The effect of the innovative split-sleep schedule on objective and subjective sleep in nurses working night shifts

Abstract:

Shift work has grown extensively and is associated with decreased health and increased risk in the working environment. Sleeping and working at an adverse circadian time may result in these negative effects. The current study focused on the effect of a split-sleep schedule on subjective and objective sleep measurements in nurses working night shifts. We hypothesized that following the split-sleep schedule would result in a higher total sleep time (TST) and sleep efficiency (SE). Participants were randomly divided into a consolidated daytime condition (N = 11, mean ± age = 24.73 ± 2.28) and a split-sleep condition (N = 7, mean ± age = 25.57 ± 2.51). The daytime group slept once per 24 hours (e.g. 8.30 AM until 4.30 PM) and the split-sleep condition slept twice per 24 hours (e.g. 8.30 AM until 1.30 PM and 6.00 PM until 9.00 PM). The results showed that participants in the split-sleep condition obtained a significant higher subjective TST during night shifts compared to the participants in the consolidated daytime condition. No significant difference in the SE and TST two nights after the night shift series was found between the conditions. These results suggest that the innovative split-sleep schedule may be a good alternative to a consolidated daytime sleep as it may improve safety, productivity and counteract decreased health. It is expected that with a higher sample size these results will only be stronger.

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Introduction

Over the last few decades, shift work has grown extensively (Roach et al., 2017). The term shift work usually means that people have a work schedule outside the standard daytime 9 AM to 5 PM. According to Åkerstedt (1998), there are four types of shift work: day work, permanently displaced work hours, rotating shift work, and roster work. Many industries rely on shift work, because of e.g. increased customer demands and the emergence of global competition, industries are encouraged to expand to 24 h-a-day, seven days-a-week operations (Åkerstedt, 2003; Roach et al., 2017). In Europe alone, 20% of the working population is involved in some kind of shift work (Wang, Armstrong, Cairns, Key, & Travis, 2011). Especially in healthcare, shift work in the form of roster work is mostly. Roster shift work involves working in morning shifts, afternoon shifts, and night shifts. The shifts are irregular and more flexible than other types of shift work (Åkerstedt, 1998, 2003; Jackson, Banks, & Belenky, 2014; Keklund & Akerstedt, 1997; Muecke, 2005).

Risk Factors due to Shift work

According to Roach, Reid, & Dawson, (2003), shift workers have a poor quality of sleep compared to day workers. Roach et al., (2003) explain that long work hours and rotating work shifts hinder recovery and disturb social well-being. When their night shift is finished nurses are forced to sleep during the day. However, this sleep moment is not convenient as it interferes with the natural rhythm of the circadian clock that at that time of the day promotes wakefulness (Roach et al., 2003). Homeostatic and circadian processes control the quality of wakefulness and sleep in mammals (Arendt, 2010). The circadian clock is seen as an internal biological clock of which the primary role is to promote wakefulness during the internal biological day, and promotes the consolidation of sleep during the internal biological night. In shift workers, because of daytime sleep, a misalignment of the circadian clock occurs. Subsequently, the total sleep time during the day is shorter and of lower quality leading to sleep deprivation and excessive fatigue (Arendt, 2010).

A healthy adult needs 7.5 to 8.5 hours of sleep per day (Ruggiero & Redeker, 2014) and according to the National Sleep Foundation humans need a minimum of seven hours of sleep per night to prevent adverse effects on daytime alertness, reaction time and mood (Hirshkowitz et al., 2015). A critical consequence of loss of the amount of sleep concerns deficits in arousal and attention. Nurses aspire to give a high standard of care, but they will probably not be able to provide this standard due to incomplete recovery (Han, Yuan, Zhang, & Fu, 2016). When the degree of sleep deprivation increases, performance deteriorates, which could lead to serious mistakes (Muecke, 2005). To summarize, sleep deprivation and excessive fatigue have an adverse effect on performance in the short term and on the quality of patient care during night shifts.

Besides the above-mentioned short-term effects of shift work evidence has suggested that shift work may also affect long-term health and safety (Kecklund & Axelsson, 2016). The misalignment of the circadian clock can affect homeostatic body mechanisms and eventually result in, for example, metabolic disorders such as obesity and type 2 diabetes (Gonnissen, Hursel, Rutters, Martens, & Westerterp-Plantenga, 2013; Huang, Ramsey, Marcheva, & Bass, 2011). It is also associated with increased risk of occupational accidents, sleeping disorders and possibly elevated mortality risks as breast cancer, cardiovascular disease and gastrointestinal disorders (Arendt, 2010; Belenky, Jackson, Tompkins, Satterfield, & Bender, 2012; Han et al., 2016; Jackson et al., 2014; Kecklund, Milia, Axelsson, Lowden & Akerstedt, 2012; Muecke, 2005). In addition, a recent study of Marquié, Tucker, Folkard, Gentil, & Ansiau, (2015) also found that in the long-term shift work could chronically impair cognition.

Research suggests that adverse work environment exposure, lifestyle factors, and poor work-life balance contributes to the diseases associated with shift work and long working (Harrington, 2001). However, the relation between stressful working time arrangements and health impairments are not entirely understood. Conversely, recent research shows that incomplete recovery may play a key role, as incomplete recovery can be a result of short and disturbed sleep. Therefore, incomplete recovery is suggested to be an important mediator between difficult working times and ill health (Kecklund et al., 2012).

Split-Sleep

Shift work is inevitable because so many industries rely on it (Harrington, 2001). Therefore, it is necessary for people that work during shifts to find an optimal sleep pattern that realizes sufficient recovery time and improves total sleep time (Kecklund & Axelsson, 2016). On the one hand, the consolidated schedule is the most frequently used working schedule in the healthcare industry, which contains one work period and one rest period within a 24-hour period (Bohle, Quinlan, Kennedy, & Williamson, 2004). On the other hand, a split-sleep schedule may restore alertness and performance as sufficiently as consolidated sleep (Jackson et al., 2014; Schweitzer, Randazzo, Stone, Erman, & Walsh, 2006). A split-sleep schedule is defined as two or more sleep opportunities within a 24-hour period. This ranges from a primary sleep and one or more naps to multiple naps with no primary sleep (Jackson et al., 2014; Takeyama, Kubo, & Itani, 2005).

