Daylight-Dependent, Seasonal Patterns in Industrial Incident Data

Jan Krüger
Holger Reyhl
Jens Kinne
Federal Institute for Occupational Safety and Health
Dresden, Germany
krueger.jan@baua.bund.de

***Abstract*—This article illustrates the close connection between daylight, the circadian system and safety at the workplace. It is initially explained that safety-related behaviour outcomes such as fatigue, alertness, cognitive performance and sleep are influenced by the circadian system. This influence is then reflected in practice in case of accidents, wherein circadian lows are associated with an increased risk of accident. The role of daylight is then addressed as an important zeitgeber (time cue) for the internal clock and the circadian system, and – with regard to incident analyses – it is illustrated that daylight-dependent, seasonal patterns can arise in industrial incident data.**

***Index Terms*—Circadian, Daylight, Incident, Safety, Season**

INTRODUCTION

Many studies indicate that a link exists between circadian-controlled performance parameters and accidents. The influence of the circadian system on fatigue, alertness, cognitive performance and sleep is particularly significant. These are safety-related behaviour outcomes which can be linked to incidents or accidents.

The influence of the circadian system on fatigue and alertness can be verified in particular by using instruments for the assessment of the subjective condition (e.g. sleepiness scales) [1]. With continuous recording over the whole day, circadian rhythms show marked alertness lows [2].

With regard to cognitive performance parameters, objective tests in laboratory investigations have shown that performance in specific standardised tests, such as the psychomotor vigilance task, search and detection tasks, sorting tasks, logical thinking and the reading accuracy of instruments is correlated to markers of the circadian phase [1]. These findings are supported by neuroimaging studies, which show that brain responses are influenced by the circadian system [3].

The relationship between sleep and the circadian system is also explained by the „two-process model of sleep regulation“ [4], [5]. The model describes the overlap of the circadian rhythm of sleep propensity with the homeostatic sleep pressure which linearly increases with elapsed time awake. The model has been used in many laboratory studies on fatigue and performance and could be verified in field investigations.

The statements of the previous sections should illustrate that the circadian system and safety at the workplace are closely linked. Along with the influence of the circadian system on fatigue, alertness, cognitive performance and sleep in laboratory investigations, a possible link between the circadian system and safety is also reflected in practice. The effects of these safety-related behaviour outcomes are particularly significant on incidents in work environments where short attention deficits can lead to direct damage (e.g. railway transport, transport in motor vehicles, aviation, healthcare). Retrospective analyses illustrate that accidents in the mentioned areas occur especially at times of circadian lows (e.g. at night, in the early morning and in the early afternoon) [6]. Various authors were able to establish marked circadian rhythms in accident frequency rates [7], [8]. Furthermore, studies that have researched the effects of daylight saving time on incidents point towards a fatigue-related increase of accident risk after the changing of the clocks in the spring [9].

So far, the role of light has not been considered in the outlined connection between the circadian system and safety. Light is the most important zeitgeber for the internal clock. The circadian system synchronises with daylight even in the modern world [10]-[12]. The influence of the above described behaviour outcomes is therefore evident through daylight changes. Particularly noticeable changes in the photoperiod arise with the change of the seasons. Strong changes occur in particular for sunrise times, day length and loss or gain of daylight. Figure 1 shows seasonal changes of the listed parameters, wherein the loss or gain of daylight is calculated with the difference of day lengths of previous and following calendar weeks.

