Current Biology

Report

Aligning Work and Circadian Time in Shift Workers Improves Sleep and Reduces Circadian Disruption

Highlights

- Extreme chronotypes slept up to 0.5 hr longer on workdays
- Self-reported sleep quality in extreme chronotypes improved on workdays
- Overall social jetlag was reduced by ≈1 hr
- Frequent night shifts are better tolerated by very late chronotypes

Authors

Céline Vetter, Dorothee Fischer, Joana L. Matera, Till Roenneberg

Correspondence

till.roenneberg@med.uni-muenchen.de

In Brief

The health deficits associated with shift work have been linked to circadian stress and disrupted sleep. Vetter et al. performed the first intervention study in a real-life industrial setting that adjusted shifts to individual chronotype and show that workers sleep longer and better and suffer from less social jetlag.

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Aligning Work and Circadian Time in Shift Workers Improves Sleep and Reduces Circadian Disruption

Céline Vetter,[1,2] Dorothee Fischer,[1] Joana L. Matera,[1] and Till Roenneberg[1,*]
[1]Institute of Medical Psychology, Ludwig-Maximilian-University, 80336 Munich, Germany
[2]Present address: Channing Division of Network Medicine, Brigham and Women's Hospital, Harvard Medical School, 181 Longwood Avenue, Boston, MA 02115, USA
*Correspondence: till.roenneberg@med.uni-muenchen.de
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SUMMARY

Sleep loss and circadian disruption—a state of misalignment between physiological functions and imposed sleep/wake behavior—supposedly play central roles in the etiology of shift work-related pathologies [1–4]. Circadian entrainment is, however, highly individual [5], resulting in different chronotypes [6, 7]. Chronotype in turn modulates the effects of working times: compared to late chronotypes, earlier ones sleep worse and shorter and show higher levels of circadian misalignment during night shifts, while late types experience more sleep and circadian disruption than early types when working morning shifts [8]. To promote sleep and reduce the mismatch between circadian and working time, we implemented a chronotype-adjusted (CTA) shift schedule in a factory. We abolished the most strenuous shifts for extreme chronotypes (i.e., mornings for late chronotypes, nights for early ones) and examined whether sleep duration and quality, social jetlag [9, 10], wellbeing, subjective stress perception, and satisfaction with leisure time improved in this schedule. Intermediate chronotypes (quartiles 2 and 3) served as a control group, still working morning (6:00–14:00), evening (14:00–22:00), and night (22:00–6:00) shifts, with two strenuous shifts (out of twelve per month) replaced by evening ones. We observed a significant increase of self-reported sleep duration and quality, along with increased wellbeing ratings on workdays among extreme chronotypes. The CTA schedule reduced overall social jetlag by 1 hr, did not alter stress levels, and increased satisfaction with leisure time (early types only). Chronotype-based schedules thus can reduce circadian disruption and improve sleep; potential long-term effects on health and economic indicators need to be elucidated in future studies.

RESULTS AND DISCUSSION

We designed the chronotype-adjusted (CTA) schedule in view of employees' chronotypes (n = 114, Figure 1A), as assessed by mid-sleep time on free days after evening shifts, corrected for sleep debt during the work week (MSF^{E}_{sc}) with the Munich chronotype questionnaire for shift workers ($MCTQ^{Shift}$) [11], and production requirements (e.g., equally staffed shift groups). Employees were ranked and assigned by chronotype quartiles to the CTA schedule (Early1 = 2:26–3:34, Early2 = 3:36–4:08, Late1 = 4:11–4:52, and Late2 = 4:55–7:34). The local ethics committee approved the study, and participants gave written informed consent.

In general, the chronotype distribution resembled the one of the general population (Figure 1A; Kolmogorov-Smirnov test: D = 0.45, p = 0.21) but lacked extreme mid-sleep times, i.e., measures of $\leq$1:00 or $\geq$9:00 [5]. We examined the match between sleep log (n = 47) and actimetry-derived (n = 19) homologs with the questionnaire-based chronotype proxy MSF^{E}_{sc}, and both corresponded well to the $MCTQ^{Shift}$ chronotype measure (range, intraclass correlation coefficient [ICC] = 0.74–0.78, $p < 0.001$; Figure 1B; for further information, see Supplemental Experimental Procedures, 3.2.).