Split-Sleep Strategies

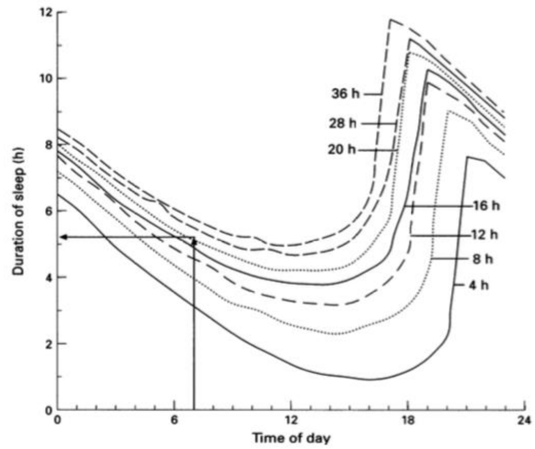
There is a variety of options to split-sleep within a period of 24 hours. One strategy is napping during the night shift. It has shown to effectively prevent the adverse effects resulting from night shift work (Takeyama et al., 2005). Nevertheless, this form of split-sleep has not been accepted due to sleep inertia and work environmental changes (Edwards, McMillan, & Fallis, 2013; Fallis, McMillan, & Edwards, 2011). Sleep inertia arises when a nap is longer than 30 minutes. Sleep inertia can be experienced right after awakening and could result in a period of disorientation, decreased performance or sleepiness and is more severe when the napping time increases (Ficca, Axelsson, Mollicone, Muto, & Vitiello, 2010; Tassi & Muzet, 2000). Additionally, sleep inertia can last for up to two hours (Takahashi M, Artio H, Takahashi, Arito, & Fukuda, 1999). This is not convenient, as the nurses need to be alert and maintain their quality of performance. Furthermore, sleeping during night shifts may result in work environmental changes which can lead to higher health costs (McMillan, & Edwards, 2011, Edwards, Mcmillan, and Fallis 2013). For example, investments have to be made to create napping rooms and extra staff is required during napping times to sustain productivity. It can be concluded that to avoid sleep inertia and work environmental changes the split-sleep opportunities should be implemented before and after the night shift.

Another strategy of split-sleep is to divide the sleep opportunities more equally. Jackson et al. (2014) conducted a laboratory study where a split-sleep condition, consisting of two 5 hour sleeping opportunities in 24 hours (time in bed 3.00 AM until 8.00 AM and 3.00 PM until 8.00 PM) was compared to a 10 hour consolidated night-time sleep (TIB 10.00 PM until 8.00 AM) and a 10 hour consolidated daytime sleep (TIB 10.00 AM until 8.00 PM). The results show that participants in the split-sleep schedule had a significant higher total sleep time (TST) than participants in the consolidated daytime sleep. Also, a laboratory study of Roach et al. (2017) compared a split-sleep schedule with a consolidated sleep. Here, the split-sleep schedule consisted of 4 hours of sleep per 14 hours and the consolidated sleep consisted of 7.6 hours of sleep per 28 hours. On the one hand, the results show that the participants in the split-sleep schedule had a lower percentage of wake after sleep onset and a greater percentage of slow wave sleep than the participants in the consolidated condition. On the other hand, the sleep onset latency was higher in the split-sleep condition and there was a greater percentage of stage 1 sleep. These results suggest that the split-sleep schedule may have been beneficial but more research has to be done to illuminate further on the subject.

To summarize, although a napping strategy can be beneficial, it is not practical for nurses working night shifts. In addition, more equally divided split-sleep schedules appear to be promising to oppose sleep deprivation during a night shift period. However, unfortunately, there is limited data available about the effectiveness of a split-sleep schedule in a real life setting (Ficca et al., 2010; Jackson et al., 2014).

Innovative split-sleep schedule

The current study uses a split-sleep schedule which is based on the prediction models of (Akerstedt & Folkard, 1995, 1996a, 1996b) in which we propose to have sleep sessions before and after the night shift. Akerstedt and Folkard made three models that predict sleep duration, sleep latency and alertness within a 24-hour cycle (Figure 1, 2 and 3). The models display the circadian variation over the time of day. The sleep duration prediction model predicts that sleeping during the day results in a shorter sleep duration. This is because this sleep moment takes place at the circadian peak when activity is promoted. The sleep duration prediction model predicts that the sleep duration will be around five hours when sleeping starts in the morning (e.g., around 9 AM until approximately 2 PM). In addition, because the prior time waking is maximal six hours, it is possible to nap during the evening (Figure 1). According to the prediction model of sleep onset latency, sleep onset latency in the early evening is around 20 to 25 minutes and (Figure 2). Considering the 20 to 25 minutes of sleep onset latency and to make sure that 8 hours of sleep is reached, napping in the early evening should be around two to three hours. Lastly, the model of alertness predicts that an increase in time awake results in a decline of alertness. Alertness is lowest at the circadian nadir; this is between 4 AM and 6 AM at night (Figure 3). Unfortunately, the circadian nadir cannot be prevented. However, the nap during the evening as mentioned before could improve alertness, as the time awake will be shorter when the nadir occurs.



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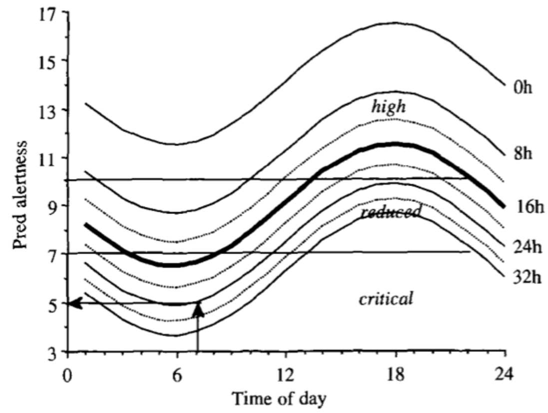

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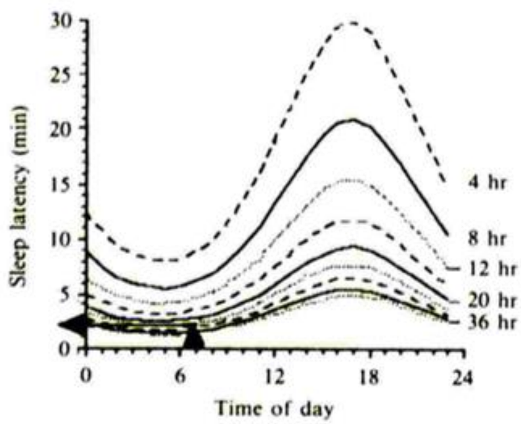


c.

