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All cause and cause specific mortality associated with transition to daylight saving time in US: nationwide, time series, observational study

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ABSTRACT

OBJECTIVES To estimate the association between the transition to daylight saving time and the risks of all cause and cause specific mortality in the US.

DESIGN Nationwide time series observational study based on weekly data.

SETTING US state level mortality data from the National Center for Health Statistics, with death counts from 50 US states and the District of Columbia, from the start of 2015 to the end of 2019.

POPULATION 13 912 837 reported deaths in the US.

MAIN OUTCOME MEASURES Weekly counts of mortality for any cause, and for Alzheimer's disease, dementia, circulatory diseases, malignant neoplasms, and respiratory diseases.

RESULTS During the study period, 13 912 837 deaths were reported. The analysis found no evidence of an association between the transition to spring daylight saving time (when clocks are set forward by one hour on the second Sunday of March) and the risk of all cause mortality during the first eight weeks after the transition (rate ratio 1.003, 95% confidence interval 0.987 to 1.020). Autumn daylight saving time is defined in this study as the time when the clocks are set back by one hour (ie, return to standard time) on the first Sunday of November. Evidence indicating a substantial decrease in the risk of all cause mortality during the first eight weeks after the transition to autumn daylight saving time (0.974, 0.958 to 0.990). Overall, when considering the transition to both spring and autumn daylight saving time, no evidence of any effect of daylight saving time on all cause mortality was found (0.988, 0.972 to 1.005). These patterns of changes in mortality rates associated with transition to daylight saving time were consistent for Alzheimer's disease, dementia, circulatory diseases, malignant neoplasms, and respiratory diseases. The protective effect of the transition to autumn daylight saving time on the risk of mortality was more pronounced in elderly people aged ≥75 years, in the non-Hispanic white population, and in those residing in the eastern time zone.

CONCLUSIONS In this study, transition to daylight saving time was found to affect mortality patterns in the US, but an association with additional deaths overall was not found. These findings might inform the ongoing debate on the policy of shifting daylight saving time.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Several international scientific communities have expressed concerns about the adverse effects of transition to daylight saving time on health, and called for an end to daylight saving time

⇒ Less is known about the adverse health effects of transition to daylight saving time from population level studies, particularly the risks of different causes of mortality associated with transitions in the general population

WHAT THIS STUDY ADDS

⇒ In this nationwide study in the US, transition to spring daylight saving time was associated with a slight but non-significant increase in all cause mortality during the first eight weeks after the transition, but the transition to autumn daylight saving time was associated with a substantial decrease in all cause mortality for the first eight weeks after the transition

⇒ Among the top five causes of death, transition to autumn daylight saving time was associated with weak but substantial decreases in mortality for dementia, circulatory diseases, malignant neoplasms, and respiratory diseases, but not for Alzheimer's disease

⇒ Substantial decreases in mortality risks after transition to autumn daylight saving time were more pronounced in elderly people aged ≥75 years, in the non-Hispanic white population, and in those residing in the eastern time zone

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE, OR POLICY

⇒ The results of this study might contribute to the discussion on the policy of shifting daylight saving time

⇒ More research based on daily cause specific mortality data are needed to further examine the changes in mortality risks associated with transition to daylight saving time

Introduction

The transition to daylight saving time is a biannual time change policy and is common in mid-latitude and high-latitude countries, which cover more than 1.5 billion people globally.[1] Daylight saving time was officially implemented in the US in 1966 under the uniform time act of 1966. According to the time shifting policy for daylight saving time in the US, the clock is set forward by one hour on the second Sunday of March (ie, spring daylight saving time) and set back by one hour (ie, return to standard time) on the first Sunday of November (in this paper, referred to throughout as autumn daylight saving time). The policy of daylight saving time involves almost all populations in the US, except for the states of Arizona and Hawaii where daylight saving time was

SZ and WC contributed equally

not implemented, and lasts for 34 weeks, about 65% of the whole year.

More studies are emerging on the adverse effects of daylight saving time. The one hour time shift from standard time to daylight saving time in the spring means less exposure to morning light but more exposure to evening light, which might result in sleep loss[2 3] and daytime sleepiness.[4] Transition to spring daylight saving time was found to be associated with increased risks of cardiovascular diseases,[5] including the onset and clinical severity of myocardial infarction,[1 6–10] ischaemic stroke,[11 12] and hospital admission for atrial fibrillation,[13] as well as risks of unintentional injuries,[14–17] mood disturbances,[18] and suicide.[19 20] Circadian rhythm is essential for wellbeing, regulating numerous biological processes, including immune responses, oxidative stress, and inflammation. Biologically, daylight saving time could adversely affect human health by alternating the timing of the circadian biological clock, hence causing misalignment between the circadian clock and the sleep-wake cycle,[21] leading to substantial acute and chronic public health and safety risks,[1 22 23] particularly after the transition to spring daylight saving time.[6]

Motivated by evidence supporting the adverse effects of transition to daylight saving time on public health, several international scientific communities called for the discontinuation of daylight saving time and return to permanent standard time.[24–27] As of 2023, this dramatic policy change from a seasonal shift in daylight saving time to permanent standard time was still under debate among various scientific, public, and political communities. Evidence from population level studies is lacking, however, particularly on the risks of different causes of mortality associated with transition among the general population.[28]

In this study, our aim was to investigate the relation between transition to daylight saving time and the risks of all cause and cause specific mortality among more than 13 million deaths in the US, from 2015 to 2019. We also performed subgroup analyses to identify subpopulations that were vulnerable to shifts in daylight saving time by time zones, age, and race and ethnic group. The results of these risk assessments might provide insights into the effects of transition to daylight saving time on mortality at a population scale, which is important for healthcare professionals and decision makers to inform the ongoing debate on the policy of daylight saving time.