Participants filled out daily sleep logs, reporting sleep onset and offset, quality, and wellbeing (minimum: 0, maximum: 10, respectively) within 4 weeks of baseline measures in a fast-forward rotating schedule (Figure 2A, "2-2-2"), directly after transition to the CTA schedule (CTA1), and within the last 4 weeks (CTA2) of the 5-month intervention period. Similarly, questionnaire-based perceived stress levels [12] and satisfaction with the amount of free time [13] were assessed during baseline and twice within the CTA schedule.

Overall, 58 employees (51%) filled out a sleep log; dropout rates were low (3.5%). In the analyses, we included all employees (1) whose chronotype was congruent with their group assignment (group-specific MSF^{E}_{sc} range ± 0:15) and (2) who completed sleep logs at baseline, CTA1, and CTA2 (for information on recruitment and exclusion procedures, see Supplemental Experimental Procedures, 3.1.). Late1 was not eligible for analysis, as two participants only fulfilled those criteria. The final sleep log sample (n = 28) included individuals that were mostly male (96%), 40.4 ± 10.6 years old (mean ± SD), overweight

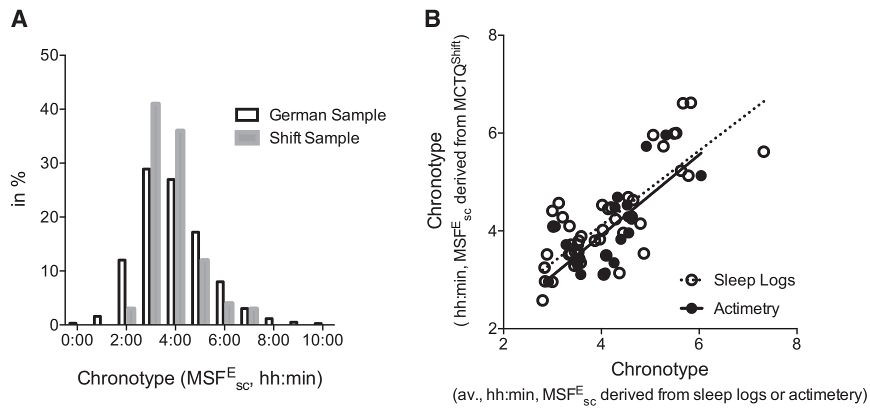

Figure 1. Chronotype Distributions and the Validity of the Chronotype Measures

(A) Chronotype distribution in Germany (2012, MCTQ database, n = 72,469) and among the shift workers at the steel factory (n = 114).

(B) Correlation between the MCTQ^{Shift}-derived chronotype variable (mid-sleep on free days, corrected for sleep debt accumulated during the work week) with averaged (av.) homologs extracted from sleep logs (open circles and dotted line, n = 47) and actimetry (black circles and solid line, n = 19).

(BMI of 28.2 ± 5.6 kg/m^2), in a relationship (68%), had at least one child (54%), and had a chronotype of 03:58 ± 01:01. Those characteristics were similar across subgroups and instrument-specific samples (Table S1), with the exception of younger Late2 participants (29.3 ± 7.4 years). We used repeated-measures ANOVAs to assess the effects of the CTA schedule (see also Supplemental Experimental Procedures, 3.2.).

The CTA Schedule Increases Sleep Duration and Quality on Workdays

We initially aimed at using actimetry for objective sleep timing and duration assessments. However, recruitment rate (n = 26, 22.4%) was low, and after exclusions (see Supplemental Experimental Procedures, 3.1.), only 19 participants were eligible for analysis. We therefore used all data available at baseline and compared sleep log (n = 47) and actimetry-derived (n = 19) sleep duration and timing (see Supplemental Experimental Procedures, 3.3. and 3.4.; overlap between samples: n = 17). Indeed, self-reported and objective sleep duration and mid-sleep parameters (sleep onset + 0.5 × sleep duration) corresponded well to one another (range, ICC = 0.65–0.94, p values < 0.007, Bonferroni corrected), suggesting that self-reports were indicative of actual behavior.