Figure 1. **a.** A predictive model of sleep duration (Åkerstedt & Folkard, 1996b). Total sleep time is predicted by each curve after a given prior hours awake. Duration of sleep is found by drawing a vertical line at a certain time of day, towards the appropriate curve and a horizontal line towards the left. **b.** A predictive model of alertness (Åkerstedt & Folkard , 1995). Each curve represents the circadian variation of alertness over a certain time of day and after a certain number of awake hours. The predicted alertness score is found by drawing a vertical line at a certain time of day towards the appropriate curve, which fits the prior time awake. Secondly, a horizontal line is drawn from the curve towards the left vertical axis. **c.** A predictive model of predicting sleep latency (Åkerstedt & Folkard, 1996a). The circadian variation of sleep latency at a certain time a day after a certain number of awake hours is represented by each curve (right side). To calculate the sleep latency a vertical line is drawn towards the appropriate curve and a horizontal line is drawn towards the left vertical axis.

Objective and Subjective Sleep Measures

Objective and subjective measures are widely used in sleep research to assess sleep problems and quality. The objective sleep quality consists of the total duration of sleep, the architecture of sleep, the amount of wakefulness during the sleep episode and the frequency and duration of awakenings across the night.

In order to measure objective sleep quality in laboratory settings, polysomnography (PSG) is the traditional measurement and currently still the gold standard for sleep disorder diagnosis (de Souza et al., 2003; Jean-Louis et al., 2000). There are alternative measurements of PSG in non-laboratory settings of which wrist actigraphy is the most widely used and a validated measure (Sadeh & Acebo, 2002). Wrist actigraphy gives less detailed information as compared to the PSG, though it still provides useful information about sleep patterns. Additionally, it can easier be used in a home environment (Van De Water, Holmes, & Hurley, 2011) and for a longer period of time.

Next to objective measure of sleep, the subjective experience of one's sleep is important. This cannot be measured objectively and therefore, many questionnaires have been developed to assess sleep subjectively. They mostly focus on subjective estimates of sleep duration, latency, awakenings during the night, but also factors such as medication and coffee intake, which could influence sleep quality and duration (O'Donnell et al., 2009). The Pittsburgh sleep quality index (PSQI) from Buysse, Reynolds, Monk, Berman, & Kupfer, (1989) is the most widely used questionnaire to measure subjective sleep quality. The PSQI gives an overall rating of sleep quality and indicates if there is a major sleep problem. As there are more questionnaires for overall quality of sleep, there are also questionnaires that assess subjective sleep quality per sleep moment, and they are usually advised to be completed shortly after awakening (O'Donnell et al., 2009).

Besides sleep structure, subjective measures assess the same parameters but also factors that could influence the quality of sleep. These factors are medication, stimulants, and questions as general satisfaction with sleep and how well rested one feels upon awakening (Carney et al., 2012; Pilcher, Ginter, & Sadowsky, 1997). However, there is often a dissimilarity between subjective sleep and objective sleep measures. An example is that the perceived quality of sleep by subjects often varies from the actual sleep structure (Torbjorn Akerstedt, Fredlund, Gillberg, & Jansson, 2002; D J Buysse et al., 1991; Suzuki et al., 2004; Vitiello, Larsen, & Moe, 2004). Åkerstedt (1994) found that subjective sleep quality was closely related to sleep efficiency but not to sleep stages. This difference can be explained by either a poorer perception of sleep, where people overestimate their sleep duration or a disruption in the objective measurements (Kecklund & Axelsson, 2016).

Because of the discrepancy between objective and subjective sleep, it is very important to assess both measures. Especially, as shown by O'Donnell et al., (2009) because subjective perception can help to determine screening or treatment for an underlying objective sleep complaint. Not only is subjective perception helpful for underlying objective sleep complaints, but also the ‘feeling’ of sleep quality is important. A study of Pilcher et al., (1997) found that subjective sleep quality is more related to measures of health, well-being, and sleepiness. Poor sleep quality was correlated with increased physical health complaints and increased feelings of anxiety, depression, anger, fatigue, and confusion but also a decrease in satisfaction with life (Pilcher et al., 1997).

In sum, subjective sleep should not be considered more important than objective sleep as they are both crucial measurements for assessing sleep quality. Therefore, in the current study, the aim is to see if there is an effect of the split-sleep schedule on both subjective and objective sleep measures.

The current study focused on the effects of a split-sleep schedule on subjective and objective sleep measurements in nurses working night shifts. Nurses are a special occupational group that have to make critical decisions and have to cope with stressful situations during working hours. Safety, quality of performance and patient care are important to maintain. Unfortunately, research shows that shift work is associated with several hazards as it disrupts the normal sleep-wake cycle of nurses causing insufficient restorative daytime sleep (Kecklund & Axelsson, 2016).

The main research question of the current study is: What is the effect of a split-sleep schedule on measured objective sleep and reported subjective sleep in nurses that work night shifts? We hypothesize that nurses following a split-sleep schedule will have higher TST and SE compared to nurses following a continuous sleep schedule. For subjective sleep, we also hypothesize that nurses following a split-sleep schedule will have higher TST and SE compared to nurses following a continuous sleep schedule.

Methods

Participants, Recruitment and Screening

A total of 22 non-smoking participants took part in the study, four of which were excluded due to missing data. Thus, all data presented below is from 18 participants (see Table 1 for demographic details). Participants (16 females, 2 males) were recruited from The Catharina Hospital Eindhoven by sending an invitation letter. People that were interested could respond by sending an email and hereafter in- and exclusion criteria were checked via a telephone conversation. To be eligible for participation in this study, participants were required to have at least two series with three or more night shifts during the four to eight weeks of participation and have an age between 18 and 65 years old. They could not use sleep medication, travel to a different time zone or take a holiday for more than five days during participation. In addition, participants with more than 10 years of experience were excluded from participation due to the possible development of personal coping strategies regarding sleep during their night shift period. When the participants met these inclusion criteria, an intake appointment was scheduled one to three days before their first night shift.

