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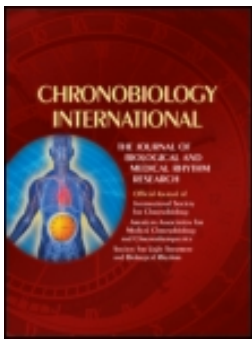
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SLEEP LENGTH AS A FUNCTION OF MORNING SHIFT-START TIME IN IRREGULAR SHIFT SCHEDULES FOR TRAIN DRIVERS: SELF-RATED HEALTH AND INDIVIDUAL DIFFERENCES

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Forty-six male train drivers (mean age = 46.5, SD = 5.1) were recruited to participate in a diary study for 14 consecutive days with questions about their sleep and working hours. A polynomial mixed-effect regression model showed a curvilinear relation ($p < .001$) between shift-start time and sleep duration for shifts starting at 03:00–12:00 h and with a near linear increase for ones starting between 04:30 and 09:00 h of approximately 0.7 h for every 1 h the shift was delayed. The longest sleeps were estimated at ~8 h before shifts that started at ~10:00 h. The shortest sleeps were found for shifts that started before 04:30 h and were estimated at ~5 h. Individual differences were estimated with a random-effect standard deviation of 0.51 h, independent of shift-start time ($p = .005$). One-half of the between-subject variance was explained by subjective health. A one-step decrease in health was associated with a 26 min increase in sleep length. The results have practical implications for constructing shift schedules. Early morning shifts reduced sleep length substantially and should be mixed with later start hours to avoid the accumulation of sleep debt. Delaying the shift-start past 10:00 h had little effect on sleep opportunity; however, delaying shift-start to between 04:30 and 9:00 h had a strong impact on sleep length, with 70% of the extra time used for sleep, suggesting large positive effects for this range of shift-start times. (Author correspondence: michael.ingre@stressforskning.su.se)

Keywords Shift-start time, Sleep duration, Train drivers, Irregular shift schedules

INTRODUCTION

Sleepiness and fatigue are major risk factors for accidents in the transport sector (Åkerstedt & Horne, 1995; De Pinho et al., 2006; Dinges, 1995; Jay et al., 2006; Jones et al., 2006). One of the most important factors

determining sleepiness is prior sleep-length. Partial and total sleep-deprivation has been shown to drastically increase sleepiness and reduce performance in laboratory studies (Belenky et al., 2003; Van Dongen & Dinges, 2003), which suggests that occupational groups with frequent exposure to sleep deprivation and sleepiness are at elevated risk for accidents. This is particularly true for shift workers with extremely irregular work hours, short rest times, and frequent night and early morning work (Åkerstedt, 2003).

There are numerous shift-work studies that indicate sleep length is shortened after night as well as before morning shifts (Axelsson et al., 1998, 2004; Gillberg, 1998; Härmä et al., 2002; Ingre et al., 2000; Kandelaars et al., 2006; Kecklund et al., 1994, 1997; Sallinen et al., 2003). Most shift-work studies describe shifts with relatively fixed start hours; however, some groups have more irregular schedules with a large variation of shift-start times. This is particularly true for train drivers with very early morning work. In Swedish long-distance and commuter-passenger train drivers, the prevalence of early morning shifts (starting between 03:00–06:00 h) has been estimated to be 28% of the total number of shifts (Ingre et al., 2000). Hak and Kampman (1981) used another criterion for Dutch, mainly passenger, train drivers and estimated 7.5% early morning (04:00–06:00 h) and another 25% morning (06:00–08:00 h) shift-start times. Härmä et al. (2002) reported a prevalence of 26% of shift-start times between 03:00–07:00 h) in Finnish cargo and passenger-train drivers. Collectively, these studies indicate the need for knowledge about sleep in connection with morning shifts that may begin anytime from the early to later morning hours so that accurate models for predicting sleep recovery can be developed for complex shift schedules.

In a previous experimental field study, we found that sleep length was increased by 1 and 2 h, respectively, when the shift-start time was delayed from 05:49 to 07:49 and 09:49 h, indicating a 0.5 h increase in sleep length for every 1 h later shift-start (Ingre et al., 2004). The objective of the present study was to extend the knowledge gained from our first study using observed data to estimate the relationship between shift-start time and sleep length for shifts commencing between 03:00–12:00 h. A second objective was to separate within- and between-subject effects to evaluate individual differences in sleep length in those working an irregular shift schedule.