Methods

Mortality data

We obtained state level mortality data from the National Center for Health Statistics, which had aggregated death counts on a weekly basis from 50 US states and the District of Columbia, from the start of 2015 to the end of 2019.[29] Causes of death were identified according to ICD-10 codes (international classification of diseases, 10th revision), including Alzheimer's disease (G30), dementia (F00-F03), circulatory diseases (I00-I09, I11, I13, I20-I51, I60-I69), malignant neoplasms (C00-C97), and respiratory diseases (J00-J06, J10-J18, J30-J39, J40-J47, J67, J70-J98). These conditions were the top five causes of death in the original dataset of the National Center for Health Statistics. The mortality data were grouped by age, and by race and ethnic group. This observational study used secondary aggregated data that were publicly available and thus the study was exempt from ethical approval.

To calculate mortality rates, we obtained data from the US Census Bureau for the mid-year annual population size by age, and by race and ethnic group, for each state, from 2014 to 2020.[30] We converted the annual data to weekly data by linear interpolation, where we included data from 2014 and 2020 as the boundary conditions for implementing linear interpolation. Mortality and population data were grouped into six age groups (<25, 25-44, 45-64, 65-74, 75-84, and ≥85 years) and five race and ethnic groups (Hispanic, non-Hispanic Asian, non-Hispanic black, non-Hispanic white, and other race and ethnic groups).

Daylight saving time

Since the official implementation in the US in 1966, two daylight saving time shifting dates were applied to 48 states and the District of Columbia (excluding the states of Arizona and Hawaii), on the second Sunday of March (in the 10th or 11th epidemiological week) and the first Sunday of November (in the 44th or 45th epidemiological week). We considered the periods of interest as eight weeks after the shifting dates for transitions to both spring and autumn daylight saving time (0-7 weeks after either spring or autumn daylight saving time). Apart from these 16 weeks, the rest of the year was considered the control period. The period of interest (0-7 weeks after either spring or autumn daylight saving time) was selected among different periods, ranging from 0-2 weeks to 0-10 weeks, and 0-7 weeks was the longest duration among those with a significant (adjusted P value <0.05) effect size (online supplemental table S32).

Meteorological variables and air pollution assessment

Daily ambient air pollution and meteorological data were obtained from the US Environmental Protection Agency's Air Quality System, including fine particulate matter ($PM_{2.5}$), ozone, ambient temperature, relative humidity, and wind speed.[31] Based on these daily data, we calculated the state level weekly average data for these air pollutants and meteorological variables by taking an average of all monitoring stations within each state and by each week. Online

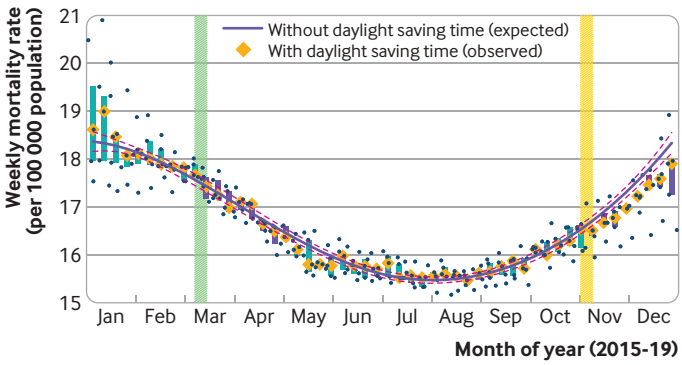

Figure 1 | Observed and expected weekly all cause mortality rates in the US by calendar month, divided annually for the dataset 2015-19. Circle symbols show the observed mortality rate of each epidemiological week, 2015-19, and diamond symbols show the median observed mortality rate from the observations in the same epidemiological weeks of different calendar years. Vertical bond bars (cyan or purple) are interquartile range of observed mortality rates in the same epidemiological weeks of different calendar years. Purple bars indicate the period of 0-7 weeks after spring or autumn daylight saving time, whereas cyan bars are for the other weeks (as the reference period); starting times in March (green bar) and November (yellow bar) are indicated. In this study, spring daylight saving time is the time when the clocks are set forward by one hour on the second Sunday of March and autumn daylight saving time is the time when the clocks are set back by one hour (ie, return to standard time) on the first Sunday of November. Curves are mean estimate and 95% confidence interval of the fitted baseline mortality rate from the unadjusted Poisson regression model

supplemental appendix section S1 describes the data and variables used in this study.

Statistical analyses

To account for the overdispersion feature, which occurs when count data contain a relatively large heterogeneity, weekly death counts were analysed with fixed effects negative binomial log linear regression models with the natural logarithm of population size as an offset (online supplemental appendix section S2).[32] The associations between the weeks after transition to daylight saving time and mortality risks were examined while accounting for long term trends, seasonality, federal holidays, ambient temperature, relative humidity, wind speed, $PM_{2.5}$, and ozone. The potential non-linear associations between meteorological factors and mortality were considered by using spline functions with the degree of freedom selected according to the Akaike information criterion score.[33 34]

We expressed the results of the study in terms of both relative risk and absolute risk. Relative risk was measured by the mortality rate ratio. Absolute risk was measured by the absolute excess mortality rate associated with the weeks after transition to daylight saving time, and was defined as $\alpha\times(1-1/\text{rate ratio})$,[35] where α=weekly mortality rate for a particular epidemiological week, cause of death, and population subgroup. Under the likelihood based statistical inference framework, the statistical uncertainty of model estimates was assessed by constructing the 95% confidence interval and Benjamini-Hochberg adjusted P values from Wald's tests. We reported both week specific and aggregated estimates of relative risk and absolute excess mortality rate for the period 0-7 weeks after transition to daylight saving time. The aggregated estimates were calculated as the pooled effect size with all week specific estimates (16 weeks, including 0-7 weeks after transition to spring or autumn daylight saving time), which could be interpreted as an average association between daylight saving time and mortality during the period 0-7 weeks after spring or autumn daylight saving time.