During the intake, the Pittsburgh Sleep Quality Index (PSQI) was completed. The PSQI of Buysse et al. (1989) differentiates good and poor sleepers with the total score ranging from zero to 21. Participants scoring an eight or higher were excluded because this indicates sleep disturbances (Beck, Schwartz, Towsley, Dudley, & Barsevick, 2004; Han et al., 2016). None of the participants needed to be excluded, as they all scored below eight on the PSQI. All participants signed a written informed consent. The Internal Committee Biomedical Experiments (ICBE) of Philips Research approved the study on 23rd of May 2016.

Table 1

Demographic details with the mean (M) and standard deviation (SD) of the total group, control group and the intervention group

	Total *N = 18*	Control *N = 11*	Intervention *N = 7*
	M ± *SD*	***M*** ± *SD*	***M*** ± *SD*
Age	**25.06** ± 2.34	**24.73** ± 2.28	**25.57** ± 2.51
BMI	**21.93** ± 3.18	**22.34** ± 3.51	**21.29** ± 2.70
PSQI	**3.50** ± 1.33	**3.64** ± 1.13	**3.43** ± 1.51
Shift work experience	**3.37** ± 2.57	**3.40** ± 2.41	**3.06** ± 2.99

Note: The control group (N=11) consisting of one sleep moment (after night shift) per 24 hours (and the intervention group following the split-sleep schedule, consisting of two sleep moments per 24 hours, taking place before (e.g. 6.00 PM until 9.00 PM) and after the night shift (e.g. 8.30 AM until 1.30 PM). With Age and shift work experience in years; BMI, body mass index; PSQI, Pittsburgh Sleep Quality Index; Years of shift work experience.

Procedure and Design

The intake appointment was held at a location that was convenient for the participants. During the intake, the informed consent was signed, the Pittsburgh Sleep Quality Index (PSQI) was filled in and participants received the Spectrum PRO and a link to fill in the consensus sleep wake diary (CSD) (Carney et al., 2012). Afterwards participants were informed in which group they were assigned (see Table 1) and received explanation and instructions about the measurements. At the end of the intake appointment, an exit appointment was scheduled.

The study was conducted during a period of 8 months, starting the 23rd of June 2016. Participants took part for four to eight weeks with at least two night shift series with minimal three consecutive night shifts. For this study, a between groups experimental design was used. Participants were randomly divided into two groups; one intervention condition (split-sleep) and one control condition (consolidated daytime sleep) (Table 1). The participants in the control condition slept as usual (after the night shift), once per 24 hours (e.g. from 8.30 AM until 4.30 PM). Participants in the intervention condition were instructed to split their sleep into two sleep moments. The first sleep moment was in the morning after the night shift and participants were advised to sleep five to six hours (e.g. 8.30 AM until 1.30 PM), which is approximately 70% of the total sleep time (TST). The second sleep opportunity was during the early evening and consisted of two to three hours (e.g. 6.00 PM until 9.00 PM) which is approximately 30% of TST. The split-sleep schedule was only followed when working night shifts. Therefore, nurses slept as usual (once per 24 hours) when they did not work night shifts (Figure 4).

During the exit appointment, the participants returned the Spectrum PRO and participants were interviewed about their experiences with the study and potential abnormalities that could have influenced the data.

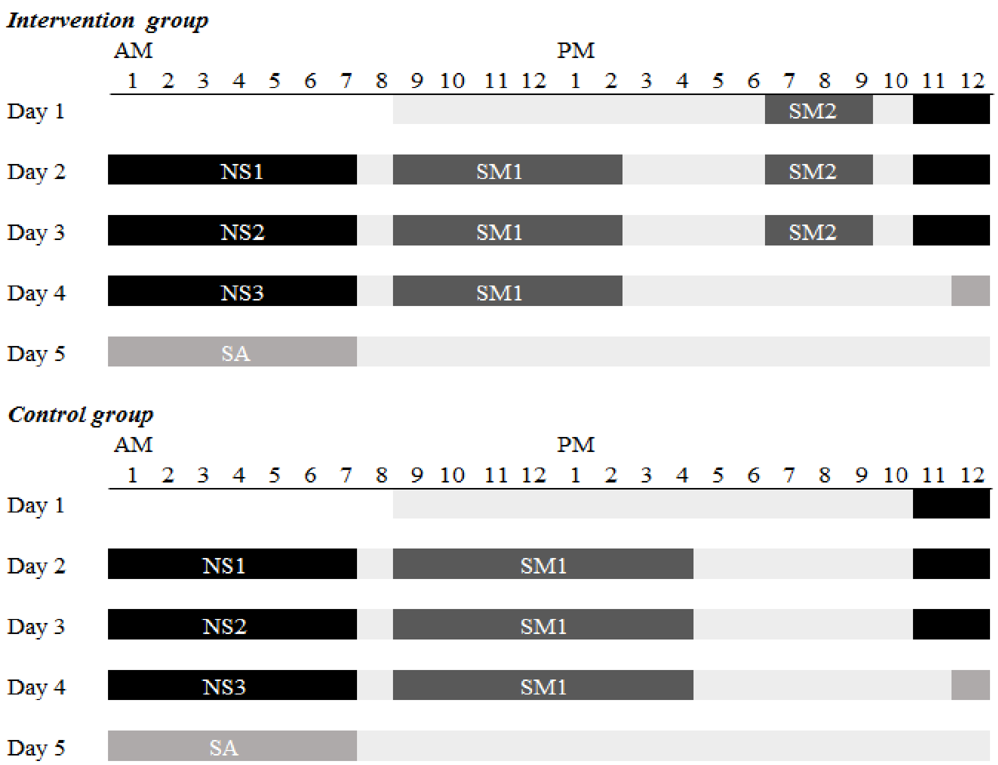


Figure 4. The sleep schedules of the intervention group and the control group of the first night shift series (24-hour period per day). SM1 = sleep after night shift; SM2 = sleep before night shift; NS1 = night shift 1; NS2 = nights shift 2; NS3 = nights shift 3; SA = Sleep moment after finished night shift series.

Subjective Sleep Measures

The consensus sleep diary (CSD) was used to assess the subjective sleep (Carney et al., 2012). The (CSD) is derived from collaboration with insomnia experts and potential users and consists out of 14 questions of which six were used that were relevant for this study (see Table 2). The control group filled in the (CSD) once per day and the intervention group twice per day during their night shift period, the other days the CSD was completed once a day.