METHODS

Forty-six male train drivers (mean age = 46.5, SD = 5.1) were recruited to participate in a diary study for 14 consecutive days. The train drivers were driving a mix of long-distance passenger (up to 4–5 h

drives) and local commuter trains in the area of Stockholm, Sweden. The study was approved by the local ethical committee at Karolinska Institute and was conducted in accordance with the Helsinki Committee rules, which conforms with the journal's ethical requirements (Touitou et al., 2006).

The diary consisted of questions about the workers sleep, workday, stress, and sleepiness, but in the present study, only data about sleep times and working hours are used. The train drivers also completed a questionnaire with questions about background data plus overall health and well-being. A selection of these variables was used to try to explain individual differences in sleep length. Descriptive statistics of sleep and work variables are presented in Figure 1.

Data were analyzed using a mixed-effects regression model with sleep length the dependent variable and time of shift-start the next morning as the predictor. Sleep length was calculated as the time between the subjects rated time of falling asleep and final awakening. Individual differences in sleep length were modeled by means of a random intercept. The analyses were performed with the xtmixed procedure for Stata 9.2 (StataCorp, 2003).

Only sleeps that preceded shifts that commenced between 03:00 and 12:00 h were analyzed ($n = 230$). A linear regression model was fitted and used as a baseline model. However, as the function is likely to be curvilinear, with both a floor and a ceiling effect on sleep length, a second- and third-order polynomial regression model was also fitted and tested for significance against the baseline model by means of a likelihood ratio test.

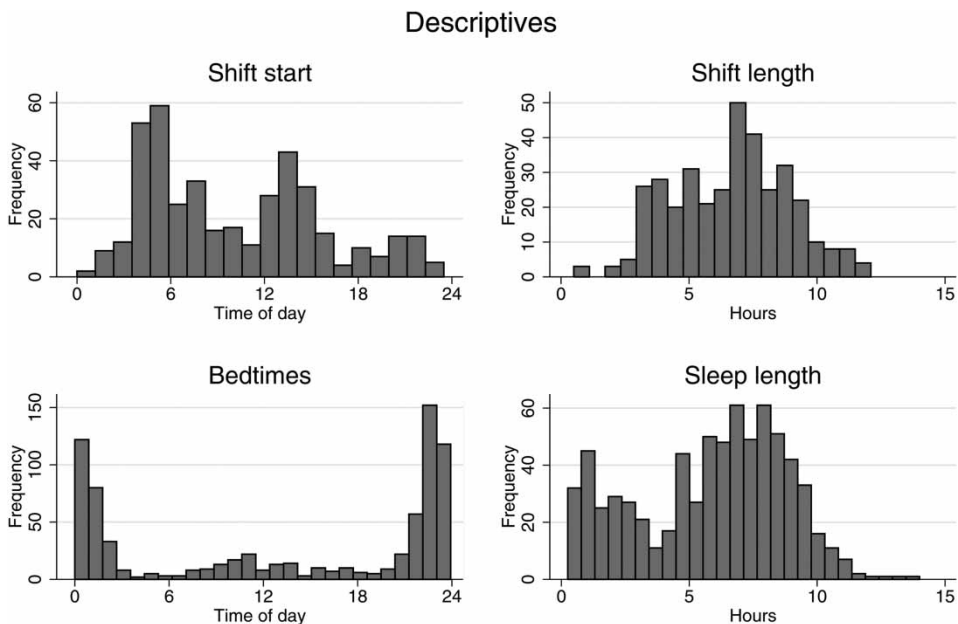


FIGURE 1 Descriptive statistics of working hours and sleep variables.

Individual differences were tested for significance with an adjusted likelihood ratio test based on a 50/50 mixture of chi-square distributions, with one and zero degrees of freedom to account for the boundary effect of zero variance. The models were estimated with maximum likelihood to meet the assumptions behind the likelihood ratio test during model testing, but the final model was estimated using restricted maximum likelihood. In addition, explained variance was calculated for the final model by means of the squared Pearson correlation coefficient between predicted and observed data. This was performed for a model with only a random intercept as well as the full model with fixed effects to illustrate the influence of fixed and random effects on explained variance in the dataset.