To explore spatial heterogenicity and differences in personal characteristics for transition to daylight saving time on the risk of mortality, we conducted subgroup analyses with different fixed effect regression models but the same model complexity (as the main analysis), separately for different subgroups of data, according to cause of death, time zone, age, and race and ethnic group. To assess the robustness of our findings, we carried out a series of sensitivity analyses under various model settings of adjustments of covariables. These adjustments included changing the model flexibility for long-term trends, seasonality, and confounding adjustments for variables. For partial data, we excluded deaths in the weeks after daylight saving time for model fitting. Online supplemental appendix section S3 has the details of the subgroup and sensitivity analyses.

As a negative control, for comparison, we also repeated our main analysis for regions where transitions to daylight saving time were not implemented, including the state of Hawaii and most regions in the state of Arizona. All statistical

analyses were performed with R statistical software (version 4.2.1).[36] Results were considered significant when the Benjamini-Hochberg adjusted P value was <0.05.

Patient and public involvement

Because this study used deidentified mortality data, which cannot be used to identify individuals, no patient or member of the public was involved in implementing the study design. Public data (released by the US government) were used in this study, and thus patients and the public were not involved in the research. We have no plans to disseminate the results of the research directly to study participants.

Results

We included 13 912 837 reported deaths in the US from 2015 to 2019. With an increasing trend, the crude all cause mortality rate ranged from 850.8 per 100 000 person years (2 701 797 of the population size of 317.5 million) in 2015 to 874.0 per 100 000 person years (2 845 957 of the population size of 325.6 million) in 2019. Among all 13 912 837 deaths, 4 271 598 (30.7%) people died with the underlying causes of circulatory diseases, followed by malignant neoplasms (21.4%), respiratory diseases (9.9%), and Alzheimer's disease and dementia (9.3%).

The weekly mortality rates showed seasonal trends, with an increasing trend in spring and a decreasing trend in autumn (figure 1). Compared with the expected seasonal trends, we found an apparent decrease in the all cause mortality rate after transition to autumn daylight saving time from early November to late December, whereas a slight but not significant increase was noted for the transition to spring daylight saving time.

We found a slight but non-significant increase in all cause mortality associated with the transition to spring daylight saving time, with an average rate ratio of 1.003 (95% confidence interval 0.987 to 1.020) for 0-7 weeks after the transition to daylight saving time (figure 2 and online supplemental table S1). In contrast, the transition to autumn daylight saving time was associated with a decrease in all cause mortality, with an average rate ratio of 0.974 (0.958 to 0.990) for 0-7 weeks after transition to daylight saving time, corresponding to 0.384 (0.086 to 0.688) deaths per 100 000 person weeks, or about 10 000 deaths in the US annually (table 1). We consistently found a decreased mortality rate for all eight weeks after transition to autumn daylight saving time (table 1). Combining the effects of transition to both spring and autumn daylight saving time, we found no evidence of any association for the shift to and from daylight saving time.

Consistent with all cause mortality, the transition to spring daylight saving time was also associated with a slight but non-significant increase in mortality from dementia, circulatory diseases, malignant neoplasms, respiratory diseases, and Alzheimer's disease over 0-7 weeks (figure 2). Slight increases in the risk of mortality in some of the weeks after spring daylight saving time were significant for dementia and malignant neoplasms (online supplemental tables S2–S6). Autumn daylight saving time was consistently associated with a decrease in the risk of mortality, with the rate ratio ranging from 0.934 to 0.980 for dementia, circulatory diseases, malignant neoplasms, and respiratory diseases, but not for Alzheimer's disease (table 1). We found that the mortality risk of respiratory diseases had a relatively large reduction in terms of rate ratio (0.934, 95% confidence interval 0.891 to 0.978) associated with autumn daylight saving time, which suggested a mortality rate reduction of 0.87 deaths per 100 000 person years. In contrast, the effect of autumn daylight saving time was weak for malignant neoplasms which were associated with a 2% reduction in cancer mortality.

We found spatial heterogeneity for the change in mortality risks associated with the transition to daylight saving time across six different time zones in the US. Among the four major time zones in continental US, mortality risks decreased substantially after autumn daylight saving time in the eastern and Pacific time zones, but no significant change was detected in central, or mountain time zones (figure 3). A relatively large reduction in the risk of mortality after autumn daylight saving time was detected in the eastern time zone, with a rate ratio of 0.970 (95% confidence interval 0.951 to 0.989), and a reduction of 3.74 deaths per 100 000 person years (online supplemental tables S7–S13). The Hawaii time zone was used as a negative control because daylight saving time was not implemented in Hawaii. We detected no effects associated with spring or autumn daylight saving time in Hawaii (online supplemental table S13). Similarly, daylight saving time was not implemented in most regions in the state of Arizona, and we found no evidence of any difference between observed and expected mortality rates (online supplemental figure S6).

The change in mortality risks after daylight saving time varied across different age groups and different race and ethnic groups. We found that rate ratio estimates for autumn daylight saving time decreased significantly (P<0.001 for trend) as age increased, from 1.014 (95% confidence interval 0.976 to 1.054) among the population aged >25 years, to 0.965 (0.941 to 0.990) among those aged ≥85 years (figure 4). Mortality rates in the 75-84 and ≥85 year age groups reduced by 18.4 and 77.8 deaths per 100 000 persons annually, respectively, during the 0-7 weeks after the transition to autumn daylight saving time. Most of the weekly specific rate ratios after transition to autumn

