Author(s): Onninen, Jussi; Pylkkönen, Mia; Tolvanen, Asko; Sallinen, Mikael

Title: Accumulation of sleep loss among shift-working truck drivers

Year: 2021

Version: Accepted version (Final draft)

Accumulation of sleep loss among shift-working truck drivers

Jussi Onninen[ab]*, Mia Pylkkönen[ab], Asko Tolvanen[b], and Mikael Sallinen[ab]

[a]Finnish Institute of Occupational Health, Helsinki, Finland; [b]Department of Psychology, University of Jyväskylä, Jyväskylä, Finland

* Correspondence:

Jussi Onninen, PO Box 35, FI-40014 University of Jyväskylä, Finland. Email: jussi.onninen@jyu.fi. ORCID iD: https://orcid.org/0000-0002-0082-0792

Abstract

Sleep loss is known to contribute to road traffic accidents. Professional drivers are vulnerable to curtailment of sleep due to long driving bouts and shift work. To fill in the gap in the literature related to the build-up of sleep loss in irregular shift systems, we recorded the sleep and working hours of 47 shift-working long-haul truck drivers during a two-week period. Sleep (time in bed) was verified by actigraphy and sleep logs. Sleepiness was measured using the Karolinska Sleepiness Scale (KSS). Individual sleep need was based on self-assessments. We examined the accumulated sleep versus self-reported sleep need across the study period, using midnights as points of observation, and the accumulated sleep loss within 72h prior to shift end (sleep versus need, SVN72). Across the study period, the drivers' sleep was close to their self-reported sleep need, but 45% of the drivers showed accumulated sleep loss of >6h at least once. SVN72 averaged -1.5h and was 2.87h shorter in connection with morning shifts compared to day or evening shifts. Night shifts showed no such difference. During days off, sleep exceeded sleep need by 1.13h and was not dependent on the type of preceding work shift. SVN72 showed small-to-medium negative associations with on-duty KSS even after accounting for sleep within the 24h prior to shift end. Our results show that long-haul truck drivers are exposed to severe levels of accumulated sleep loss while working irregular shifts, but they can catch up on their lost sleep especially during days off.

Keywords: Long-haul truck drivers, cumulative sleep loss, sleepiness, shift work, recovery, transportation, sleep need

Introduction

Sleepiness is a major risk factor in road traffic accidents (Bioulac et al. 2017). Among professional truck drivers, difficulties staying alert at work and insufficient sleep are not uncommon (Carter et al. 2003; Mitler et al. 1997; Philip et al. 2002; Pylkkönen et al. 2015). Sleepiness at the wheel in truck drivers can be partly attributed to shift work that causes circadian disruption and limited sleep opportunities (Horne and Reyner 1999).

The causal chain linking insufficient sleep and impaired driving performance has been well characterized. Experimental studies have shown that chronic sleep loss produces cumulative, dose-dependent deficits in neurobehavioral performance (Belenky et al. 2003; Van Dongen et al. 2003a). Functional impairment under sleep loss is known to vary as a function of prior sleep (Arnal et al. 2015; Rupp et al. 2009), and time of day (Cohen et al. 2010; Mollicone et al. 2010). Recovery after recurrent or prolonged sleep loss may require several days, depending on the amount of recovery sleep (Axelsson et al. 2008; Banks et al. 2010; Belenky et al. 2003; Pejovic et al. 2010; Sallinen et al. 2008). Incomplete recovery may not be evident until when the circadian drive for sleep is the highest, i.e., nighttime (Cohen et al. 2010). Assessing the fitness-to-drive of professional drivers is usually restricted to considering sleep that a driver has obtained within only 1-2 d before duty hours (Dawson and McCulloch 2005; Dawson et al. 2021). These findings underline the need to investigate the dynamics of sleep loss build-up over periods of irregular shifts in safety-critical occupations.

Previous studies suggest that individuals with irregular working hours may be unable to satisfy their sleep need, resulting in accumulated sleep loss (Van Dongen et al. 2003b). Based on a survey of a random sample of European truck drivers, Philip et al. (2002) noted that drivers build up sleep loss based on their sleep need and actual sleep times during working periods. In a study of train drivers and traffic controllers working irregular shifts (Sallinen et al. 2003), the self-reported sleep need was associated with sleep period length. In night and morning shifts, a 1h increase in sleep need prolonged the preceding main sleep period by 17 min and 9 min, respectively. In a study using the same data as the current paper (Pylkkönen et al. 2015), insufficient sleep compared to self-reported sleep need was most pronounced in consecutive night shifts. Although much research has been conducted to explore the impact of irregular working hours on sleep, it is still unclear how shift workers in the field of transportation build up sleep debt and are able to recover from it during intermittent work shifts and days off. Here, our aim was to quantify the degree and variation of accumulated sleep loss among long-haul truck drivers as a function of their shift patterns and days off. We also examined whether accumulated sleep loss was associated with on-duty sleepiness. We hypothesized that the greater the degree of accumulated sleep loss, the sleepier the drivers feel while on duty.

Methods

Fifty-four long-haul truck drivers volunteered to participate from four middle-sized haulage companies operating in Finland. Inclusion criteria were an age of 20–65 y, at least 2 y of driving experience, and operating both day and night shifts regularly. The drivers' health status was assessed with health questionnaires. Two drivers withdrew from the study before it began, and three were excluded due to critical missing data (sleep need). Another two drivers were excluded due to missing data on sleep. A total of 47 male drivers were thus included in the study. All drivers gave written informed consent. All drivers were provided with a monetary compensation of 150 euros. This study was approved by the Ethics Board of the Finnish Institute of Occupational Health (FIOH) and conforms to the ethical standards of Chronobiology International (Portaluppi et al. 2010).