Empirical Bayes' predictions of individual subjects' deviation from the fixed part of the model was used to analyze individual differences. These predictions were plotted (see Figure 2), but also scored into a variable describing individual differences in habitual sleep length and correlated against a few variables from the questionnaire to explore possible explanations of the individual differences.

RESULTS

The observed data for sleep lengths and shift-start times are plotted in Figure 2. A linear regression model showed a significant effect of shift-start time, indicating that sleep length was increased with $0.443 \pm .04$ (coefficient $\pm$ standard error) h for every 1 h the shift-start time was delayed ($p < .001$). A second-order polynomial regression model did not improve the fit of this model over the baseline one ($\chi^2 = 3.47$, $df = 1$, $p = .062$).

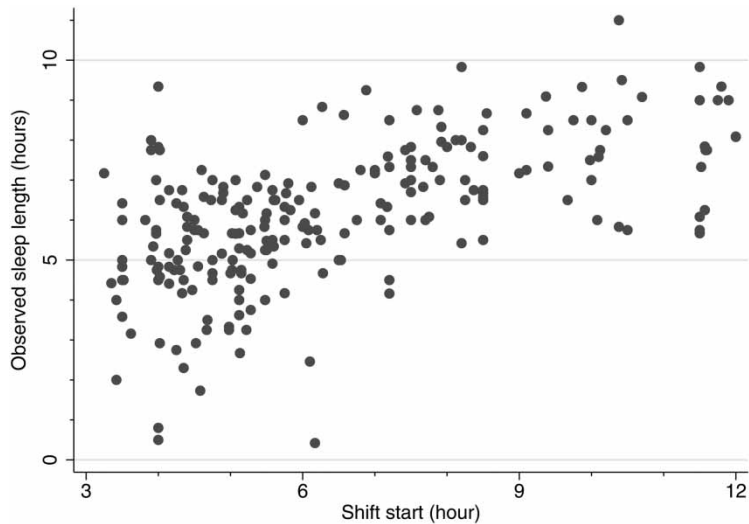


FIGURE 2 Observed sleep length plotted against clock hour of shift-start time (n = 230).

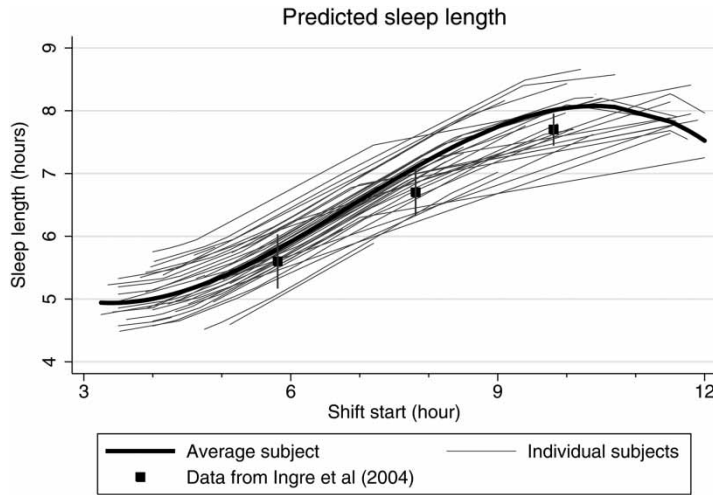


FIGURE 3 Empirical Bayes' prediction of sleep length for the average subject and individual subjects based on the third-order polynomial model. Plots from individual subjects only use observed data points, which makes these lines linear over sections where data are missing. For comparison, the figure also includes mean $\pm 95\%$ confidence intervals from an experimental field study of train drivers involving three 12 h shifts starting at 05:49, 07:49, and 09:49 h (Ingre et al., 2004).

The third-order regression model did improve the model fit, both over the second-order ($\chi^2 = 5.71$, $df = 1$, $p = .017$) and baseline ($\chi^2 = 9.18$, $df = 2$, $p = .010$) model, indicating a curvilinear function between shift-start time and sleep length. A fourth-order model did not further increase model fit ($\chi^2 = 2.11$, $df = 1$, $p = .146$).