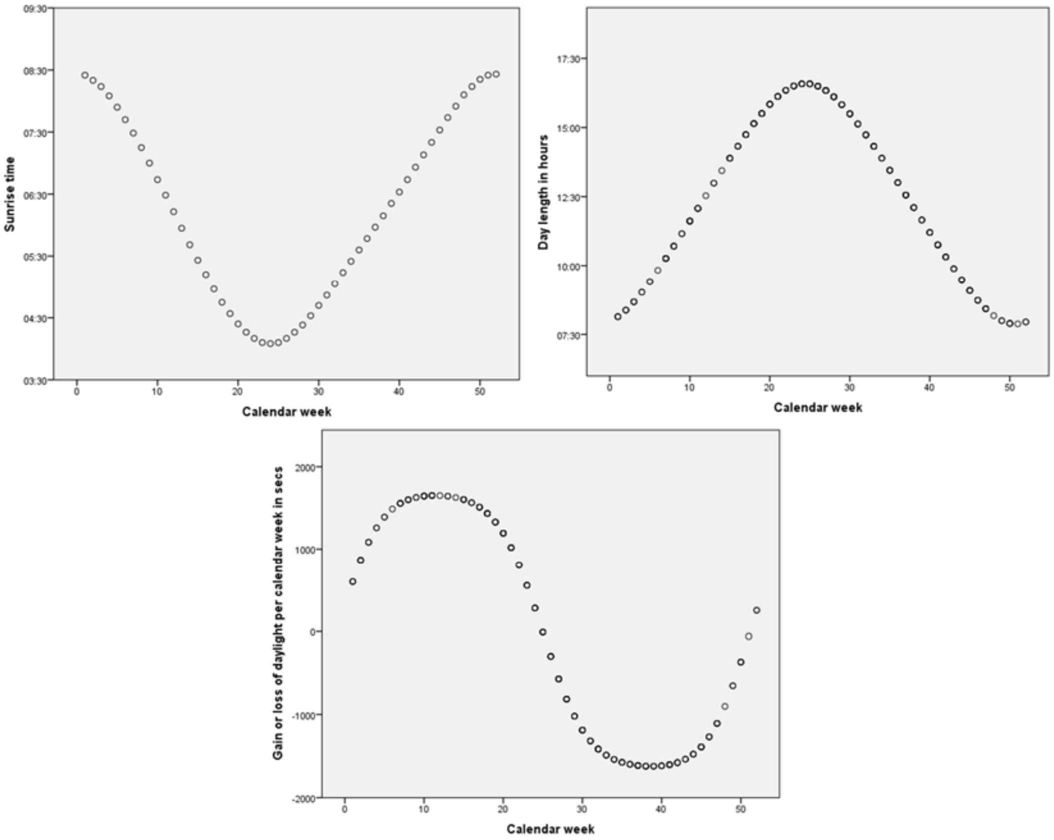

Figure 1. Changes in the seasonal photoperiod (exemplary for Central Germany)

The studies illustrated below indicate that adaptations of the circadian system to seasonal changes of the photoperiod effectively take place. Investigations on the seasonal adaptation of the circadian system date as far back as 180 years ago [13]. Seasonal rhythms could be observed particularly in sleep and in body temperature [14], [15]. Paul [16] and Kantermann [17] point to other indications of seasonal sleep rhythm; they determined significant differences in sleep duration between the seasons, wherein sleep duration is reduced in the summer in comparison to the winter. Furthermore, Cajochen was able to demonstrate that subjective and objective sleep parameters vary in an analogous manner to the moon phases [18]. A more recent neuroimaging study even suggests that cognitive brain functions such as sustained attention and working memory performance are subjected to seasonal changes [19].

Against the backdrop of the illustrated connection between daylight, the circadian system and safety at the workplace, the following hypotheses were formulated and verified according to an incident data set of the German Federal Environmental Agency:

1. The time of man-induced incidents varies between the seasons.
2. The time of technically-induced incidents does not vary between the seasons.
3. The median time of man-induced incidents shifts in an analogous manner to the seasonal changes of sunrise times.
4. The frequency of man-induced incidents shows an annually recurring seasonal effect.
5. The frequency of technically-induced incidents shows no annually recurring seasonal effect.
6. The annual frequency distribution of industrial incidents is correlated with changes of day length over the course of the year.

METHOD

In a retrospective analysis of 3,000 incidents reported to the German Federal Environmental Agency in the period between 1990 and 2015, the influence of the circadian system on the occurrence of incidents was examined. The statistic models for the analysis included factors such as date, time, geographical location, season and cause of incident. Furthermore, interfering factors such as daylight saving time, shift work and the amount of workforce were considered.

For the identification of possible influencing factors of the circadian system, various filter criteria were applied to the incident data set. Due to the fact that changes in daylight not only depend on the season, but also on the geographical location, only incidents within Germany were considered. The cause of the incident was further classified according to man-induced and technically-induced incidents. This separation is based on the assumption that only man-induced incidents can be influenced by the circadian system. In another step, the time of the incident was adjusted to normal time. The effects daylight saving time were hereby removed. The time adjustment was carried out with the aim of establishing a higher correlation between the natural daylight period and the time. Furthermore, all the incidents that did not occur between 8 a.m. and 4 p.m. were excluded from the analysis. The reason for the exclusion of night and early shift data is shiftworkers' frequent lack of adjustment to natural daylight. In particular, night shift work is associated with a decoupling of natural daylight and circadian desynchronisation [20]. By limiting the times, it can further be ensured that an almost constant number of employees was working in the mentioned time period. By contrast, it is for example known that less employees work during night shifts. If these differences are not considered in the number of working employees in relation to daylight, this can lead to erroneous interpretations in the analysis of incident frequency. After using the listed filter criteria, about 10% of the reported incidents remain for further analysis.

