleep/zsaa030

Lahti T, Nysten E, Haukka J, Sulander P, Partonen T. 2010. Daylight saving time transitions and road traffic accidents. J Environ Public Health. 2010:657167. doi: 10.1155/2010/657167

Lambe M, Cummings P. 2000. The shift to and from daylight savings time and motor vehicle crashes. Accident Anal Prev. 32:609–611. doi: 10.1016/S0001-4575(99)00088-3

Lo JC, Lee SM, Lee XK, Sasmita K, Niyn C, Tandi J, Cher WS, Gooley JJ, Chee MWL. 2018. Sustained benefits of delaying school start time on adolescent sleep and well-being [Internet]. Sleep. 41. doi: 10.1093/sleep/zsy052.

Martín-Olalla JM, Mira J. 2023. Sample size bias in the empirical assessment of the acute risks associated with daylight saving time transitions. Chronobiol Int. 40:186–191. doi: 10.1080/07420528.2022.2157738

Meltzer LJ, Plog AE, Wahlstrom KL, Strand MJ. 2022. Biology vs. Ecology: a longitudinal examination of sleep, development, and a change in school start times. Sleep Med. 90:176–184. doi: 10.1016/j.sleep.2022.01.003

Meltzer LJ, Saletin JM, Honaker SM, Owens JA, Seixas A, Wahlstrom KL, Wolfson AR, Wong P, Carskadon MA. 2021. COVID-19 instructional approaches (in-person, online, hybrid), school start times, and sleep in over 5,000 U.S. adolescents. Sleep. 44:zsab180. doi: 10.1093/sleep/zsab180

Meltzer LJ, Wahlstrom KL, Plog AE, Strand MJ. 2021. Changing school start times: impact on sleep in primary and secondary school students. Sleep. 44:zsab048. doi: 10.1093/sleep/zsab048

Meyerhoff NJ. 1978. The influence of daylight saving time on motor vehicle fatal traffic accidents. Accident Anal Prev. 10:207–221. doi: 10.1016/0001-4575(78)90012-X

Ming X, Koransky R, Kang V, Buchman S, Sarris CE, Wagner GC. 2011. Sleep insufficiency, sleep health problems and performance in high school students. Clin Med Insights Circ Respir Pulm Med. 5:CCRPM.S7955. doi: 10.4137/CCRPM.S7955

Minges KE, Redeker NS. 2016. Delayed school start times and adolescent sleep: a systematic review of the experimental evidence. Sleep Med Rev. 28:86–95. doi: 10.1016/j.smrv.2015.06.002

Molina JE, Kitali A, Alluri P. 2023. Relationship between daylight saving time and traffic crashes in Florida. Transp Res Rec. 2677:792–802. doi: 10.1177/03611981221108396

Nahmod NG, Lee S, Buxton OM, Chang A-M, Hale L. 2017. High school start times after 8: 30 am are associated with later wake times and longer time in bed among teens in a National Urban Cohort Study. Sleep Health. 3:444–450. doi: 10.1016/j.sleh.2017.09.004

Nahmod NG, Lee S, Master L, Chang A-M, Hale L, Buxton OM. 2019. Later high school start times associated with longer actigraphic sleep duration in adolescents. Sleep [Internet]. 42. doi:10.1093/sleep/zsy212

Nasa P, Jain R, Juneja D. 2021. Delphi methodology in healthcare research: how to decide its appropriateness. World J Methodol. 11:116–129. doi: 10.5662/wjm.v11.i4.116

Neuroth LM, Ma M, Brooks-Russell A, Zhu M. 2021. The relationship of school start times, sleep duration and mental health among a representative sample of high school students in Colorado, 2019. IJERPH. 18:5708. doi: 10.3390/ijerph18115708