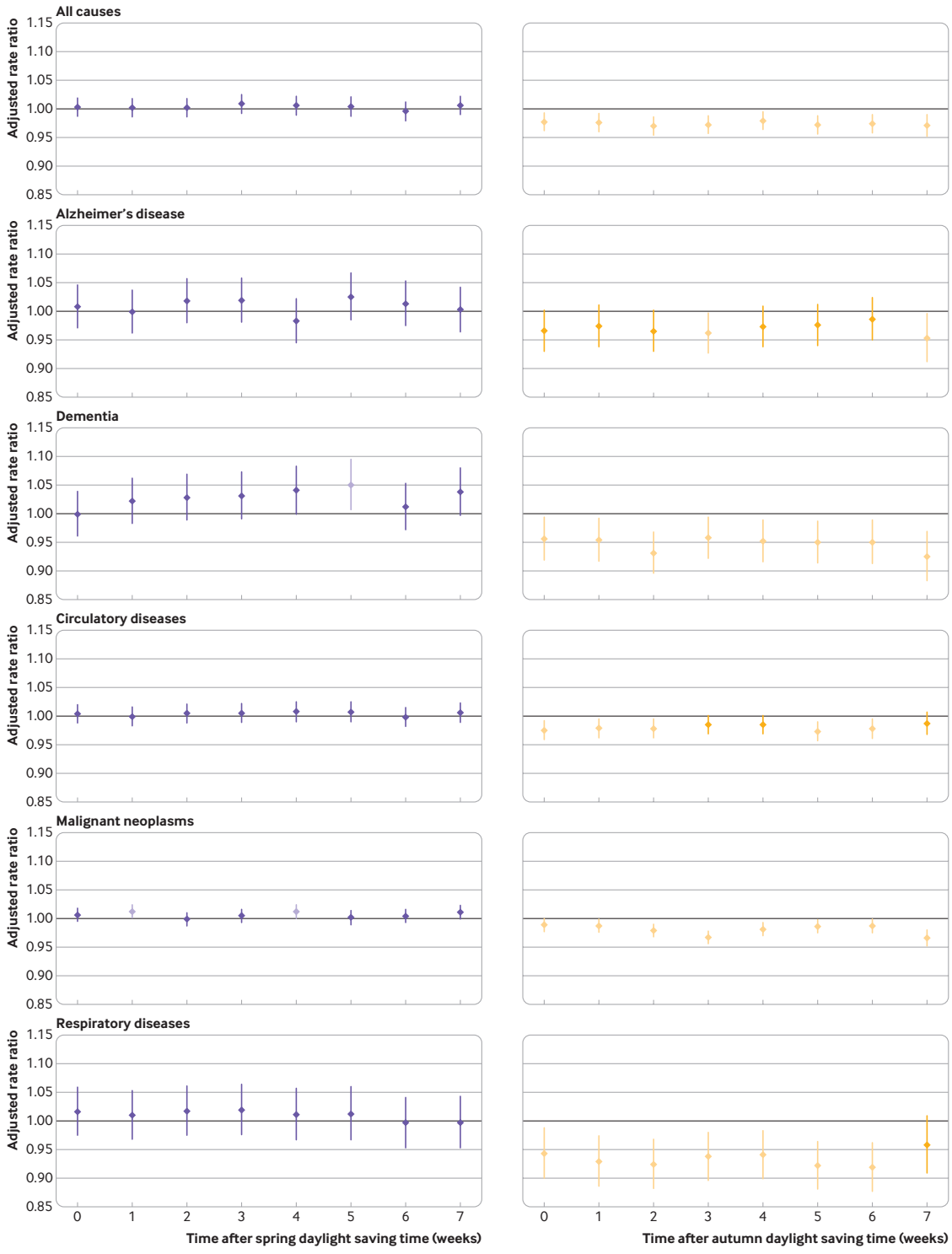

Figure 2 | Adjusted rate ratio estimates of mortality in the US associated with the transition to spring or autumn daylight saving time, grouped by underlying cause of death: all causes, Alzheimer's disease, dementia, circulatory diseases, malignant neoplasms, and respiratory diseases. Threshold of adjusted rate ratio=1 is indicated by the horizontal line. Significance is indicated by lighter coloured symbols (light purple for weeks after spring daylight saving time and light yellow for weeks after autumn daylight saving time), according to unadjusted P values <0.05 (ie, without Benjamini-Hochberg adjustment for false discovery rate). In this study, spring daylight saving time is the time when the clocks are set forward by one hour on the second Sunday of March and autumn daylight saving time is the time when the clocks are set back by one hour (ie, return to standard time) on the first Sunday of November

Table 1 | Summary of observed and estimated mortality rate, and adjusted rate ratio, pooled for 0-7 weeks after daylight saving time, by cause of death