For correctly filling in the diary, the instructions of the CSD of Carney et al., (2012) were used and adjusted for this study. The general instructions that were given are:

1. The sleep diary has to be completed every day, preferably within an hour of getting out of bed.
2. Every sleep moment lasting longer than an hour has to be filled in according to the given questions.
3. The sleep diary should be left blank for that day the participant forgets to fill in or is unable to finish it.
4. Brief notes have to be made when sleep or daytime functioning is affected by an unusual event.
5. Naps lasting less than an hour have to be reported in the note section with sleep times and duration.
6. The participants have to give their best estimate of their sleep in the time

Table 2

Six questions of the CSD with answer instructions (Carney et al., 2012)

Questions	Answer instruction
1. What time did you get into bed?	Time in hour and minutes (hh:mm, AM/PM)
2. How long did it take you to fall asleep?	Number of minutes
3. In total, how long did the moments of awakening last? (Between falling asleep and final wake up in min)	Number of minutes
4. What time did you get out of bed?	Time in hour and minutes (hh:mm AM/PM)
5. How long have you slept in total?	Number of minutes
6. How do you rate the quality of your sleep?	5-point scale: ▪ very bad ▪ bad ▪ reasonable ▪ good ▪ very good

Objective sleep measure

To assess the objective sleep/wake pattern, the Philips Actiwatch Spectrum PRO (Respironics, Philips, n.d.) was used. The Spectrum PRO is a reliable and valid wrist-worn accelerometer, which collects sleep/wake patterns and activity (de Souza et al., 2003; Sadeh, 2011; Sadeh & Acebo, 2002).

Participants were instructed to wear the Spectrum PRO as much as possible during participation. The only situation the Spectrum PRO was not worn was during working hours due to hygiene regulations. Participants had to press the event marker on the left side of the Spectrum PRO for three seconds when they intended to fall asleep as well as when they got out of bed. When participants forgot to press the marker, they were instructed to skip this marker point and continue to press the event marker at the next sleep moment. For missing event marker data the reported sleep times from the CSD was used.

Data analysis

The Spectrum PRO and the first five questions of the CSD measure the same five outcome variables: Sleep onset latency (SOL), this was defined as the number of minutes between lying in bed and falling asleep. Wake after sleep onset (WASO), this was defined as wakefulness after initial sleep onset in minutes. Total time in bed (TTIB), this was defined as the total number of minutes spent in bed. Total sleep time (TST), this was defined as the total time in bed minus wakefulness. Final, sleep efficiency (SE), this was defined by dividing TST by TTIB in percentage (See Table 3 for an overview of the outcome variables with the respective calculations).

Table 3

Calculations of the outcome variables of the Spectrum PRO and CSD

Outcome variable	Calculation (in minutes)
Total time in bed (TTIB)	Time out of bed (TOB) - Time in bed (TIB)
Sleep onset latency (SOL)	Time falling asleep - Time in bed (TIB)
Wake after sleep onset (WASO)	Add up moments awake between falling asleep and wake up time
Total sleep time (TST)	TTIB - SOL - WASO
Sleep efficiency (SE)	TST/TTIB x 100 %

The primary outcome variables in this study are the TST during the night shifts and the TST two nights after the night shift series and the SE two nights after the night shift series. The two nights after the night shift series were included to see the effect of the transition from following the sleep schedules to normal sleep.

The same procedure for analysis was used for the Spectrum PRO and the CSD. In order to have an equal amount of data per participant not all data was used. For the variable TST during night shifts, only sleep data between the first and second night shift and the second and third night shift of two night shift series was used. This sleep data was averaged per participant. Sleep data of the two nights after the night shift series was averaged and thus called TST two nights after and SE two nights after.

In order to compare the TST of the intervention group with the TST of the control group, the TST of the first and second sleep moment of the split-sleep group were summed. This was also done for the TTIB. The other outcome variables were not summed, as this would not create a valid comparison. This is because TST and TTIB are calculated over a 24-hour period and the other outcome variables give information about the specific instances of sleep.

Statistical analyses were performed with IBM SPSS statistics (version 24). In addition, the Spectrum PRO data was exported from the Respironics Actiware software (version 6.0.9.) to Excel. Since the data was not normally distributed, a non-parametric Mann-Whitney U test was applied to test the effect of a split-sleep schedule on TST during nights shifts, TST two nights after and SE two nights after, both for Spectrum PRO and CSD.

Question six of the CSD measures the subjective quality of sleep on a 5-point scale ranging from ‘very bad’ to ‘very good’. The intervals between scale points were assumed to be equal. Since the data of question six was not normally distributed, a Mann-Whitney U test was applied to test the difference between the control group and intervention group on the reported scale points of subjective quality of sleep during and after the night shift series.

Results

The dataset was tested for normality on each group. In the control group, we found significant deviations from normality in the subjective total sleep time (TST) after night shifts ($D(11) = .251$, $p = .05$), and the sleep efficiency (SE) with reported TST two nights after the night shift series ($D(11) = .337$, $p < .001$). Because we wanted to use similar tests on all data, the non-parametric Mann-Whitney test was chosen for analyses.

Total sleep time (TST)

We hypothesized that the following the split-sleep schedule would result in higher subjective TST compared to following a daytime consolidated sleep schedule. The subjective TST during the night shifts was significantly higher in the intervention group *(Median* = 457.50 minutes, *mean* = 451.79 minutes*)* compared to the control group *(Median* = 411.67 minutes, *mean* = 406.48 minutes), $U = 64.00$, z = 2.31, $p = .02$, $r = .54$. Thus splitting their sleep into two sleep moments resulted in on average of 45.31 minutes of extra sleep during the night shift series. An independent t-test comparing the means for subjective TST during night shifts of the control group (*mean* = 406.48, *SD* = 31.06*)* and the intervention group (*mean* = 451.79, *SD* = 33.31,*)* gave a similar significant result, $t(16) = -2.925$, $p = .01$. However the objective TST during the night shifts did not significantly differ between the intervention group (*Median* = 370.50*)* and the control group *(Median* = 356.50), $U = 56.00$, $z = 1.59$, $p = .126$, $r = .37$.

Secondly, we tested the effect of the split-sleep schedule on night time sleep after the night shift series was finished. Therefore, the TST two nights after the night shift series was analyzed. There was no significant difference between the intervention group and the control group of the TST two nights after the night shift series, either subjectively (Intervention*: Median* = 505.00, Control*: Median* = 498.75, $U = 43.00$, $z = 0.408$, $p = .724$, $r = .09$) or objectively (Intervention: *Median* = 488.25, Control: *Median* = 459.75, $U = 60.00$, $z = 1.95$, $p = .056$, $r = .45$).