Nohl A, Seelmann C, Roenick R, Ohmann T, Lefering R, Brune B, Weichert V, Dudda M, The TraumaRegister DGU. 2021. Impact of DST (daylight saving time) on

major trauma: a European cohort study. Int J Environ Res Public Health. 18:13322. doi: 10.3390/ijerph182413322
Orsini F, Giusti G, Zarantonello L, Costa R, Montagnese S, Rossi R. 2023. Driving fatigue increases after the Spring transition to daylight saving time in young male drivers: a pilot study. Transp Res Part F. 99:83–97. doi: 10.1016/j.trf.2023.10.014
Orsini F, Zarantonello L, Costa R, Rossi R, Montagnese S. 2022. Driving simulator performance worsens after the Spring transition to daylight saving time. iScience. 25:104666. doi: 10.1016/j.isci.2022.104666
Owens JA, Belon K, Moss P. 2010. Impact of delaying school start time on adolescent sleep, mood, and behavior. Arch Pediatr Adolesc Med [Internet]. 164. doi: 10.1001/archpediatrics.2010.96
Owens JA, Dearth-Wesley T, Herman AN, Oakes JM, Whitaker RC. 2017. A quasi-experimental study of the impact of school start time changes on adolescent sleep. Sleep Health. 3:437–443. doi: 10.1016/j.sleh.2017.09.001
Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, Shamseer L, Tetzlaff JM, Akl EA, Brennan SE, et al. 2021. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ. 372:n71. doi: 10.1136/bmj.n71
Paksarian D, Rudolph KE, He J-P, Merikangas KR. 2015. School start time and adolescent sleep patterns: results from the US national comorbidity survey—adolescent supplement. Am J Public Health. 105:1351–1357. doi: 10.2105/AJPH.2015.302619
Patte KA, Cole AG, Qian W, Leatherdale ST. 2017. Youth sleep durations and school start times: a cross-sectional analysis of the COMPASS study. Sleep Health. 3:432–436. doi: 10.1016/j.sleh.2017.07.011
Patte KA, Qian W, Cole AG, Faulkner G, Chaput J-P, Carson V, Leatherdale ST. 2019. School start time changes in the COMPASS study: associations with youth sleep duration, physical activity, and screen time. Sleep Med. 56:16–22. doi: 10.1016/j.sleep.2018.09.020
Peltz JS, Rogge RD, Connolly H, O'Connor TG. 2017. A process-oriented model linking adolescents' sleep hygiene and psychological functioning: the moderating role of school start times. Sleep Health. 3:465–471. doi: 10.1016/j.sleh.2017.08.003
Perkinson-Gloor N, Lemola S, Grob A. 2013. Sleep duration, positive attitude toward life, and academic achievement: the role of daytime tiredness, behavioral persistence, and school start times. J Adoles. 36:311–318. doi: 10.1016/j.adolescence.2012.11.008
Prats-Uribe A, Tobías A, Prieto-Alhambra D. 2018. Excess risk of fatal road traffic accidents on the day of daylight saving time change. Epidemiology. 29:e44–e45. doi: 10.1097/EDE.0000000000000865
Rhie S, Chae KY, Oster H. 2018. Effects of school time on sleep duration and sleepiness in adolescents. Oster H, editor. PLOS ONE. 13:e0203318. doi: 10.1371/journal.pone.0203318
Robb D, Barnes T. 2018. Accident rates and the impact of daylight saving time transitions. Accident Anal Prev. 111:193–201. doi: 10.1016/j.aap.2017.11.029
Short MA, Gradisar M, Lack LC, Wright HR, Dewald JF, Wolfson AR, Carskadon MA. 2013. A cross-cultural comparison of sleep duration between U.S. and Australian adolescents: the effect of school start time parent-set bedtimes, and extracurricular load. Health Educ Behav. 40:323–330. doi: 10.1177/1090198112451266
Singh R, Sood R, Graham DJ. 2022. Road traffic casualties in Great Britain at daylight savings time transitions: a causal regression discontinuity design analysis. BMJ Open. 12: e054678. doi: 10.1136/bmjopen-2021-054678
Smith AC. 2016. Spring forward at your own risk: daylight saving time and fatal vehicle crashes. Am Econ J. 8:65–91. doi: 10.1257/app.20140100