Workday sleep duration differed significantly between groups ($F(2,25) = 7.40$, $p = 0.003$, partial $\eta^2 = 0.37$) with Early1 sleeping less (6 hr 23 min ± 29 min) than Late2 (7 hr 11 min ± 56 min, Bonferroni-corrected post hoc test: p = 0.003; Table S2 summarizes group-specific means ± SD). Both slept longer at CTA2 than at baseline (Early1: +28 min; Late2: +24 min; $F(2,50) = 3.84$, $p = 0.03$, partial $\eta^2 = 0.13$), while Early2 slept 14 min less (Figure 3A). Free day sleep duration showed a non-significant decrease from baseline to CTA2 in Early1 (−24 min), Early2 (−13min), and Late2 (−58 min) (Figure 3B).

Sleep log-derived sleep quality (scale from 0 to 10: "very well") improved on workdays in Early1 (+1.17) and Late2 (+0.60) but remained similar in Early2 (+0.01; $F(2,50) = 3.48$, $p = 0.04$, partial $\eta^2 = 0.12$; Figure 3C). Free day sleep quality was not affected by the shift schedule change (p = 0.65). Our results suggest that reducing exposure to the most strenuous shifts in extreme chronotypes could ameliorate chronic sleep deprivation, a major health and security hazard in shift workers [1, 14], and improve sleep quality on workdays. Early2, who experienced mainly social and ergonomic changes, but no major reduction of strenuous shifts, showed relatively stable measures of sleep duration and quality throughout the study. Despite the lack of a true control condition, this is suggestive of the potential benefit of CTA schedules on self-reported sleep duration and quality.

The CTA Schedule Can Reduce Circadian Misalignment

Social jetlag [9, 10], our central measure of circadian misalignment, was derived from sleep logs and computed by the absolute difference between the mid-point of sleep on workdays and free days. In shift workers, total social jetlag is the weighted average of shift-specific social jetlag, thereby accounting for the

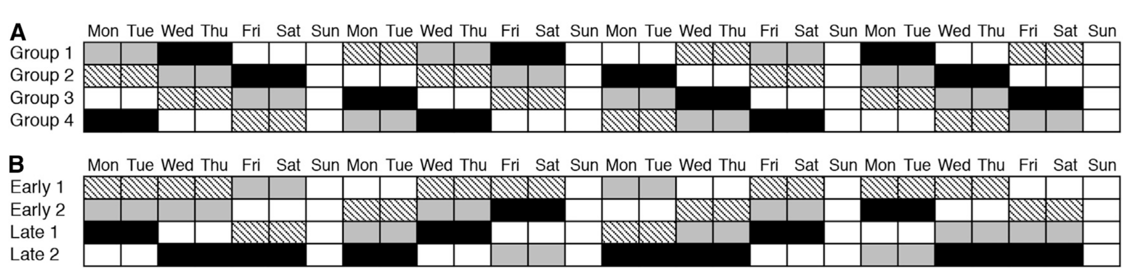

Figure 2. Shift Schedules

(A) The initial 2-2-2 schedule. Employees work the identical sequence of shifts. Morning shift (MS) is indicated by the striped box; evening shift (ES) is indicated by the gray box; night shift (NS) is indicated by the black box; and free day is indicated by the white, black-rimmed box.

(B) The chronotype-adjusted (CTA) schedule. We abolished the theoretically most strenuous shifts for extreme chronotype groups (NS for Early1, MS for Late2). The intermediate groups, Early2 and Late1, experienced less dramatic changes with regards to the shift sequence (Early2: two NS less, two ES more; Late1: two MS less, two ES more).