Sleep efficiency (SE)

The sleep efficiency during the night shifts could not be compared between the control group and the intervention group. As explained in the methods this is because the SE gives information about the specific instances of sleep. Therefore the SE of the two sleep moments during the night shifts of the intervention group could not be summed to make a comparison with the sleep moment of the control group.

We hypothesized that following the innovative split-sleep schedule would result in a higher SE compared to following a daytime consolidated sleep schedule. We took several measures of SE: subjective SE two nights after the night shift series obtained via the reported TST, subjective SE two nights after the night shift series obtained via the calculated TST (see Table 3 for calculations) and objective SE two nights after the night shift series. First, the subjective SE based on calculated TST did not significantly differ between the intervention group *(Median* = 92.59*)* and the control group *(Median* = 94.12), *U* = 20.00, *z* = -1.132, *p* =.285, *r* = -.26. Second, the subjective SE based on reported TST also showed no significant difference between the intervention group (*Median* = 86.87) and the control group (*Median* = 88.04), *U* = 34.00, *z* = -.408, *p* = .724, *r* = -.09. Lastly, the objective SE also did not significantly differ between the intervention group *(Median* = 86.31*)* and the control group *(Median* = 83.75), *U* = 50.00, *z* = 1.042, *p* = *.328*, *r* = .24.

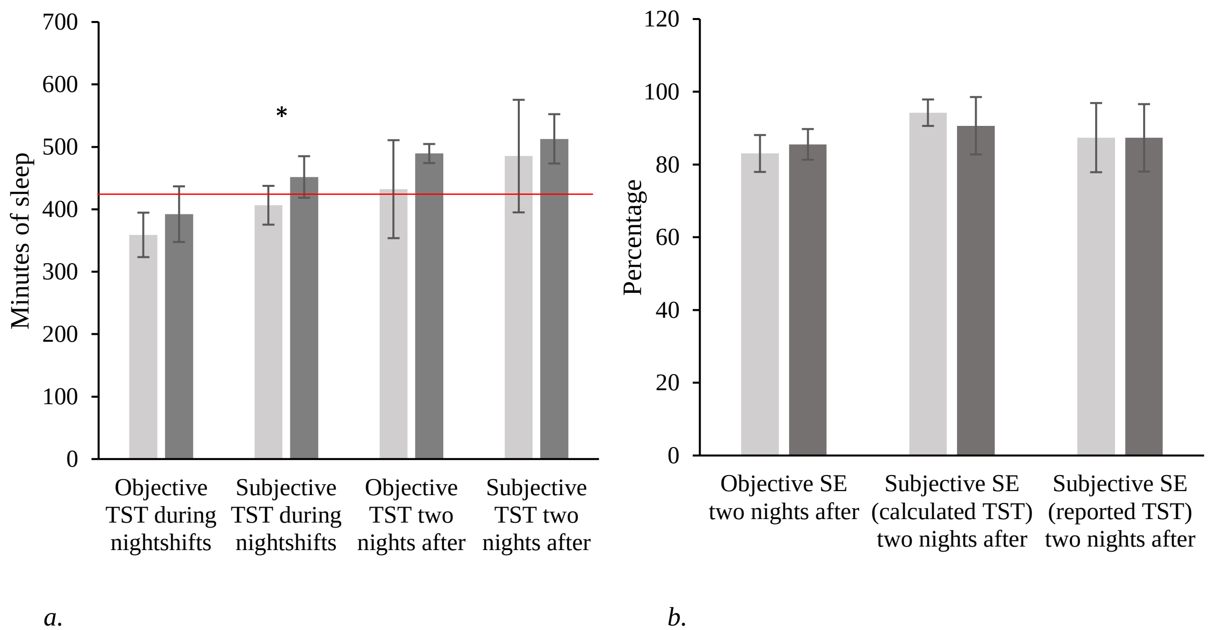


Figure 4. *(a)* The mean in minutes of the TST outcome variables with SD error bars for the control (gray) and intervention group (black). (b) The mean in minutes of the SE outcome variables with SD error bars for the control (gray) and intervention group (black). *Note*: *. p < .05

Objective and Subjective Correlations

To check the correlation between objective and subjective measures of both TST and SE a Spearman correlation was performed (see Table 4 and 5).

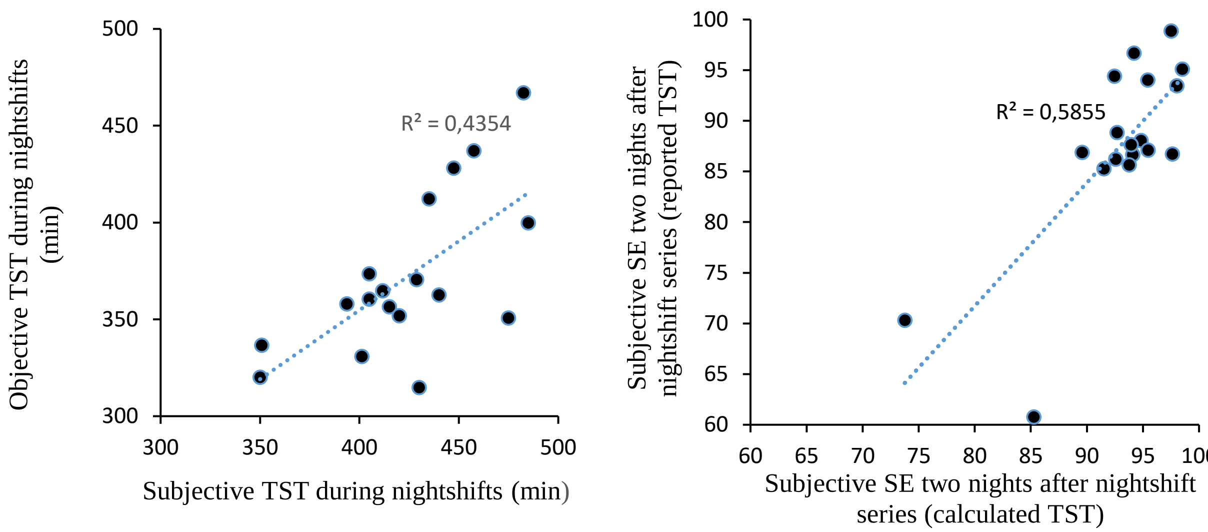
1. TST

There was a significant positive correlation between objective and subjective TST during night shifts, r_s =.594, p (two-tailed) .009 (figure 6a). The objective TST, two nights after the night shift series, was both significantly correlated with the subjective TST during night shifts, r_s = .529, p (two-tailed) .024, and the subjective TST two nights after the night shift series, r_s = .798, p (two-tailed) .000.