Sood N, Ghosh A. 2007. The short and long run effects of daylight saving time on fatal automobile crashes [Internet]. BE J Econ Anal Policy. 7. doi: 10.2202/1935-1682.1618.
Stevens CR, Lord D. 2006. Evaluating safety effects of daylight savings time on fatal and nonfatal injury crashes in Texas. Transp Res Rec. 1953:147–155. doi: 10.1177/0361198106195300117
Sullivan JM, Flannagan MJ. 2007. Determining the potential safety benefit of improved lighting in three pedestrian crash scenarios. Accid Anal Prev. 39:638–647. doi: 10.1016/j.aap.2006.10.010
Teke C, Kurtoğlu ÇG, Yıldırım Ç, Şener A, Tanrıverdi F, Kahraman FA, Gökhan Ş. 2021. Assessment of the number of admissions for road traffic collisions and severity of injury in daylight saving time and permanent daylight saving time periods. Int J Clin Pract. 75:e14798. doi: 10.1111/ijcp.14798
Thacher PV, Onyper SV. 2016. Longitudinal outcomes of start time delay on sleep, behavior, and achievement in high school. Sleep. 39:271–281. doi: 10.5665/sleep.5426
UK Time Zone History. [accessed 2024 Aug 9]. https://www.timeanddate.com/time/uk/time-zone-background.html
van den Eijnden RJJM, Geurts SM, Ter Bogt Tfm, van der Rijst VG, Koning IM. 2021. Social media use and adolescents' sleep: a longitudinal study on the protective role of parental rules regarding internet use before sleep. Int J Environ Res Public Health. 18:1346. doi: 10.3390/ijerph18031346
Varughese J, Allen RP. 2001. Fatal accidents following changes in daylight savings time: the American experience. Sleep Med. 2:31–36. doi: 10.1016/s1389-9457(00)00032-0
Vedaa Ø, West Saxvig I, Wilhelmsen-Langeland A, Bjorvatn B, Pallesen S. 2012. School start time, sleepiness and functioning in Norwegian adolescents. Scand J Educ Res. 56:55–67. doi: 10.1080/00313831.2011.567396
Vincent A. 1998. Effects of daylight savings time on collision rates. N Engl J Med. 339:1167–1168. doi: 10.1056/NEJM199810153391617
Wahistrom K. 2002. Changing times: findings from the first longitudinal study of later high school start times. NASSP Bull. 86:3–21. doi: 10.1177/019263650208663302
Wahlstrom KL, Plog AE, McNally J, Meltzer LJ. 2023. Impact of changing school start times on teacher sleep health and daytime functioning. J Sch Health. 93:128–134. doi: 10.1111/josh.13254
Weingart R, Bryan C, Olson D, Gazmararian J, Rosati B, Hale L, Gilder MV. 2021. Adolescent sleep duration and timing during early COVID-19 school closures. Sleep Health. 7:543–547. doi: 10.1016/j.sleh.2021.07.003
Whittaker JD. 1996. An investigation into the effects of British summer time on road traffic accident casualties in Cheshire. J Accid Emerg Med. 13:189–192. doi: 10.1136/emj.13.3.189

Widome R, Berger AT, Iber C, Wahlstrom K, Laska MN, Kilian G, Redline S, Erickson DJ. 2020. Association of delaying school start time with sleep duration, timing, and quality among adolescents. JAMA Pediatr. 174:697. doi: 10.1001/jamapediatrics.2020.0344

Winnebeck EC, Vuori-Brodowski MT, Biller AM, Molenda C, Fischer D, Zerbini G, Roenneberg T. 2020. Later school start times in a flexible system improve teenage sleep. Sleep. 43:zsz307. doi: 10.1093/sleep/zsz307

Yeo SC, Lai CKY, Tan J, Lim S, Chandramoghan Y, Tan TK, Gooley JJ. 2023. Early morning university classes are associated with impaired sleep and academic performance. Nat Hum Behav. 7:502–514. doi: 10.1038/s41562-023-01531-x

Zhou R, Li Y. 2022. Traffic crash changes following transitions between daylight saving time and standard time in the United States: new evidence for public policy making. J Saf Res. 83:119–127. doi: 10.1016/j.jsr.2022.08.009