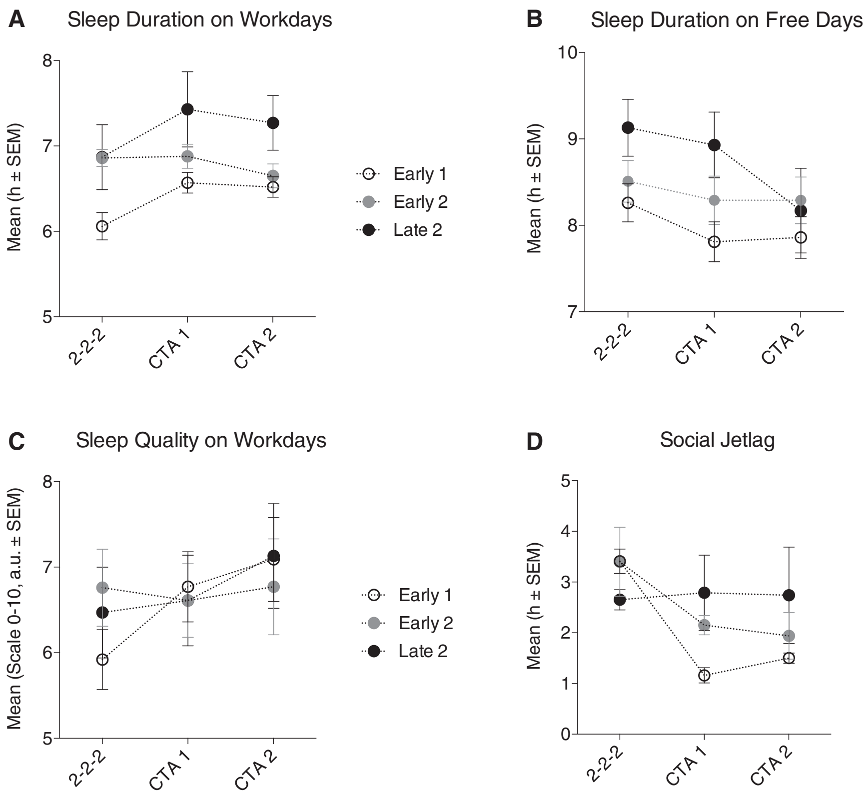

Figure 3. Effects of the CTA Schedule on Sleep and Circadian Misalignment

(A) Self-reported sleep duration on workdays increases significantly for Early1 and Late2 in the CTA schedule, as compared to baseline assessments.

(B) Free day sleep duration decreased in the CTA schedule, especially in extreme chronotypes, but this change was not significant. Sleep duration in Early2 was stable across time points.

(C) Sleep quality improved significantly on workdays, again only in extreme chronotypes, while the control group Early2 did not show significant changes across schedules (higher values represent better sleep quality).

(D) Social jetlag decreased most in the earlier chronotypes (Early1, D); Early2 showed a slight decrease of social jetlag when comparing baseline to CTA2. Late2, however, on average did not show changes in circadian misalignment. An intention-to-treat analysis comprising all participants—irrespective of whether their chronotype was an ideal match with the intervention group, i.e., irrespective of congruence—showed that the CTA schedule could reduce circadian misalignment by 1 hr (data not shown), which represents a meaningful change, as we have previously reported that 1 hr of social jetlag can increase the odds of being overweight [10].

frequency of given shifts within a schedule ([11]; for computation details, see Supplemental Experimental Procedures).