Cause of death and daylight saving time	Weekly mortality rate per 100 000 population			Rate ratio (95% CI)		P value for adjusted rate ratio*
	Observed	Baseline	Difference (95% CI)	Crude	Adjusted	
All cause mortality 0-7 weeks after daylight saving time:						
Spring	16.90	16.94	−0.039 (−0.287 to 0.204)	0.998 (0.980 to 1.015)	1.003 (0.987 to 1.020)	0.71
Autumn	17.08	17.46	−0.384 (−0.688 to −0.086)	0.978 (0.961 to 0.996)	0.974 (0.958 to 0.990)	0.004
Either spring or autumn	16.99	17.20	−0.212 (−0.487 to 0.059)	0.988 (0.971 to 1.005)	0.988 (0.972 to 1.005)	0.06
Alzheimer's disease 0-7 weeks after daylight saving time:						
Spring	0.71	0.70	0.004 (−0.019 to 0.025)	1.005 (0.967 to 1.044)	1.009 (0.971 to 1.048)	0.60
Autumn	0.76	0.78	−0.023 (−0.051 to 0.005)	0.971 (0.935 to 1.009)	0.969 (0.933 to 1.007)	0.21
Either spring or autumn	0.73	0.74	−0.009 (−0.035 to 0.015)	0.988 (0.951 to 1.026)	0.989 (0.952 to 1.027)	0.36
Dementia 0-7 weeks after daylight saving time:						
Spring	0.85	0.84	0.009 (−0.021 to 0.038)	1.010 (0.967 to 1.054)	1.028 (0.987 to 1.069)	0.18
Autumn	0.90	0.93	−0.038 (−0.077 to −0.001)	0.960 (0.919 to 1.002)	0.947 (0.910 to 0.985)	0.02
Either spring or autumn	0.87	0.89	−0.014 (−0.049 to 0.019)	0.985 (0.943 to 1.028)	0.986 (0.948 to 1.026)	0.05
Circulatory diseases 0-7 weeks after daylight saving time:						
Spring	5.21	5.22	−0.009 (−0.091 to 0.071)	0.998 (0.980 to 1.017)	1.004 (0.987 to 1.021)	0.69
Autumn	5.31	5.38	−0.073 (−0.172 to 0.024)	0.987 (0.968 to 1.005)	0.980 (0.963 to 0.997)	0.03
Either spring or autumn	5.26	5.30	−0.041 (−0.132 to 0.048)	0.992 (0.974 to 1.011)	0.992 (0.975 to 1.009)	0.15
Malignant neoplasms 0-7 weeks after daylight saving time:						
Spring	3.56	3.55	0.010 (−0.024 to 0.045)	1.003 (0.991 to 1.015)	1.006 (0.995 to 1.018)	0.28
Autumn	3.58	3.65	−0.070 (−0.110 to −0.030)	0.981 (0.969 to 0.993)	0.980 (0.969 to 0.992)	0.003
Either spring or autumn	3.57	3.60	−0.030 (−0.067 to 0.008)	0.992 (0.980 to 1.004)	0.993 (0.981 to 1.005)	0.03
Respiratory diseases 0-7 weeks after daylight saving time:						
Spring	1.79	1.79	−0.001 (−0.068 to 0.064)	0.999 (0.955 to 1.044)	1.010 (0.967 to 1.055)	0.69
Autumn	1.64	1.75	−0.109 (−0.190 to −0.031)	0.938 (0.894 to 0.984)	0.934 (0.891 to 0.978)	0.01
Either spring or autumn	1.72	1.77	−0.055 (−0.129 to 0.016)	0.968 (0.924 to 1.013)	0.971 (0.928 to 1.016)	0.09

CI=confidence interval.

In this study, spring daylight saving time is the time when the clocks are set forward by one hour on the second Sunday of March and autumn daylight saving time is the time when the clocks are set back by one hour (ie, return to standard time) on the first Sunday of November.

*Adjusted P value calculated from two tailed Wald's test with the adjustment based on the Benjamini-Hochberg procedure for controlling false discovery rate.

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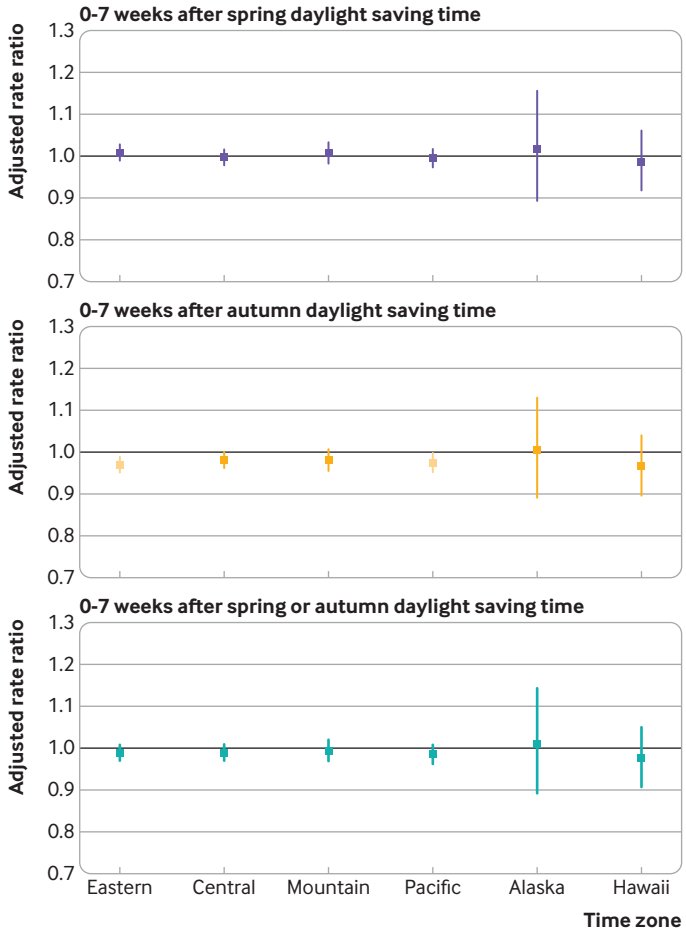

Figure 3 | Adjusted rate ratio estimates of mortality in the US according to spring or autumn daylight saving time, by time zone. Pooled estimates for 0-7 weeks after spring and autumn daylight saving time, and aggregated estimates (spring or autumn daylight saving time) are shown. In this study, spring daylight saving time is the time when the clocks are set forward by one hour on the second Sunday of March and autumn daylight saving time is the time when the clocks are set back by one hour (ie, return to standard time) on the first Sunday of November. Threshold of adjusted rate ratio=1 is indicated by the bond horizontal line. Significance is indicated by lighter coloured symbols (light yellow for weeks after autumn daylight saving time), according to unadjusted P values <0.05 (ie, without Benjamini-Hochberg adjustment for false discovery rate)

daylight saving time, however, were in the direction of effect but were not significant for any age groups (online supplemental tables S14–S20). For different race and ethnic groups, a substantial decrease in mortality risks was found in the non-Hispanic white population, with a rate ratio of 0.969 (95% confidence interval 0.952 to 0.987) (figure 5 and online supplemental tables S21–S26), which also had the highest mortality rate of 1094.4 per 100 000 person years for 2015 and 2019, among all race and ethnic groups.