The final model showed a standard deviation of the random effect of $0.514 \pm .13$, indicating individual differences in habitual sleep length. The residual error was estimated with a standard deviation of $1.32 \pm .68$. An adjusted likelihood ratio test indicates the individual differences to be significant ($\chi^2 = 6.55$, $p = .005$). The function from the final model is presented in Figure 3, and it suggests a near linear increase in sleep length with later start times for shifts beginning between $\sim 04:30$ and $09:00$ h. Outside these hours, the function levels out, revealing little to no increase; for shifts starting near noon, the results indicate a possible slight decrease in sleep length with later shift-start times. A linear regression model fitted only to shifts that began between $04:30$ and $09:00$ h indicates an increase in sleep length of $0.709 \pm .08$ h for every 1 h delay in the shift-start time. Explained variance for a model including only a random intercept was estimated at 51%; it increased to 71% when the polynomial function was added to the model. A prediction based on only the fixed part of the model explained 61% of the variance.

The estimated random-effect variance was also used to score empirical Bayes' predictions, also known as best linear unbiased predictors (BLUPs), of individual differences in sleep length into a separate variable. The range of the scored variable indicates that individual subjects differed in sleep length between $-.82$ and $+.75$ h from the group mean. This variable was correlated against a number of background variables to explore possible explanations of these individual differences. Non-significant correlations were showed by: age ($r = .016$), having children < 7 yrs ($r = .148$), morning type ($r = -.197$), self-rated sleep need ($r = .148$), sufficient sleep ($r = -.147$), satisfaction with work hours ($r = -.261$), and satisfaction with work situation ($r = -.106$). Significant ($p < .05$) correlations were observed for: sleep quality ($r = -.323$), frequency of sleepiness complaints ($r = .333$), and self-rated level of health ($r = -.453$). The results indicate that train drivers with poor sleep quality, poor self-rated level of health, and more frequent complaints of sleepiness showed longer sleep length, independent of shift-start times. A stepwise-regression model suggested self-rated health to be the best predictor of the individual differences. The other predictors did not add to the explained variance over the self-rated level of health. Adding level of self-rated health to the above third-order polynomial model improved model fit ($\chi^2 = 11.25$, $df = 1$, $p < .001$) and reduced the standard deviation of individual differences from 0.51 to 0.36 . The model suggest that a one-step decrease in self-rated health (1 = very poor, 5 = excellent, mean = 3.98 , $SD = .86$) increased sleep length by $443 \pm .12$ h, independent of shift-start time. Individual differences were no longer significant in the final model ($\chi^2 = 1.98$, $df = 1$, $p = .079$). The explained variance of the fixed part of the model increased from 61% to 65% when self-rated health was added as predictor.

In a final set of analyses, the three sleeps visible in Figure 3 that were shorter than 1 h were removed as outliers. The analyses confirmed the previous results; however, the individual differences were significant also in the full model with self-rated health ($\chi^2 = 3.34$, $df = 1$, $p = .034$)

DISCUSSION

The present study shows a relationship between shift-start time and sleep length the prior night in train drivers working a very irregular shift schedule. Furthermore, this relation was found to be curvilinear over the shift-start times for the span of 03:00–12:00 h, with a near linear increase between 04:30 and 09:00 h of approximately 0.7 h for every 1 h the shift was delayed. Individual differences were estimated with a random-effect standard deviation of 0.51 h, independent of shift-start time.

The longest sleeps were estimated at ~ 8 h for the average subject before shifts that started at approximately 10:00 h. Between 10:00 and 12:00 h, sleep length seemed to decrease by ~ 0.5 h. The decrease should be interpreted with caution, though, as data are relatively scarce for these hours. However, a plausible explanation is that the train drivers may have made room for other activities before work instead of maximizing sleep length on days with late work hours. The results indicate that for shift-start times before 10:00 h, most of the extra time made available by delaying the shift-start is used to prolong sleep.