Table 4. Spearman correlations amongst the objective and subjective variables of TST

	1. Objective TST during night shifts	**2.** Objective TST two nights after night shifts	**3.** Subjective TST during night shifts	**4.** Subjective TST two nights after nigh tshifts
1. Objective TST during night shifts	-	.053	**.594****	-.189
2. Objective TST two nights after night shifts		-	**.529***	**.798****
3. Subjective TST during night shifts			-	.200
4. Subjective TST two nights after night shift series				-

**. Correlation is significant at the 0.01 level (2-tailed)
*. Correlation is significant at the 0.05 level (2-tailed).



a. *b.*

Figure 6. Spearman correlation between subjective and objective TST during night shifts (a) and between subjective SE two nights after (calculated TST) and subjective SE two nights after (reported TST) (b), with their determination coefficient.

1. SE

Subjective SE two nights after night shift series obtained with calculated TST was significantly related to the objective SE two nights after the night shift series obtained with reported TST, r = . 628, p (two-tailed) .005 (figure 6b).

Table 5. Spearman correlations amongst the objective and subjective variables of SE

	1. Objective SE two nights after night shift	**2.** Subjective SE two nights after nigh tshift (calculated TST)	**3.** Subjective SE two nights after night shift (reported TST)
1. Objective SE two nights after night shift	-	.329	.110
2. Subjective SE two nights after night shift (calculated TST)		-	**.628****
3. Subjective SE two nights after night shift (reported TST)			-

**. Correlation is significant at the 0.01 level (2-tailed)
*. Correlation is significant at the 0.05 level (2-tailed).

Overall, while not all correlations reached significance there was a relationship between objective and subjective measures of TST and SE. Of the TST variables, three correlations reached significance: objective and subjective TST during night shifts and the objective TST, two nights after the night shift series, was both significantly correlated with the subjective TST during night shifts, and the subjective TST two nights after the night shift series. Of the SE variables, subjective SE two nights after night shift series obtained with calculated TST was significantly related to the objective SE two nights after the night shift series obtained with reported TST.

Reported Sleep Quality

A Mann-Whitney test was used in order to evaluate if there was a general difference in the reported sleep quality between the control group and the intervention group. The reported sleep quality was assessed of all the sleep moments during night shifts and of all the sleep moments of the two nights after the night shift series. We found no significant difference in the reported quality of sleep between the intervention group and the control group for either during night shifts (Control: *Median* = 4.0, Intervention: *Median* = 4.0. U = 1271.50, z = 1.054, p = .292, r = .11) or two nights after the night shifts series (Control: *Median* = 4.0, Intervention: *Median* = 4.0. U = 391.50, z = -.189, p = .850, r = -.02).

In addition, we also compared the reported sleep quality of the first and the second sleep moment of the intervention group. No significant difference was found between the first sleep moment and second sleep moment in the intervention group (First sleep: *Median* = 4.0, Second sleep: *Median* = 4.0, U = 288.50, z = -1.059, p = .290, r = -.15)

Lastly, we compared the reported sleep quality of the second sleep moment of the intervention group with the sleep moments of the control group. Here, also no significant difference was found between the second sleep moments of the intervention group and the sleep moments of the control group (second sleep intervention: *Median* = 4.0, control: *Median* = 4.0, U = 545.00, z = -.367, p = .714, r = -.044).

Discussion

Summary of results

This study used several measures to examine whether following the innovative split-sleep schedule would result in higher total sleep time (TST) and sleep efficiency (SE) measured both subjectively and objectively compared to a consolidated daytime sleep schedule. The results show that participants in the intervention group reported a higher subjective TST during night shifts compared to the participants in the control group. In addition, no differences were found between the control group and intervention group for reported quality of sleep. Also, subjective measures of both TST and SE correlated significantly with their objective measures. This suggests that similar effects might be found on all measures of TST and SE, although some of these reached significance while others did not.

Subjective and Objective TST During Night shifts

Firstly, our results show that the participants in the intervention group reported a higher subjective TST during night shifts compared to the participants in the control group. This result indicates that splitting their sleep led to more minutes of sleep during night shifts, in line with our hypothesis that subjective TST will be higher for nurses following the innovated split-sleep schedule.

In addition, the intervention group also exceeded the minimum of seven hours of sleep per night, which is recommended by the National Sleep Foundation (Hirshkowitz et al., 2015). The control group remained below the seven-hour minimum. Sleeping seven to nine hours per day has a positive effect on health and well-being and it leads to noticeable improvements in daytime alertness, reaction time, and mood (Hirshkowitz et al., 2015).

Secondly, a higher subjective TST during night shifts is a positive result: perception of the quality of sleep is an important aspect as it positively relates to measures of health, well-being and sleepiness (Pilcher et al., 1997). Additionally, it can be suggested that nurses will be more motivated to switch to the innovated split-sleep schedule because they 'experience' a higher subjective TST than when this significant result was only found objectively.

Thirdly, a significant difference between the groups was also expected for objective TST during night shifts, but was not found. However, according to the correlations, subjective and objective TST during night shifts measure the same construct. This outcome result can be affected due to several nuisance factors such as sample size, conducting the test in a real life setting, subjective overestimation of sleep and a disruption in the objective measure. These factors will be discussed later in more detail. In conclusion, while no significant objective result was found, subjective measures could be considered more important, and there could be limitations to the objective measure used.

Lastly, reported quality of sleep was not degraded as no significant difference was found for the reported sleep quality during the night shift series. This suggests that the split-sleep schedule has no negative consequences on the tolerability of night shifts.

TST, SE and Reported Sleep Quality two Nights After the Night shift Series

The TST two nights after the night shift series and SE two nights after the night shift series were analyzed to see if there was an effect of the split-sleep schedule on the transition back to night time sleep. Both the TST and the SE did not significantly differ between the control group and the intervention group for both subjective and objective measures. In addition, reported quality of sleep is not degraded as no significant difference was found for the reported sleep quality two nights after the night shift series. These results suggest that the split-sleep schedule has no negative consequences on the transition from night shifts to normal sleep. This is important because implementing a split-sleep schedule that may improve total sleep time during night shifts but deteriorates the quality of sleep after these night shifts series is not acceptable as we want to maintain and improve the quality of sleep throughout.