Data regarding sleep habits were collected using the Diurnal Type Questionnaire (DTQ) (Torsvall and Åkerstedt 1980) and a sleep questionnaire developed by the FIOH. The latter included the Epworth Sleepiness Scale (ESS) (Johns 1991). Based on the DTQ, the drivers were classified as morning, intermediate (neither morning nor evening), or evening types. Individual daily sleep need was self-reported using the following item of the questionnaire: “How many hours of sleep do you need per 24 hours (how many hours would you sleep if you could sleep as long as you want)? In other words, how much sleep do you need to be alert and fit for duty the next day?” For drivers who gave minimum and maximum values instead of one value (n = 4), the mean of these values was used as their individual daily sleep need. A detailed description of the study design is presented in Pylkkönen et al. (2015).

The field data were collected between November and March during a two-week period including different work shifts and days off. Shifts were first defined according to the criteria by Härmä et al. (2015) as follows: early morning shifts (start time 03:01–05:59h), morning shifts (start time 06:00–06:59h), day shifts (start time 07:00 at the earliest and end time 18:00h at the latest), evening shifts (start time 12:00h at the earliest and end time 02:59h at the latest), and night shifts (≥ 3h of the shift between 23:00 and 03:00h). First (n = 87) and successive night shifts (n = 124) were separated into two discrete shift types, as the former is usually preceded by nighttime sleep and the latter by daytime sleep. Next, shifts that started 07:00h–12:00h and ended 18:01h–02:59h were labelled late day shifts. Finally, to have sufficient observations in each shift type, the early morning (n = 63) and morning shifts (n = 68) were combined (hereinafter referred to as morning shifts) as well as the day (n = 33), late day (n = 30), and evening shifts (n = 30) (hereinafter referred to as day or evening shifts). The proportions and timing of the final shift types is illustrated in Figure 2. Out of these shift types (morning, day or evening, night), every driver worked two to three different shifts during the study period. The remaining free time on calendar days following night shifts was defined as recovery days.

Driver sleepiness was measured using the Karolinska Sleepiness Scale (KSS) (Åkerstedt and Gillberg 1990; Åkerstedt et al. 2014). During driving bouts, the drivers were instructed to report once per hour how sleepy they were currently feeling using the KSS. This rating scale was presented on a smartphone that was attached to the dashboard. Sleep periods were determined using wrist-worn actigraphy units (Actiwatch 7, CamNtech Ltd, Cambridgeshire, UK). Time in bed (TIB) was obtained from the actigraphy data. Additionally, sleep diaries were used in which the drivers reported their sleep and wake patterns (timing, duration, and location). Any missing actigraphy data (6.5%) were replaced with sleep parameters from the sleep diaries, where available. Accumulation of sleep loss during the study period was obtained by first subtracting daily self-reported sleep need from all sleep per each 24h period (main sleep periods and naps combined) and then summing these differences over a period of successive days. Calculating the accumulation of sleep loss began at the first nocturnal main sleep period (sleep with ≥3h falling between midnight and 06:00h). We examined the average, minimum, and maximum values of accumulated sleep loss as well as the percentage of drivers that reached different maximum degrees of accumulated sleep loss during the study period, using midnights as points of observation. For the analyses of the accumulated sleep loss in connection with work shifts, all sleep periods within a 72h time window were summed and compared to the self-reported sleep need multiplied by three (sleep versus need, SVN_{72}). This method is illustrated in Figure 1.

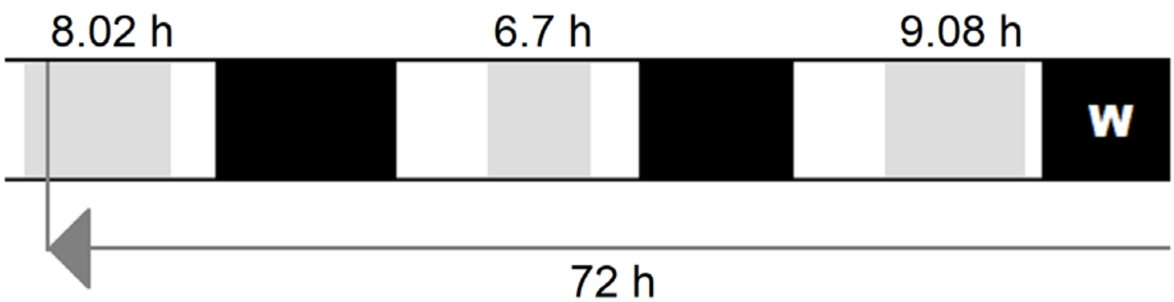

Figure 1. Model representing sleep (grey) and work (black rectangles) within a 72h time window (grey arrow) prior to the end of a target work shift (W). Any sleep occurring before the start of the time window (vertical line) is not included. For a driver whose self-reported sleep need is 8h, sleep versus sleep need within 72h prior to shift end (SVN_{72}) would total 8.02h + 6.7h + 9.08h – 3 * 8h = -0.2h (12 min less than sleep need).