The shortest sleeps, on average ~ 5 h, were found for shifts that began before 04:30 h. Compared to our previous study (Ingre et al., 2004), the predicted sleep length was slightly longer, but the general pattern was similar (see Figure 2). The slight difference in sleep length is likely to be explained by the focus on tough 12 h shifts with long drives for a highly selected and older group in our previous study.

The results also showed individual differences in sleep length with a random-effect standard deviation of .51 h. In a recent study, Tucker et al. (2007) used a similar statistical technique (i.e., random intercept) in an experimental design, and estimated the random-effect standard deviation of total sleep time at 0.7 h. The higher estimate may be related to using polysomnography and a more controlled experimental design. However, the most important factor is likely to be the 12 h extended time-in-bed period. The train drivers of the present study were constrained to a real-life situation working an irregular shift schedule with little opportunity for 12 h in-bed periods. Lammers-van der Holst et al. (2006) present a standard deviation of the group mean of .82 h for young recruits (mean age: 28 yrs) at the police academy attending school at fixed daytime hours, thereby indicating an even larger variation for young individuals with fixed daytime “working hours.”

The individual differences found in the present study are based on empirical Bayes's estimates, also known as BLUPs, in (polynomial) linear models (Rabe-Hesketh & Skrondal, 2005; Skrondal & Rabe-Hesketh, 2004). Tucker et al. (2007) presented “95% reference intervals” calculated as the standard deviation of the random intercept multiplied by 3.92. Such an estimate would be 2 h in the present study, and because it does not adjust for measurement error, it is larger than the extreme range ($-.82$ to $+.75$ h) of the empirical Bayes' estimates for all the studied subjects.

The explorative analyses showed that the random-effect standard deviation was reduced from 0.51 to 0.36 h when the level of self-rated health was entered into the model, indicating a 50% reduction of the random-effect variance, which leads to a 4% increase in the variance explained by the fixed part of the model. A one-step decrease in health on a five-point scale was associated with an average increase in sleep length of 26 min. The results suggest that a large portion of the observed individual

differences was not individual differences per se (i.e., traits), but they instead might constitute a more or less stable state associated with within-subject variation in health status. However, it is not possible to draw any conclusions about causality due to the explorative approach and observational design. The results need to be interpreted with caution and verified in future studies; however, the findings do correspond well with epidemiological studies showing increased risk of morbidity and mortality for long sleepers, thus suggesting a link between long sleep and poor health (Grandner & Drummond, 2007; Kripke et al., 2002; Youngstedt & Kripke, 2004). Similar, but less pronounced, correlations were found also for sleep quality and sleepiness, indicating a possible association between poorer sleep quality and less sleepiness complaint with increased sleep length.

The residual error term was relatively large in the present study with a standard deviation of 1.3 h. Only 13% of the total error variance could be explained by individual differences compared to 46% in the study by Tucker et al. (2007). This illustrates the main challenges of modeling sleep using real-life data. A number of factors influence sleep besides working hours. Social factors influence the opportunity to sleep, and prior sleep history influences the need for sleep. Stress- and health-related complaints might influence the ability and need for sleep. These factors interact with working hours to produce the final sleep-wake pattern, and in the present study it was only possible to estimate the average effect of shift-start times on sleep length.

The present study constitutes a first attempt to model within-subject sleep length in an extremely irregular shift schedule, taking into account individual differences. The results have practical implications for constructing shift schedules. Thus, early morning shifts will reduce sleep length substantially and should be mixed with later shift-start times to avoid an accumulation of sleep debt. The longest sleeps were estimated at approximately 8 h for shifts commencing at 10:00 h. Delaying the shift-start time past 10:00 h did not increase sleep length, indicating little to no extra recovery sleep for shifts with later start times. Delaying the shift-start time to between 04:30 and 09:00 h had a strong impact on sleep length, with 70% of the extra time used for sleep, thus suggesting large positive effects for shift beginning between these clock times.

The analyses were based on 230 sleeps of 46 subjects, an average of five sleeps per individual over a two-week period. The results of this study suggest that a large portion of observed seemingly trait-like individual variation might not constitute a trait but instead be associated with state variation in health. This calls for future studies with larger datasets and more longitudinal designs to address the stability of individual differences over longer time periods. Future modeling should also attempt to

incorporate additional factors into the model to reduce the residual error term, which further increases the need for larger datasets.

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