RESULTS ON INCIDENT TIMES

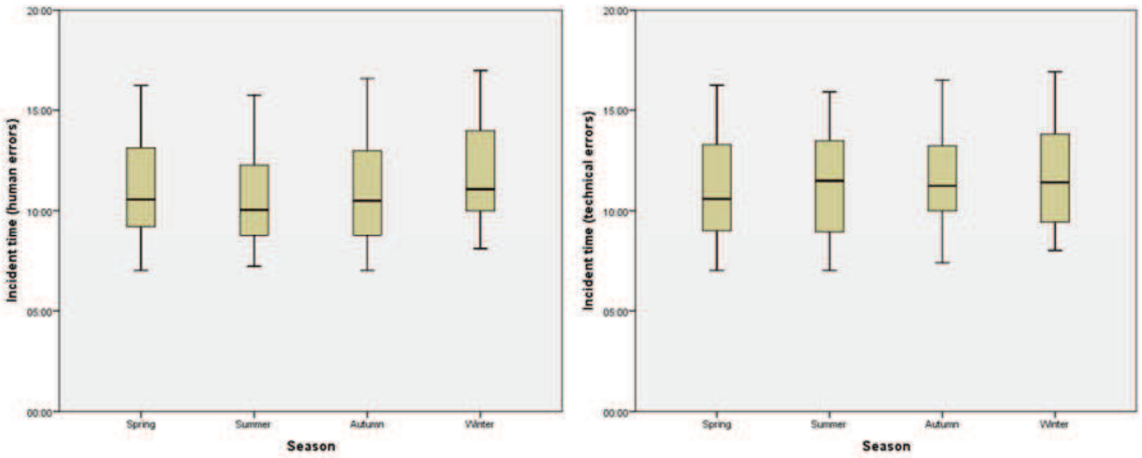

Figure 2. Box plots of incident times for human and technical errors

Figure 2 shows a shift of the median time of man-induced incidents to an earlier time in the summer (10:02 a.m.) and to a later time in the winter (11:05 a.m.). This pattern occurred in an analogous manner to seasonal changes in the photoperiod (earlier sunrise in the summer, later sunrise in the winter). In line with our hypothesis, this daylight-dependant, seasonal pattern does not appear in technically-induced incidents (figure 2).

By means of variance analysis, significant differences could be proven between the average values of incident times in man-induced errors (F(3.251)=3.47 p=0.017). Bonferroni post hoc tests for the paired comparison of the seasons resulted in a significant difference between the incident times in the summer and in the winter (p=0.007). In conformity with hypothesis 2, the statistics show no seasonal effects in technically-induced incidents (F(3.336)=0.60; p=0.62).

RESULTS ON INCIDENT FREQUENCY

For the analysis of incident frequency, cross tabulations of incident frequency were inspected as a first step in relation to the season. The chi^2 test showed a significant difference of incident frequency between the seasons $\chi^2(27, N=236)=167.82$ $p<0.001$ (Cramers V=0.49). A Poisson regression with the season as a factor and the incident frequency as a dependant variable also resulted in a significant effect (Wald-$\chi^2(3, N=236)=22.00$ $p<0.001$). The results suggest that the number of incidents varies between the seasons.

In an in-depth analysis, it was attempted to further restrict the seasonal difference in incident frequency. The visual inspection of the histogram on incident frequency (figure 3) over the calendar week suggests a certain similarity with the annual course of the day length (figure 1). A moderate correlation between the annual change of the day length and incident frequency could be determined (r(236)=0.33, p<0.001).