The data were analyzed using generalized estimating equations (GEE) (Liang and Zeger 1986). A priori correlation structure selection was based on the quasi-likelihood under the independence model criterion (QIC) (Pan 2001). Cohen's f^2 was used as the effect size measure (Cohen 1992). Missingness was <5% in all analyses and was considered negligible. Alpha was set at 0.05 in all analyses. Data were analyzed in R 4.0.3 using the package *saws* (Fay and Graubard 2001) that reduces small sample related bias.

Results

Work shift characteristics

Figure 2 shows all 433 shifts categorized into the four types used in the analyses (morning, day or evening, first night, and successive night shifts).

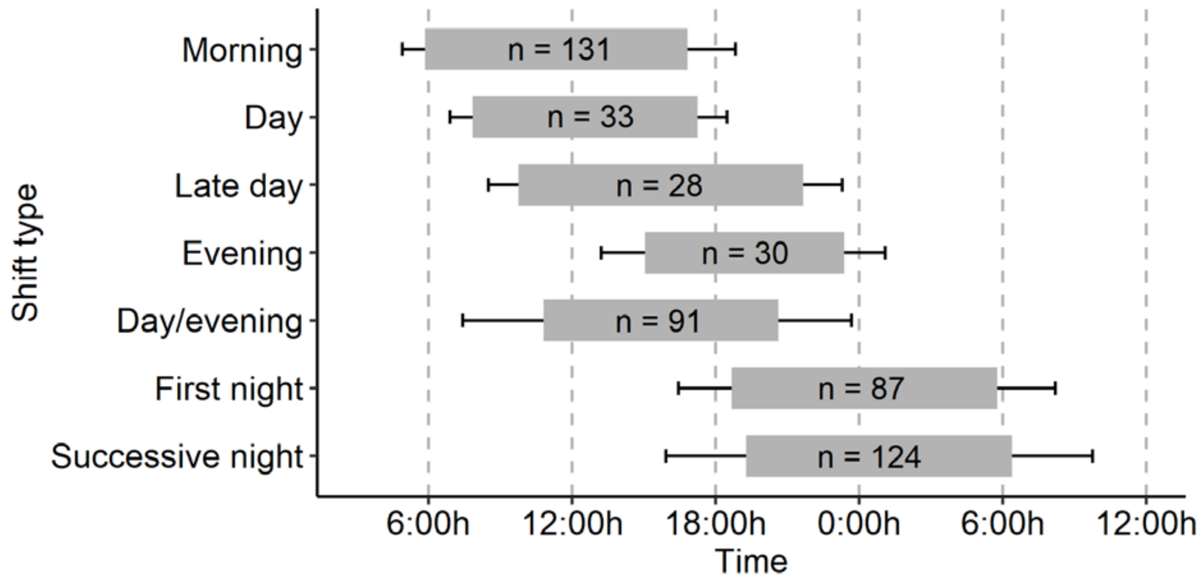

Figure 2. The timing of the work shifts.

Driver demographics, sleep, and accumulated sleep loss

On average, the drivers were 38 y old and had 15 y of trucking experience (Table 1). Most of the drivers reported needing 7-9h of sleep. The drivers who reported needing <7h of daily sleep averaged 7.73h of sleep per day. Out of these five drivers, four slept an average of ≥7h per day. The drivers who reported needing ≥9h of daily sleep averaged 8.58h of sleep per day. The self-reported sleep need of morning, intermediate, and evening diurnal types averaged 7.17, 7.8, and 8.7h, respectively. Of all the main sleep episodes recorded, none took place in the vehicle, and 1.4% were reported to have taken place outside home.

Table 1. Driver demographics and sleep need details.

		Mean ± SD or %
Age (y)		37.77 ± 10.58
Work experience (years)		15.13 ± 10.12
Body mass index		27.53 ± 4.60
Epworth Sleepiness Scale score		6.9 ± 3.98
Has children under 18 y		42.2%
Has children under 7 y		17.0%
Employment type		
	Employment contract	87.2%
	Subcontractor	8.5%
Wage basis		
	Payment by the hour	80.9%
	Piecework pay	8.5%
	Payment by the hour and piecework pay	6.4%
Diurnal type*		
	Morning	23.4%
	Evening	14.9%
	Intermediate	57.4%
Self-reported sleep need (h)		7.8 ± 0.94
Self-reported sleep need		
	<7h	10.6%
	7-9h	85.1%
	>9h	4.3%

Note. * = Based on Diurnal Type Questionnaire (DTQ) (Torsvall and Åkerstedt 1980)

On average, the drivers slept close to what their self-reported sleep need was during the 2-week measurement period, including working days and days off (Table 2). A maximum degree of accumulated sleep loss of 6h or more at least once during the study period was observed in roughly 45% of the drivers, using midnights as points of observation. Visual inspection of the drivers' accumulated sleep loss (Figure 3) suggests that those who reported needing more sleep were vulnerable to more severe degrees of sleep loss during the study period.

Table 2. Descriptive statistics of variables related to sleep and sleep loss.

		Mean ± SD or %
Daily sleep (h)		7.77 ± 2.03
Daily sleep vs self-reported sleep need (h)		-0.03 ± 2.1
Mean accumulated sleep loss over the 2-week measurement period (h)*		
	Average	-0.03 ± 6.73
	Minimum	-6.15 ± 6.43
	Maximum	5.92 ± 8.12
Drivers who had accumulated various degrees of sleep loss over the 2-week measurement period (h)*		
	<2h	91.5%
	<0h	85.1%
	<-2h	68.1%
	<-4h	59.6%
	<-6h	44.7%
	<-8h	34.0%
	<-10h	23.4%
Accumulated sleep loss within 72h prior to shift end (h)*		
	Average	-1.57 ± 2.97
	Minimum	-5.72 ± 2.92
	Maximum	2.13 ± 3.47

Note. * = Negative values denote sleep loss with respect to self-reported sleep need.