In most subgroup analyses, the risk of mortality after spring daylight saving time increased slightly, but the increase was not significant. Mortality risk after autumn daylight saving time decreased substantially across a range of causes of death. By examining the overall change in mortality risk during the 16 weeks after transition to daylight saving time, the rate ratio of mortality was towards negative but associations were not significant after spring or autumn daylight saving time. Thus we detected no evidence of an overall change in the risk of mortality associated with two transitions to daylight saving time for any of the subgroups (ie, cause of death, time zone, age, or race and ethnic group). Our results were validated by sensitivity analyses with multiple variations of model settings (online supplemental figures S1–S5). We found that the mortality risk estimates were generally consistent and robust with different model settings (online supplemental tables S27–S31 and online supplemental appendix section S4.5).

Discussion

Principal findings

We investigated the relation between transition to daylight saving time and all cause and cause specific mortality in the US, based on a nationwide dataset. The dataset used in this study had nearly 14 million reported deaths across different states, ages, and

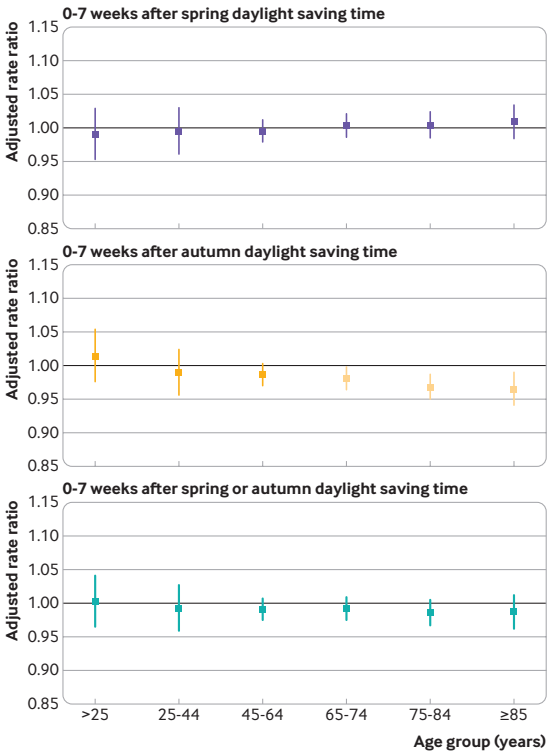

Figure 4 | Adjusted rate ratio estimates of mortality in the US, by age group. Pooled estimates for 0-7 weeks after spring and autumn daylight saving time, and aggregated estimates (spring or autumn daylight saving time) are shown. In this study, spring daylight saving time is the time when the clocks are set forward by one hour on the second Sunday of March and autumn daylight saving time is the time when the clocks are set back by one hour (ie, return to standard time) on the first Sunday of November. Threshold of adjusted rate ratio=1 is indicated by the bond horizontal line. Significance is indicated by lighter coloured symbols (light yellow for weeks after autumn daylight saving time), according to unadjusted P values <0.05 (ie, without Benjamini-Hochberg adjustment for false discovery rate)

race and ethnic groups, over a five year period (2015-19). Our results suggested a slight but non-significant increase in mortality after spring daylight saving time, but a substantial decrease in mortality after autumn daylight saving time. Although the increase in mortality after spring daylight saving time was not significant, similar positive associations were reported in the literature for a range of severe medical conditions.[8 13] The non-significant rate ratio estimates after spring daylight saving time were likely because of low time resolution (ie, weekly rather than daily data). In addition, we found a substantial decrease in mortality after autumn daylight saving time for different causes of death. The protective effect of the transition to autumn daylight saving time on the risk of mortality was more pronounced in elderly people aged ≥75 years, in the non-Hispanic white population, and in those residing in the eastern time zone.

Comparison with other studies

We found a substantial decrease in mortality after autumn daylight saving time for different causes of death. This finding seems to be consistent with the literature that assumed that switching back to standard time in autumn could have no effect,[1 8 10] or a protective effect against diseases, unintentional injuries, and mortality.[6 14 16 22 37] Moreover, we found that the combined effect of transitions to both spring and autumn daylight saving time was a decrease in the risk of mortality but the decrease was not significant. Similar to a previous study that investigated general mortality risks after daylight saving time in 16 European countries,[28] our finding was also in contrast with the general scientific postulate in the daylight saving time literature that minimal sleep deprivation might lead to an increase in the risk of mortality.[8 20 38]

We investigated changes in mortality during a relatively long period, up to eight weeks after the transition to daylight saving time. Although not univocally stated, changes in the risk of adverse health conditions was suggested to be greatest on the transition day (Sunday) and the following days within one week. Few studies, however, have investigated the health consequences after a minimal shift in circadian rhythm (eg, daylight saving time) compared with a relatively long term shift. The effects of daylight saving time might be shortlasting for cardiovascular diseases,[1 8 11] and we also reported a generally decreasing trend in the rate ratio for mortality from circulatory diseases as the weeks increased after autumn daylight saving time. For deaths caused by dementia, malignant neoplasms, and respiratory diseases, however, we detected a decrease in the risk of mortality until six weeks after autumn daylight saving time. We also found an increasing trend for mortality from dementia during the first five weeks after spring daylight saving time, including a rate ratio of 1.050 (95% confidence interval 1.007 to 1.095) in the fifth week, although the underlying mechanisms were unclear. These findings suggest that the effect of transition to daylight saving time on mortality could last longer than one week for a range of causes.