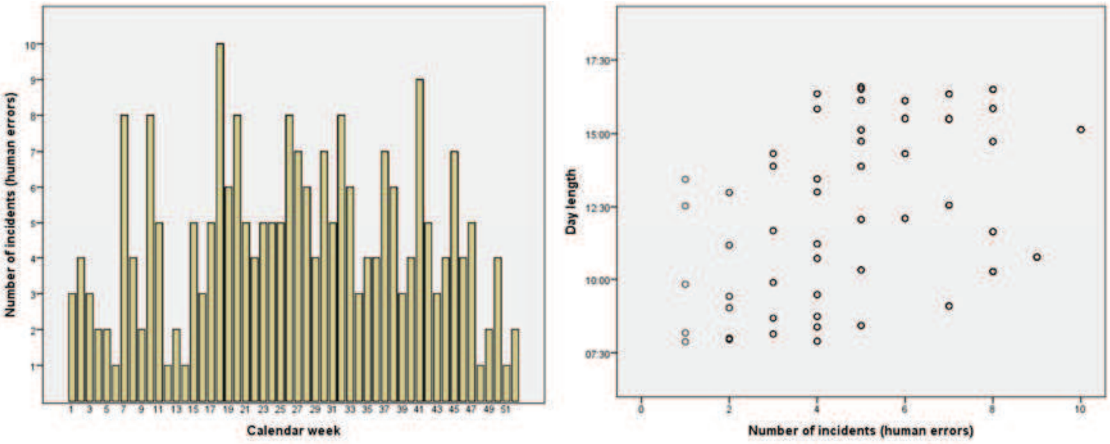

Figure 3. Histogram of incident frequency and scatter plot on the number of incidents in relation to day length

Contrary to the above illustrated hypothesis 5, technically-induced errors showed the same significant effects of a man-induced error. Even the technical error is significantly dependant on the season and shows a moderate correlation with day length ($r(321)=0.44$, $p<0.001$). For the man-induced error, against the backdrop of the above illustrated relations between the circadian system and work safety, the effect can be easily interpreted. For the technical error, the significant effect cannot be explained.

Discussion

Looking back on the hypotheses formulated in the introduction, the seasonal effects are reflected in the time of the incident as well as in the development of incident frequency. Except for hypothesis 5, none of the hypotheses to be tested had to be rejected. The results indicate an influence of the circadian system on incident occurrence which should not be ignored. Other non-significant results of our analysis support this assumption. For instance, an increase in incident frequency in the first week after changing the clocks in the spring or in the autumn appeared in in-depth analyses on the influence of time change.

Regression analyses further showed a geographical shift of incident times from east to west of 30 minutes. Surprisingly, the difference of sunrise times between east and west Germany amounts to 36 minutes, and therefore varies merely by 6 minutes from our result. In line with our results, Roenneberg found a shift of the chronotype from west to east to an earlier point in time [10], which indicates an adaptation of the circadian system to daylight.

Due to the fact that, in the retrospective analysis of the incidents, it could only be referred to data from the incident notification form, the represented results should be evaluated critically. Significant confounding variables, whose influence on the events cannot be excluded, are not recorded in the incident documentation and could not be considered in the analysis. These include for example:

- time elapsed since getting up
- time elapsed since starting work
- shift system
- break times
- differences in working conditions and type of work duty
- differences in lighting conditions
- individual factors such as chronotype or level of sleep deprivation

Despite not considering the listed confounding variables, some parallels can be drawn when comparing the results illustrated here with studies of other research groups on work and road accidents. Other research groups discovered similar seasonal patterns, however they were not able to provide an explanation for it [21]-[23]. For instance, Pierce researched seasonal patterns in work accident data and found an annually recurring pattern with higher accident figures in the summer and a drop in end-of-year months [24]. Pierce discusses various influencing factors, such as the weather, the length of the working day or methodical causes in the recording of accidents. In the end, Pierce concludes that none of the factors examined provide an explanation, and suspects a physiological mechanism to be the cause.

Against this backdrop, our analyses indicate a so far little observed influencing factor for safety at the workplace. Circadian factors should therefore be given greater consideration in accident analyses or in accident prevention in the future.

REFERENCES

[1] O. Tkachenko, A. M. Spaeth, J. D. Minkel and D. F. Dinges, "Circadian rhythms in sleepiness, alertness, and performance," in *Reference Module in Neuroscience and Biobehavioral Psychology*, J. Stein, Ed. Elsevier, 2017.

[2] H. Van Dongen and D. Dinges, "Circadian rhythms in sleepiness, alertness, and performance," in *Principles and practice of sleep medicine. Philadelphia*, M. Kryger, T. Roth, W. C. Dement, Eds. Elsevier, 2005, pp. 435-43.

[3] G. Vandewalle, P. Maquet and D. J. Dijk, "Light as a modulator of cognitive brain function," *Trends Cogn Sci*, vol. 13, pp. 429-38, 2009.

[4] A. A. Borbely, "A two process model of sleep regulation," *Human neurobiology*, vol. 1, pp. 195-204, 1982.