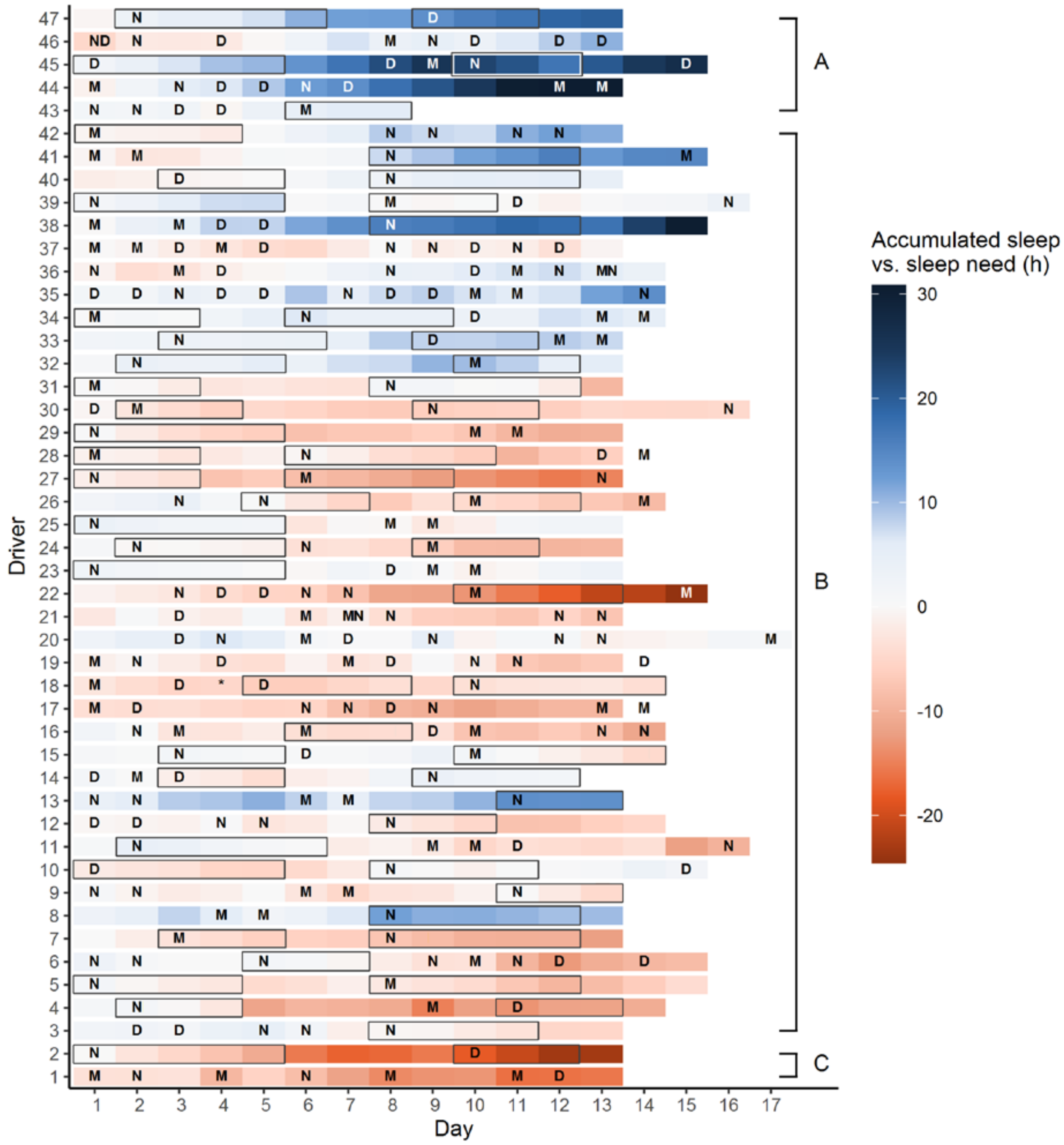

Figure 3. Accumulated sleep versus self-reported sleep need across the study period. The drivers were sorted based on their self-reported sleep need and categorized into those who reported needing <7h (A), 7–9h (B), and >9h (C) of sleep daily. Negative values denote sleep loss with respect to sleep need and positive values denote sleep exceeding sleep need. Two letters in one cell denote two shifts of respective types starting during the same day. Rectangles denote shift periods of three or more successive shifts of the same type. N = night, M = morning, D = day/evening shift, * = abnormally short shift. Interactive figure available at http://users.jyu.fi/~jujoonni/trucksleep/

Sleep and accumulated sleep loss in different shift types and days off

Using the 72h time window, accumulated sleep loss of ≥6h was observed in almost 7% of all shifts (Table 3). SVN_{72} was significantly shorter in morning shifts compared to day or evening shifts, roughly 2 h 52 min (β = -2.86 [95% confidence interval: -4.42–-1.3], p = .001) (Figure 4). Night shifts did not significantly differ from day or evening shifts in this regard (all p > .05). (For detailed analyses, see Appendix A.)

Table 3. Accumulated sleep loss (sleep versus self-reported sleep need) within 72h prior to shift end.