For different underlying causes of death, weak but significant decreases in mortality risk were detected during 0-7 weeks after autumn daylight saving time for dementia, circulatory diseases, malignant neoplasms, and respiratory diseases (table 1). Studies in recent decades have frequently reported changes in risk in the onset and severe outcomes of daylight saving time for mental or behavioural disorders,[6 39] and cardiovascular diseases,[5 7 9–12] including circulatory deaths.[40] Our findings suggested that transition to daylight saving time might have an important role not only on mental health and cardiovascular conditions, but could also be associated

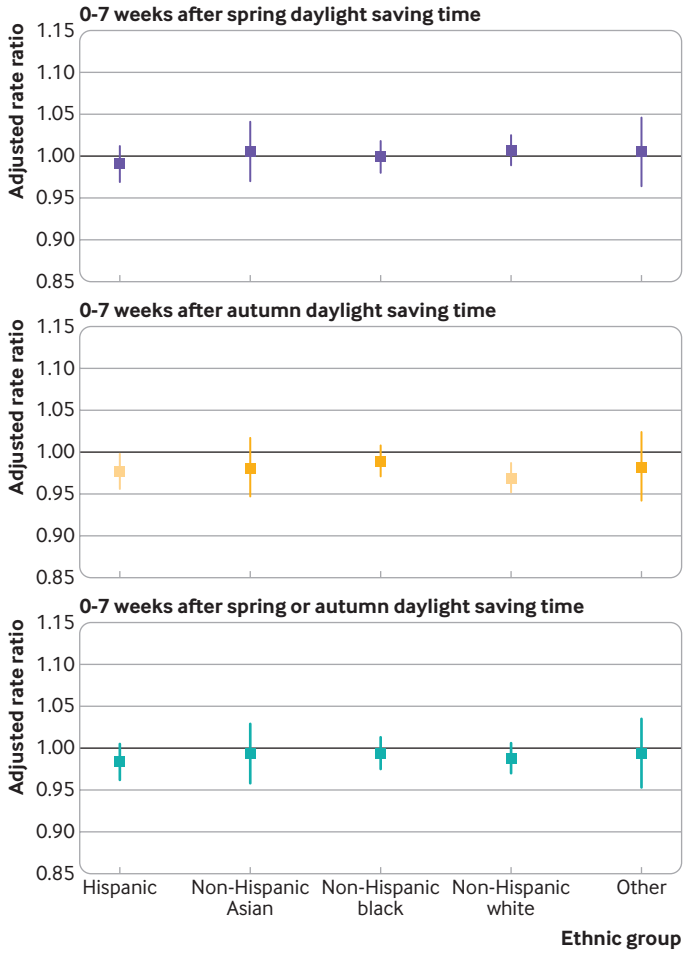

Figure 5 | Adjusted rate ratio estimates of mortality in the US, by race and ethnic group. Pooled estimates for 0-7 weeks after spring and autumn daylight saving time, and aggregated estimates (spring or autumn daylight saving time) are shown. In this study, spring daylight saving time is the time when the clocks are set forward by one hour on the second Sunday of March and autumn daylight saving time is the time when the clocks are set back by one hour (ie, return to standard time) on the first Sunday of November. Threshold of adjusted rate ratio=1 is indicated by the bond horizontal line. Significance is indicated by lighter coloured symbols (light yellow for weeks after autumn daylight saving time), according to unadjusted P values <0.05 (ie, without Benjamini-Hochberg adjustment for false discovery rate)

with changes in the mortality risks of other non-accidental diseases, including respiratory and neoplastic diseases. Positive associations were found between a mild shift in circadian rhythm (not necessarily by daylight saving time) and the risk of various pulmonary diseases[41 42] and cancers.[43–46] A slight increase in mortality from cancer associated with daylight saving time was found in the first week after transition to spring daylight saving time, and thus extra care might be helpful for patients with cancer during spring daylight saving time.

To explore spatial heterogenicity, we compared mortality risks after daylight saving time for different time zones, an important research gap in investigations of daylight saving time recognised by the American Academy of Sleep Medicine in 2020.[25] We used the Hawaii time zone as a negative control because daylight saving time was not implemented in Hawaii, and consistently, we detected no effects of spring or autumn daylight saving time. Similarly, daylight saving time was not implemented in most regions in Arizona, and we found no evidence of any difference between observed and expected mortality rates. For the six time zones in the US, we detected evidence indicating a decrease in all cause mortality only after autumn daylight saving time in the eastern time zone. The eastern time zone in the US is the closest to coordinated universal time (UTC), where sunset (ie, the start of daytime) occurs earlier than in other time zones. Although the exact mechanisms were not clear, our findings suggest that the changes in risk of mortality associated with daylight saving time might be influenced by the eastward time zone in the US. Considering that 47.6% of the continental US population live in the eastern time zone, however, which also had the highest general mortality rate among all six time zones, the only decreased mortality risks after autumn daylight save time in eastern time zone might also benefit from large population size and high mortality rate, leading

to a relatively higher statistical power. Hence further study is needed to verify our results.

For differences in personal characteristics, we found that deaths associated with daylight saving time were disproportionate for different ages and different race and ethnic groups. The effects of shifts in daylight saving time on general mortality risks were strongly increased by age. We found that the protective effects on mortality associated with autumn daylight saving time increased with age, and these protective effects were more pronounced in people aged ≥75 years. Between 2015 and 2019, 3 287 963 (23.6%) and 4 331 998 (31.1%) of 13 912 837 deaths were reported among those aged 75-84 and ≥85 years, respectively. Although we are not aware of any study that has reported on the age modifying effects of mortality associated with daylight saving time, elderly people could be more susceptible to the effects of daylight saving time on adverse health outcomes.[6 12]

Also, despite the non-significant outcome of the trend test, we found a steadily increasing trend in rate ratio estimates for spring daylight saving time as age increased. The non-significant results for both rate ratio estimates and trends for rate ratio were likely because of the low time resolution of the time series data used in the statistical analysis. Healthcare services are likely to be used more frequently by elderly patients with critical conditions after the transition to daylight saving time in spring. Acknowledging the non-significant rate ratio estimates after transitions to either spring or autumn daylight saving time, the trend for the rate ratio suggested that the overall risk of mortality was more likely to be decreased, rather than increased, after combining the effects of transitions to spring and autumn daylight saving time.