The CTA schedule reduced participants' social jetlag (2-2-2 schedule: 3 hr 17 min ± 20 min versus CTA2: 1 hr 52 min ± 1 hr 10 min; $F(2,50) = 8.86$, $p < 0.001$, partial $\eta^2 = 0.29$; Figure 3D). Compared to baseline, Early1 and Early2, but not Late2, showed less social jetlag at CTA2 (−1 hr 55 min and −1 hr 28 min, respectively, $F(4,50) = 2.85$, $p = 0.035$, partial $\eta^2 = 0.21$). At CTA2, Early1 showed comparable levels to the day-working population [10]. Interestingly, SDs in Late2 increased from 15 min at baseline to 1 hr 55 min at CTA2, suggesting that social jetlag increased for some participants but decreased for others. Further analyses in this group—independent of congruence (i.e., whether their chronotype was within the ideal chronotype range for Late2)—showed that earlier chronotypes indeed had significantly higher levels of social jetlag at CTA1 ($r = -0.64$, $p < 0.05$, $n = 11$). This association was attenuated at CTA2, potentially due to a reduced sample size ($r = -0.44$, $p = 0.19$, $n = 6$). Sleep duration and quality were also associated with chronotype in Late2 (r values = 0.67–0.83, $p < 0.05$, n = 10–12), whereas wellbeing showed a significant correlation for CTA2 only ($r_{CTA1} = 0.54$, $p = 0.08$, $n = 11$; $r_{CTA2} = 0.86$, $p = 0.003$, $n = 9$; see Figures S1A–S1D). Altogether, these findings suggest that working up to 14 night shifts per month can be beneficial, but only for very late chronotypes. Last, we used an intention-to-treat analysis approach [15]—including all participants, irrespective of congruence between CTA group and individual chronotype—and observed a total decrease of social jetlag by 1 hr 2 min ($F(1.37,47.32) = 8.86$, $p = 0.002$, partial $\eta^2 = 0.21$, Greenhouse-Geisser [GHG] corrected).

Effects on Wellbeing, Satisfaction with Leisure Time, and Perceived Stress

Compared to baseline, sleep log-derived wellbeing ratings on workdays increased in Early1 (+1.3 points, 0–10 scale) and Late2 (+0.76) but decreased slightly in Early2 (−0.36) at CTA2 (Figure 4A; $F(4,50) = 3.52$, $p = 0.013$, partial $\eta^2 = 0.22$). Free day wellbeing ratings did not change significantly ($p > 0.1$).

Forty-five participants answered the sub-section "Your social and domestic situation" of the standard shiftwork index (SSI; German translation, [13]) assessing satisfaction with the amount of leisure time (scale: 1, "not at all," to 5, "very much"). In general, satisfaction ratings decreased in the CTA schedule (CTA2 versus baseline, −0.24, Figure 4B; $F(3,41) = 8.24$, $p < 0.001$, partial $\eta^2 = 0.38$); however, patterns differed significantly across groups: ratings increased in Early1 (+0.48, scale from 0 to 5, 2-2-2 versus CTA2) but decreased in Early2 (−0.41), Late1 (−0.44), and Late2 (−0.59) ($F(5.05,68.95) = 2.95$, $p = 0.012$, partial $\eta^2 = 0.17$, GHG corrected). The increase observed in Early1 potentially reflects a gain in socially valuable time. Despite only small changes in work timing, both "control" groups were less satisfied, suggesting that other factors, such as the change in shift sequence (e.g., four consecutive evening shifts), may have interfered with leisure time. In Late2, satisfaction ratings declined most; it appears plausible that especially for younger employees, working at night on three out of four weekends per month might have significantly interfered with socially valuable time. Additionally, an increase in production demands during, but unrelated to, the CTA schedule led to an augmentation of weekly working hours on some weekends and might have further affected ratings [16]. Last, employees might not have fully

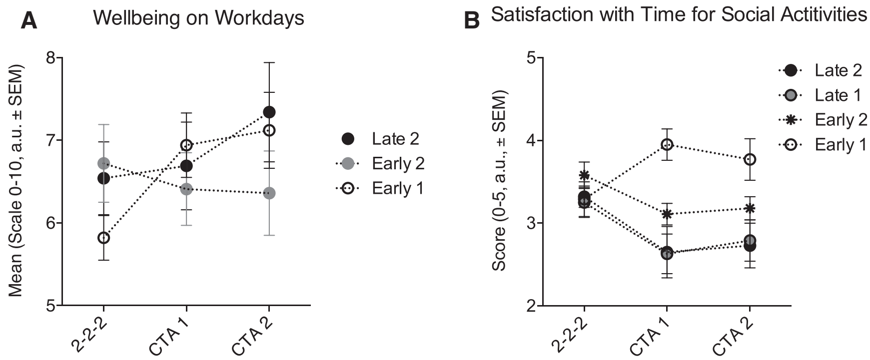

Figure 4. Changes in Self-Reported Wellbeing and Satisfaction with Leisure Time across Shift Schedules