		Shift type				
		Any shift (%)	First night (%)	Successive night (%)	Morning (%)	Day or evening (%)
Degree of accumulated sleep loss*	<2h	74.52	78.57	73.20	91.21	62.12
	<0h	61.76	64.29	61.86	74.73	51.52
	<-2h	40.21	42.86	39.18	52.75	28.79
	<-4h	22.88	26.19	26.80	28.57	10.61
	<-6h	6.86	2.38	9.28	8.79	4.55
	<-8h	2.29	0.00	5.15	1.10	1.52

Note. * = Negative values denote sleep loss with respect to self-reported sleep need.

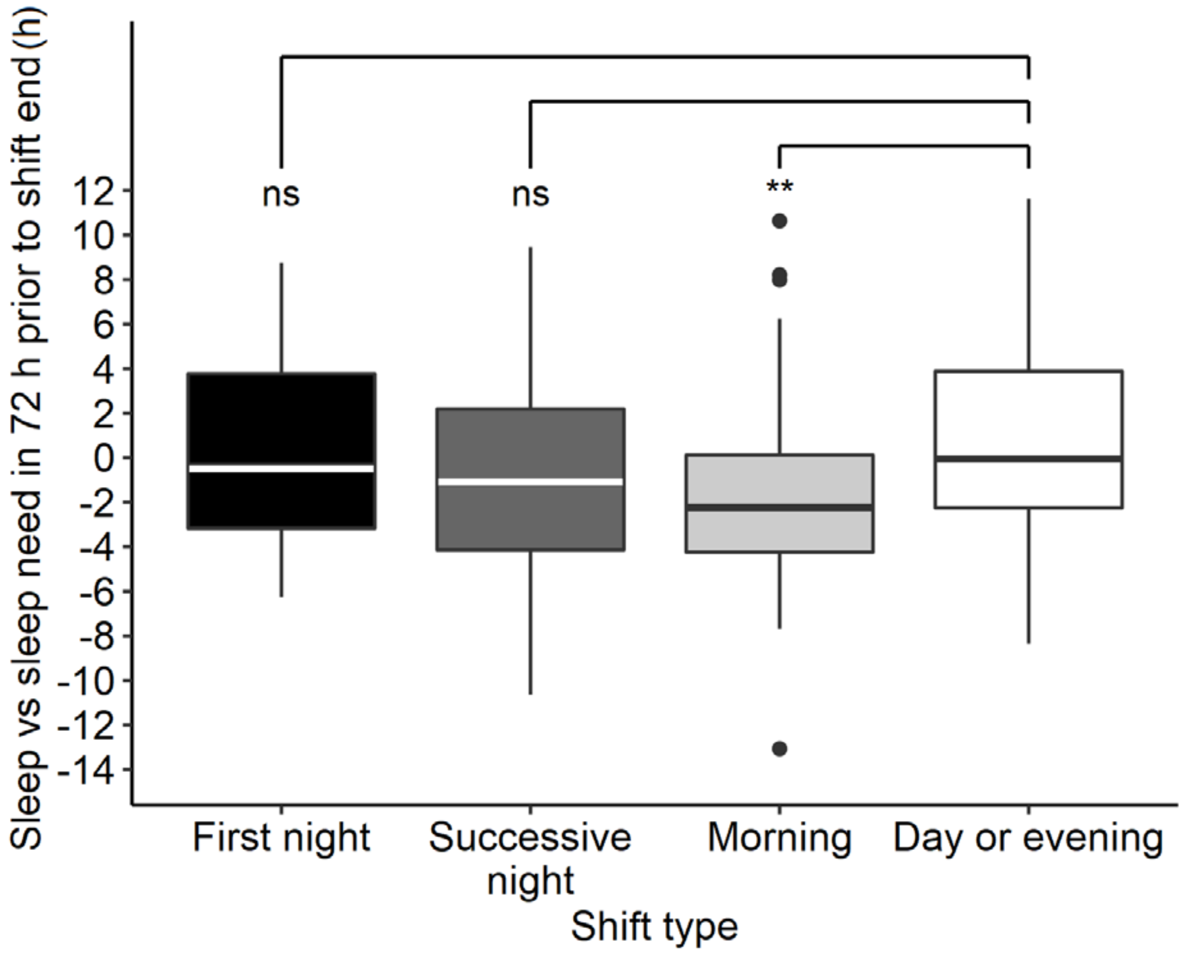

Figure 4. Accumulated sleep loss (sleep vs. self-reported sleep need, h) within 72h prior to the end of night and morning shifts compared to day or evening shifts. ** = $p < .01$, ns = $p > .05$.

On all days off (n = 224), the drivers' average sleep was 8.78 (± 1.55) h, translating to an average of 1.13 (± 1.58) h more than their self-reported sleep need (Figure 5). On single days off, their sleep averaged 1.43 (± 1.7) h in excess of their self-reported sleep need. The drivers' average bed- and waking times on days off were 00:17 (± 1.73) and 9:11 (± 1.98) h, respectively. Napping was reported in 9.7% of the days off, with an average duration of 1.38 (± 0.75) h. During periods of two and three consecutive days off, the drivers slept on average 1.22 (± 1.72) and 0.98 (± 1.47) h more than their self-reported sleep need, respectively. On days off, sleep versus sleep need was not significantly different immediately following night, morning, or day or evening shifts as compared to consecutive days off (all $p > .05$). Single days off did not significantly differ from days off with a preceding recovery day in this respect (p = .776). Sleep during recovery days averaged 5.87 (± 1.85) h. No significant differences were found when comparing first and second, or first, second, and third consecutive days off (all $p > .05$). (For detailed analyses, see Appendix A.)