Assessing mortality risks after daylight saving time at the general population level was an important contribution to the strategic decision making process about the future of the policy on daylight saving time. Compared with recent studies in Europe,[28 38] we found that the mortality patterns associated with daylight saving time in the US were different from those in Europe, especially after the transition to autumn daylight saving time. Given the conflicting results in recent studies of mortality associated with daylight saving time based on population level death records, as well as many other studies with different study designs, a discussion of the topic based on different sources of datasets and from different angles might be useful and timely.

Our findings indicated a change in all cause mortality associated with transition to daylight saving time in the general US population. We found that changes in mortality risks associated with daylight saving time were more pronounced in elderly people, in the non-Hispanic white population, and in those living in the eastern time zone. For these subgroups of individuals with critical conditions, improvements in care and drug treatments for a two month period after the spring daylight saving time, and preventive measures to improve health status for a short period before the spring daylight saving time, might be helpful to prevent excess deaths. For different causes of death, ages, race and ethnic groups, and time zones, the decrease in mortality risks after autumn daylight saving time was more pronounced than the increase after spring daylight saving time.

In the US, a bill entitled the Sunshine Protection Act (https://www.congress.gov/bill/118th-congress/senate-bill/582) was passed unanimously by the Senate in 2022 (but not by the House as yet), which proposed permanent daylight saving time in the US. From the general public perspective, large differences in attitudes towards eliminating changing the clocks were highlighted in two recent US public opinion polls in 2021 (https://today.yougov.com/politics/articles/39209-daylight-saving-time-americans-want-stay-permanent) and 2022 (https://apnorc.org/projects/dislike-for-changing-the-clocks-persists/). Regardless of the health related effects of transition to daylight saving time, increasing concerns exist about energy savings because electricity consumption shifts from lighting to transportation, commercial, and entertaining events, and hence daylight saving time contributes little to saving energy in the modern society. Therefore, discussion of the potential (or possible) effects of changing the policy of daylight saving time is timely, necessary, and of general interest. Although our findings suggested that abolishing daylight saving time might not be supported by the evidence of overall change in mortality associated with daylight saving time, future policies on daylight saving time require more solid evidence at the population level, and extensive understanding of the underlying mechanisms.

Limitations

Our study had several limitations. Because daylight saving time might affect health by affecting circadian rhythm,[22] the absence of sleep parameters (eg, sleep quality, duration, and sleep-wake cycle) and chronotypes restricted our analysis without controlling for different types of biological responses to transitions to daylight saving time.[47] Lack of adjustment for these factors might cause less precise estimates, but not bias.

The low time resolution of the time series data is a limitation because of loss of information on changes in the risk of mortality and the relatively low statistical power of the study. Because shifting of daylight saving time is only a minimal shift in circadian rhythm, time series data aggregated on a weekly basis could not reflect or adjust for a daily or even hourly distribution of mortality risk before versus after transition to daylight saving time, which was also noted in another time series study investigating

daylight saving time.[28] Mortality might be highest on the transition day to daylight saving time as well as in the following few days, with a sharp reduction in the first week, especially for cardiovascular mortality and road traffic incidents. Because this weekday-weekend pattern was not included in our study, mean weekly mortality was unlikely to be sufficiently sensitive (ie, with a relatively low statistical power) to identify associations between mortality and the shift in daylight saving time. Thus we speculate that significant increases in mortality might have been detected with the statistical methods in this study if daily or hourly time series data of deaths had been available. The low time resolution could also reduce the detection of differences in mortality risks between the east and west regions within one time zone, where this east-to-west difference might only exist for a relatively short time after the transition to daylight saving time.[16] For the US, future studies might investigate changes in cause specific hospital admissions and mortality data associated with daylight saving time in Medicare and Medicaid databases with a daily or hourly based time resolution.

Although we assessed only five different causes of death in this study, circulatory diseases, malignant neoplasms, and respiratory diseases were the leading causes of death in the US, as well as in many other countries across the world, and were broadly reported among the general population. Identifying more specific causes of death that might be associated with shifts in daylight saving time are needed for further investigation.

The original dataset released by the National Center for Health Statistics covered the time period up to 2021, but we excluded data from 2020 onwards so that the effects of the covid-19 pandemic could be removed from the study. The information was collected from the whole of the US population, but the dataset used for analysis in this study was from a five year observation period, which was relatively short for a time series study. Hence further investigation with a longer study period might be needed to verify our findings.

This observational study was based on aggregated time series data, and thus causation cannot be inferred from our findings because the results might be confounded by unmeasured factors. Further studies are needed to explore the detailed relation between shifts in daylight saving time and the risk of mortality, as well as the underlying mechanisms, when data are available.

Conclusions

Transitions in daylight saving time were associated with changes in mortality in the US for different underlying causes. We found that the risk of mortality was increased, but not significantly, after the transition to spring daylight saving time and substantially decreased after transition to autumn daylight saving time, resulting overall in no effect on deaths associated with combined transitions to daylight saving time. Our findings might inform the ongoing debate on the policy of shifting daylight saving time.

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Contributors SZ, SS, RC, and FD designed the study. SZ developed the methodology, analysed the data, and presented the results. All authors drafted and revised the paper, and approved the final version of the manuscript. SZ is the guarantor. The corresponding author attests that all listed authors meet authorship criteria and that no others meeting the criteria have been omitted. Transparency: The lead author (the guarantor) affirms that the manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as planned (and, if relevant, registered) have been explained.

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