(A and B) Wellbeing on workdays (A) changed significantly, dependent on shift group: extreme chronotypes (Early1 and Late2) felt better in the CTA schedule, as compared to baseline, while intermediate ones showed a slight decrease in wellbeing ratings. Satisfaction with time for social activities left by the schedule only increased in Early1, while it decreased in all three other groups (B). Better wellbeing and satisfaction ratings are represented by higher y axis values.

adapted family and social life to the CTA schedule, as it was introduced for a 5-month period only, potentially further entailing discontent.

The perceived stress scale (German translation, [12]) measures subjective stress appraisal in example situations (scale: 0, "never," to 4, "very often"), with higher sum scores indicating higher stress levels (maximum = 35). Compared to baseline, we observed a non-significant decrease in stress scores in all groups at CTA2 (total n = 33; Early1 = −4.58, Early2 = −0.22, Late1 = −3.0, Late2 = −4.59; all p values > 0.14).

Limitations, Implications, and Conclusions

Several limitations of our study are noteworthy: our sample is small and almost entirely male. Along with low statistical power and residual confounding inherent to field studies, this threatens the generalizability of the findings. However, in view of the consistency between self-reports and objective measures, the long-term recordings, and the concordance with predictions derived from cross-sectional studies, we believe our results constitute a proof of principle. Studies with larger samples are needed to understand to which degree our results can be extrapolated to the general population.

Additionally, this study benefitted from a unique financial framework, as employees did not experience any financial losses (e.g., due to fewer night shift bonuses), which may have biased their judgment. Also, we could not assess direct health-related, physiological measures in this study; more readily accessible variables, such as absenteeism or sick days, were not useful in the context of a 6-month-long intervention study.

Last, it is difficult to attribute the positive effects of the CTA schedule to the absence of the most strenuous shifts, as the shift schedule change concurrently altered other features of the schedule, such as rotation speed and shift sequence; Early1 and Late2, for example, experienced fewer shift changes as compared to their original schedule, which is thought to be advantageous for sleep and safety [17, 18]. Computational approaches may be a useful approach to disentangle the contribution of those highly nested factors.

The positive effects of the CTA schedule on sleep measures further suggest that extremely late chronotypes better tolerate frequent night shift work than earlier ones; however, we propose that weekly hours of frequent or permanent night shift workers should be minimized to avoid social disruption. We also recommend to staff night shifts with as little personnel as possible while assuring adequate performance. In our study, production processes required four equally staffed groups, yet we observe a bell-shaped chronotype distribution in the population [5] and in this sample. If night shifts are mandatory, as in many industrial and medical settings, working time arrangements should critically examine the manpower needed.

Shift schedules acknowledging circadian principles have been shown to improve satisfaction and subjective health more than three decades ago [19]. We took this a step further by personalizing working times according to chronotype. Our results indicate that such interventions can reduce circadian disruption and improve health-related outcomes, such as sleep [20]. Further studies are needed to extrapolate potential long-term effects of CTA schedules on health, social life, and economic indicators. Our results underline that shift-associated circadian disruption depends on individual internal time.

SUPPLEMENTAL INFORMATION

Supplemental Information includes Supplemental Experimental Procedures, one figure, and three tables and can be found with this article online at http://dx.doi.org/10.1016/j.cub.2015.01.064.

AUTHOR CONTRIBUTIONS

C.V. and T.R came up with the study concept and design. C.V., D.F., and J.L.M. collected data. C.V., D.F., J.L.M., and T.R. analyzed and interpreted the data. C.V. drafted the manuscript. D.F., J.L.M., and T.R. were responsible for critical revisions and intellectual contributions.

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