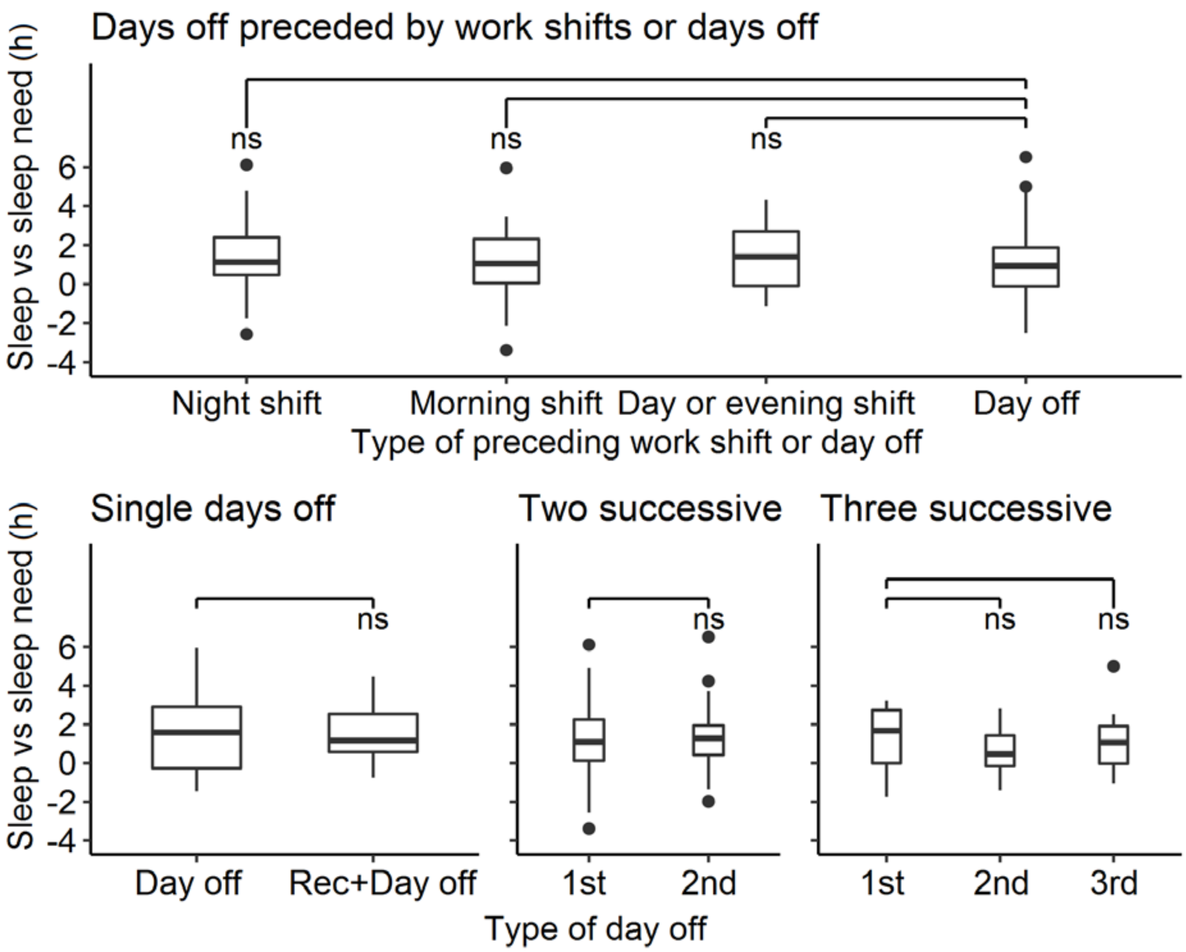

Figure 5. Sleep versus self-reported sleep need (h) during days off preceded by different shift types or days off (top panel), or in association with one (bottom left), two (bottom center), and three consecutive days off (bottom right panel). Rec+Day off refers to single days off preceded by a recovery day. ns = $p > .05$.

Association between accumulated sleep loss and on-duty sleepiness

The accumulated sleep loss within the 72h periods prior to work shifts was associated with on-duty sleepiness. One unit (h) of SVN_{72} was associated with roughly 0.04-0.09 unit increase in the KSS mean, depending on the statistical model (Table 4). That is, shorter sleep was associated with higher on-duty sleepiness, irrespective of shift type (Model 1, p = .001, Cohen's f^2 = .17). This connection remained significant after adjusting for several potentially confounding type of factors (Model 2, p = .010, Cohen's f^2 = .13) and even the difference between the sleep and self-reported sleep need during the 24h prior to the shift (Model 3; p = .034, Cohen's f^2 = .24). The association was no longer significant after adjusting for the difference between the sleep and self-reported sleep need during the 48h prior to the shift (Model 4; p = .457).

Table 4. GEE results for the association between sleep versus self-reported sleep need within 72h prior to shift end and driver sleepiness during shifts.