[5] A. A. Borbely, S. Daan, A. Wirz-Justice and T. Deboer, "The two-process model of sleep regulation: a reappraisal," *J Sleep Res*, vol. 25, pp. 131-43, 2016.

[6] A. Williamson, D. A. Lombardi, S. Folkard, J. Stutts, T. K. Courtney and J. L. Connor, "The link between fatigue and safety," *Accident Analysis and Prevention*, vol. 43, pp. 498-515, 2011.

[7] S. Folkard, D. A. Lombardi and M. B. Spencer, "Estimating the circadian rhythm in the risk of occupational injuries and accidents," *Chronobiol Int*, vol. 23, pp. 1181-92, 2006.

[8] M. M. Mitler, M. A. Carskadon, C. A. Czeisler, W. C. Dement, D. F. Dinges and R. C. Graeber, "Catastrophes, sleep, and public policy: consensus report," *Sleep*, vol. 11, pp. 100-9, 1988.

[9] J. Varughese and R. P. Allen, "Fatal accidents following changes in daylight savings time: the american experience," *Sleep Medicine*, vol. 2, pp. 31-6, 2001.

[10] T. Roenneberg, C. J. Kumar and M. Merrow, "The human circadian clock entrains to sun time," *Current Biology*, vol. 17, pp. R44-R5, 2007.

[11] C. Vetter, M. Juda, D. Lang, A. Wojtysiak and T. Roenneberg, "Blue-enriched office light competes with natural light as a zeitgeber," *Scandinavian Journal of Work, Environment & Health*, vol. 37, pp. 437-45, 2011.

[12] K. P. Wright, A. W. McHill, B. R. Birks, B. R. Griffin, T. Rusterholz and E. D. Chinoy, "Entrainment of the human circadian clock to the natural light-dark cycle," *Current Biology*, vol. 23, pp. 1554-8, 2013.

[13] T. Roenneberg, "The decline in human seasonality," *J Biol Rhythms*, vol. 19, pp. 193-5, discussion 6-7, 2004.

[14] R. G. Foster and T. Roenneberg, "Human responses to the geophysical daily, annual and lunar cycles," *Current Biology*, vol. CB 18, pp. R784-R94, 2008.

[15] D. Wey, A. Bohn and L. Menna-Barreto, "Daily rhythms of native brazilians in summer and winter," *Physiology & Behavior*, vol. 105, pp. 613-20, 2012.

[16] M. A. Paul, R. J. Love, A. Hawton and J. Arendt, "Sleep and the endogenous melatonin rhythm of high arctic residents during the summer and winter," *Physiology & Behavior*, vol. 141, pp. 199-206, 2015.

[17] T. Kantermann, M. Juda, M. Merrow and T. Roenneberg, "The human circadian clock's seasonal adjustment is disrupted by daylight saving time," *Current Biology*, vol. 17, pp. 1996-2000, 2007.

[18] C. Cajochen, S. Altanay-Ekici, M. Munch, S. Frey, V. Knoblauch and A. Wirz-Justice, "Evidence that the lunar cycle influences human sleep," *Current Biology*, vol. CB 23, pp. 1485-8, 2013.

[19] C. Meyer, V. Muto, M. Jaspar, C. Kusse, E. Lambot, S. L. Chellappa et al., "Seasonality in human cognitive brain responses," *Proceedings of the National Academy of Sciences of the United States of America*, vol. 113, pp. 3066-71, 2016.

[20] T. C. Erren and T. J. Reiter, "Revisiting chronodisruption: when the physiological nexus between internal and external times splits in humans," *Naturwissenschaften*, vol. 100, pp. 291-8, 2013.

[21] P. Evgenikos, G. Yannis, K. Folla, R. Bauer, K. Machata and C. Brandstaetter, "Characteristics and causes of heavy goods vehicles and buses accidents in europe," *Transportation Research Procedia*, vol. 14, pp. 2158-67, 2016.

[22] P. Evgenikos, G. Yannis, K. Folla, R. Bauer, K. Machata and C. Brandstaetter, "How safe are cyclists on european roads? ," *Transportation Research Procedia*, vol. 14, pp. 2372-81, 2016.

[23] P. K. Nag and V. G. Patel, "Work accidents among shiftworkers in industry," *International Journal of Industrial Ergonomics*, vol. 21, pp. 275-81, 1998.

[24] B. Pierce, "Does the year-end decline in injury risk reflect reporting error?," *American Journal of Industrial Medicine*, vol. 58, pp. 519-27, 2015.