	Model 1					Model 2				
		95% CI					95% CI			
Term	β	Low	High	p	f^2	β	Low	High	p	f^2
(Intercept)	3.113	2.776	3.449	0.000	0.17	3.185	1.783	4.588	0.000	0.13
SVN_{72}	-0.094	-0.146	-0.042	0.001		-0.042	-0.074	-0.011	0.010	
	Model 3					Model 4				
		95% CI					95% CI			
Term	β	Low	High	p	f^2	β	Low	High	p	f^2
(Intercept)	3.088	1.684	4.492	0.000	0.24	2.995	1.566	4.424	0.000	-
SVN_{72}	-0.040	-0.078	-0.003	0.034		-0.012	-0.046	0.021	0.457	

Note: SVN_{72} = Sleep versus self-reported sleep need within 72h prior to shift end. Driver sleepiness measured with Karolinska Sleepiness Scale. Model 1 = crude model, adjusted for shift type. Model 2 = model adjusted for shift type, time awake, driver age, Epworth Sleepiness Scale score, diurnal type, and being a parent of children under age 7 y (not shown). Model 3 = adjustments as in Model 2 + all sleeps in 24h prior to shift end. Model 4 = adjustments as in Model 2 + all sleeps in 48h prior to shift end. 95% CI = 95% confidence intervals for model coefficients (β). Cohen's f^2's are given for the models (all coefficients included). p values are for F tests of regression term significance (Fay and Graubard 2001).

Discussion

In this study, we quantified the degree and variation of accumulated sleep loss among long-haul truck drivers while they were working on irregular shift schedules and examined the association of this sleep loss with on-duty sleepiness. The daily sleep averaged across the measurement period was close to the self-reported individual sleep need. However, considerable variation was observed in the amount of sleep obtained daily. This was not limited to a small proportion of the drivers. Across the whole study period, severe levels of accumulated sleep loss (>6h) were observed in roughly 45% of the drivers at least once, using midnights as points of observation.

Using a 72h time span allowed us to examine the accumulation of sleep loss in connection with work shifts. The sleep loss was most prominent in morning shifts. Surprisingly, night shifts did not differ from day or evening shifts in this regard. This is contrary to earlier findings that long-haul truck drivers' sleep is curtailed between successive night shifts in steady night shift work (Mitler et al. 1997). Similarly, Pylkkönen et al. (2015), using the same data, reported that insufficient sleep prior to duty hours was most evident between consecutive night shifts. This conflict may be explained by two shift schedule characteristics. First, the average number of successive night shifts was 3.5. Therefore, in the case of consecutive night shifts, the 72h time window will occasionally have included days off (e.g., a three-day period prior to a second consecutive night shift); thus, it cannot be concluded that accumulated sleep loss does not affect consecutive night shifts. Second, the morning and day or evening shifts were preceded by days off less frequently than were the night shifts. Nearly 85% of the morning shifts were preceded by other work shifts, which contributes to the observed accumulated sleep loss in them.

The drivers' sleep on days off exceeded their self-reported sleep need by >1h regardless of the type of preceding shift. We also investigated if sleep obtained during single days off differed depending on being preceded by a recovery day (the remainder of the day following a night shift) or not. Surprisingly, no differences were found even though the drivers slept on average nearly 6h during recovery days. Likewise, no differences in sleep versus self-reported sleep need were found when comparing single days off to the first days of two or three consecutive days off. Although not statistically tested, the drivers tended to sleep more when the off-duty time was limited. This was possibly due to an intent to balance the recovery from prior work periods and social activities, domestic responsibilities, etc. In line with previous studies (Lazar et al. 2013; Roenneberg et al. 2003; Soehner et al. 2011), it can be concluded that days off present opportunities to catch up on sleep lost during periods of shift work. Importantly, the sleep on days off generally exceeded the self-reported sleep need. This strategy can be considered beneficial in terms of recovery and alertness during the work shifts afterwards (Banks et al. 2010; Patterson et al. 2019), but its effects on long-term health may be detrimental (Depner et al. 2019).

We investigated the association between the accumulated sleep loss within 72h prior to shift end and on-duty subjective sleepiness. Small associations were detected after accounting for possibly confounding demographic and shift timing related factors, and even the sleep obtained during the 24h prior to the shift. For every 1h of sleep loss, the average on-duty sleepiness increased by 0.04-0.09 KSS units. This association was no longer significant after adjusting for the sleep the driver had obtained during the 48h prior to shift end. These results suggest that compared to the traditional time window of 24/48h (Dawson and McCulloch 2005), an extra 24h may not increase the predictive value for on-duty sleepiness. However, it cannot be concluded that sleep loss accumulated during a longer-than-conventional period does not affect driver sleepiness, since sleepiness may be masked (Carskadon and Dement 1982; Åkerstedt et al. 2008) or effectively alleviated while on duty (Horne and Reyner 1996; Penetar et al. 2003). Future studies employing similar approaches should account for such moderating factors. A recent study also showed that the drivers participating in this study may have been sleepier than what their subjective ratings suggested (Sallinen et al. 2020).

Here, we showed that long-haul truck drivers working irregular shifts have marked variability in the amount of sleep they obtain during periods of work and days off. The negative effects of sleep loss in safety-critical occupations are indisputable, and general heuristics may be provided concerning sufficient sleep within up to 2 d prior to a work shift (Dawson and

McCulloch, 2005; Dawson et al. 2021). Prior studies have also linked irregular sleep patterns to poor health outcomes (Chaput et al. 2020) and poor subjective sleep quality (Monk et al. 2003). However, it is not yet well understood how repeated bouts of limited sleep and subsequent recovery might affect alertness or work well-being. Our findings highlight the need to investigate the long-term consequences of irregular working hour arrangements and accumulated sleep deficiency on performance and safety outcomes.

Several considerations are warranted when evaluating the generalizability of our results. The results are from an all-male group of drivers obtained with convenience sampling and studied during the winter months. Although the sample size was relatively small, the demographic and individual characteristics of the drivers participating in this study corresponded well to a larger sample (n = 1047) of Finnish heavy vehicle drivers (Partinen and Hirvonen, 2006). Most of the drivers had the opportunity to sleep at home, which is not possible for all long-haul truck drivers. It has been reported that sleeping, e.g., in the truck sleeper cabs or at motorway rest areas may result in disrupted sleep (Popp et al. 2015). Second, the accumulation of sleep loss across the study period was operationalized as the sum of daily sleep compared to self-reported sleep need. This relies on the premise that individuals accurately estimate their basal sleep need (Van Dongen et al. 2003b). Another way to deduce the individual sleep need would have been to examine the amount of sleep obtained during days off (Philip et al. 2002), although our results suggest that the drivers catch up on lost sleep even after two days off. Nevertheless, our method overlooks the fact that recovering from lost sleep may not require proportional (Borbély et al. 2016) or even habitual amounts of sleep (McCauley et al. 2009). Furthermore, an adaptive neural mechanism may stabilize neurobehavioral function under prolonged mild to moderate sleep restriction, delaying subsequent recovery (Belenky et al. 2003; Drake et al. 2001). We acknowledge that our method of calculating the accumulated sleep loss in connection with work shifts did not account for the temporal distribution of the prior sleep periods (Erren et al. 2017).

In conclusion, although the amount of the obtained sleep across a two-week period was close to sufficient among these long-haul truck drivers on average, severe degrees of accumulated sleep loss were not uncommon. Compared to day or evening shifts, morning, but not night shifts, were associated with accumulated sleep loss. Sleep during days off generally exceeded individual sleep need, irrespective of type of prior work shift. The accumulated sleep loss over three days was associated with slight increases in self-assessed on-duty sleepiness.

Acknowledgements

We gratefully acknowledge the contributions of Hanna-Kaisa Hyvärinen and Maria Sihvola. This work was supported by the Jenny and Antti Wihuri Foundation; Finnish Work Environment Fund under Grant 109378; and Nordic Programme on Health and Welfare under Grant 74809.

Conflict of interest: We declare no conflicts of interest.

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Appendix A

Regression models using generalized estimating equations (GEE) were fit to examine the sleep compared to individual sleep need in association with morning and night shifts compared to day or evening shifts (Supplementary Table 1), the sleep compared to sleep need in association with days off preceded by different shift types or day off (Supplementary Table 2), comparisons between single days off and single days off preceded by so-called recovery days (post night shifts) (Supplementary Table 3), and finally, comparisons of the sleep compared to sleep need between in association with two (Supplementary Table 4) and three consecutive days off (Supplementary Table 5). All coefficients are in the format of sleep compared to sleep need; i.e., positive values denote sleep in excess of sleep need.

Supplementary Table 1. GEE results for sleep vs sleep need in 72h prior to shift end (h).

		95% CI		
Term	*β*	Low	High	*p*
(Day/Evening)	0.853	-0.967	2.673	0.341
First night	-0.263	-2.174	1.648	0.780
Successive night	-1.765	-3.906	0.377	0.103
Morning	-2.862	-4.423	-1.302	0.001

Note: Terms in parentheses are model intercepts. 95% CI = 95% confidence intervals for model coefficients (*β*). *p* values are for F tests of regression term significance (Fay & Graubard, 2001). Correlation structure: exchangeable.

Supplementary Table 2. GEE results for sleep vs sleep need (h) in association with different shift types or days off.

		95% CI		
Term	*β*	Low	High	*p*
(Day off)	0.979	0.603	1.356	0.000
Night	0.424	-0.097	0.946	0.108
Morning	0.134	-0.507	0.775	0.673
Day	0.192	-0.324	0.708	0.455

Note: Terms in parentheses are model intercepts. 95% CI = 95% confidence intervals for model coefficients (*β*). *p* values are for F tests of regression term significance (Fay & Graubard, 2001). Correlation structure: independent.

Supplementary Table 3. GEE results for sleep vs sleep need (h) in association single days off.

Term	*β*	95% CI		*p*
		Low	High	
(Single day off)	1.368	0.371	2.364	0.011
Single day off + recovery day	0.167	-1.033	1.367	0.776

Note: Terms in parentheses are model intercepts. 95% CI = 95% confidence intervals for model coefficients (*β*). *p* values are for F tests of regression term significance (Fay & Graubard, 2001). Correlation structure: independent.

Supplementary Table 4. GEE results for sleep vs sleep need (h) in association with two consecutive days off.

Term	*β*	95% CI		*p*
		Low	High	
(First day off)	1.330	0.789	1.872	0.000
Second day off	-0.175	-0.651	0.302	0.456

Note: Terms in parentheses are model intercepts. 95% CI = 95% confidence intervals for model coefficients (*β*). *p* values are for F tests of regression term significance (Fay & Graubard, 2001). Correlation structure: exchangeable.

Supplementary Table 5. GEE results for sleep vs sleep need (h) in association with three consecutive days off.

Term	*β*	95% CI		*p*
		Low	High	
(First days off)	1.240	0.470	2.010	0.003
Second days off	-0.586	-1.320	0.152	0.112
Third days off	-0.218	-1.060	0.622	0.592

Note: Terms in parentheses are model intercepts. 95% CI = 95% confidence intervals for model coefficients (*β*). *p* values are for F tests of regression term significance (Fay & Graubard, 2001). Correlation structure: independent.