Relevant Influencing Factors

As shortly mentioned before, our results can be affected by several nuisance factors. Firstly, it could be plausible that there are no differences between the control and intervention group for objective TST during night shifts and the TST and SE two nights after the night shift series. However, the non-expected results could be explained by either a poorer perception of sleep, where participants overestimate their sleep duration, but also a disruption in the objective sleep measure (Lauderdale, 2008). Actigraphy is known for having several limitations. According to de Souza et al., (2003) actigraphy overestimates the total sleep time due to limitations with identifying SOL and WASO. This limitation occurs in the periods before and after sleep when most participants remain motionless when they are actually awake (Fonseca, Long, Foussier, & Aarts, 2013; Paquet, Kawinska, & Carrier, 2007). However, the TST measure from the Spectrum PRO was lower than the corresponding subjective measure. A second limitation of actigraphy which is related to arousal during sleep, could explain this outcome (Halász, Terzano, Parrino, & Bódizs, 2004). The occurrence of arousal during sleep can result in body movements. When these body movements occur during sleep it will be classified as 'awake' while the participant is actually a sleep (Fonseca et al., 2013; Jean-Louis, Zizi, Von Gizycki, & Hauri, 1998). These movements during sleep overestimate WASO and therefore underestimates the TST. This can explain why no significant differences between the two groups for objective TST during night shifts and TST and SE two nights after the night shift series was found.

Secondly, the current study took a new approach by conducting the test in a real-life setting, which increases the ecological validity. Previous research that involve split-sleep schedules only took place in laboratory settings. (e.g. Jackson et al., 2014). Unfortunately, because of this real-life setting external factors such as life-style factors, social and family life, daily structure and sleep environment could not be controlled. For example, a non-optimal sleep environment, such as humid heat and noise could disturb sleep and therefore introduce variability in TST and SE, obscuring possible differences between groups (Okamoto-Mizuno, Mizuno, Michie, Maeda, & Iizuka, 1999; Tassi & Muzet, 2000). In addition, a lack of support from social and family life for following the innovated split-sleep schedule due to non-convenient sleep moments could possibly influence the quality of sleep as well (Kogi, 1982).

Thirdly, given that the test period of this study was 8 months which fell in the summer, autumn and winter season in The Netherlands, the range of sunrise and sunset time was not the same for all of the participants. As he circadian clock is influenced by daylight exposure, reduced daytime light exposure may affect sleep quality (Figueiro et al., 2017; Touitou, Touitou, & Reinberg, 2016). Therefore, the effect of the innovative split-sleep schedule could be different at a different time of the year, particularly at such northern location with such long variation in daylight length. These nuisance factors may also explain why only a significant difference was found for the subjective TST during night shifts and not for the other outcome variables of TST and SE.

Subjects

The use of more participants was intended for the current study. However, this was not possible due to the time frame of the project. In addition, the participants were recruited from only one hospital. This study will be continued by Philips in the future to increase the amount of participants and diversity in hospitals. However, considering the sample size the significant result for subjective TST during night shifts is very promising. It is expected that with a higher sample size more significant differences will be found between the two groups as similar effect sizes here did not reach significance.

Other Split-Sleep Schedules

There is no existing literature that investigates the split-sleep schedule used in this study. However, Roach et al., (2015) conducted a different laboratory split-sleep study where the split-sleep condition had 4 hours of sleep per 14 hours. The results of Roach et al., (2015) indicated that following a split-sleep schedule was not harmful compared to a consolidated sleep schedule. This result is in line with the results found in the current study. In addition, the split-sleep schedule in the current study resulted in a higher subjective TST during night shifts, however no significant higher objective TST as was found in Jackson et al., (2014). A possible explanation for the contradiction in results could be the difference in objective applied measurements. The study of Jackson et al., (2014) used highly accurate polysomnography (PSG) measurements for obtaining sleep duration objectively, which is in contrast with the current study in which actigraphy was applied. Comparing actigraphy with PSG, as mentioned before actigraphy probably underestimates wake time and therefore overestimates total sleep time, as PSG and actigraphy mark the beginning of sleep periods in different ways. PSG marks the onset of a sleep period by using changes in the brain electrical activity patterns, whereas actigraphy records sleep onset after a period of wrist immobility. Therefore, actigraphy may overestimate sleep time as the changes in the brain electrical activity patterns often begin after a period of wrist immobility (Marino et al., 2013).

Future Research

Due to the inclusion requirements, the sample consisted of participants who did not experience major sleep problems (measured with the PSQI). Considering that the participants are relatively good sleepers, it can be suggested that they adjust more easily and therefore experience fewer difficulties with following the innovative split-sleep schedule. In addition, the innovative split-sleep schedule could be more beneficial for nurses who experience sleep problems as it improves subjective total sleep time during night shifts. Therefore, in future research it would be relevant to examine the use of the innovated split-sleep schedule for nurses who do experience sleep problems.

In addition, the current study tested nurses with little work experience, with the result that the sample consisted of relatively young adults. Subjective and objective sleep deteriorates with age (Buysse et al., 1991; Vitiello et al., 2004). The study of Vitiello et al. (2004) examined objective and subjective sleep quality of 150 healthy older men and woman without sleep disturbances and complaints. Despite that the participants didn’t experience sleep problems, the results showed that their subjective and objective sleep were significantly impaired when comparing to healthy younger subjects. The older adults had a significant longer SOL, less TST, and lower SE. Hence, in future research it will be interesting to compare the effect of the split-sleep schedule between younger and older adults as it may be more beneficial for older adults.

Considering the differences in variation of daylight length due to seasons and that our study was conducted at a northern location, the innovative split-sleep schedule has to be researched more broadly. For example, in different countries, time-zones and at different latitudes. Upon that, cultural differences like the length of working hours and the sleep and wake cycle could also influence the effect of the split-sleep schedule. In further research, it would be relevant to expand the application of the split-sleep schedule to different countries.

Conclusion

The current study found a significant difference for subjective TST during night shifts for participants following the innovative split-sleep schedule. In addition, the innovated split-sleep schedule had no negative effect on the transition from night shifts to normal sleep. These results suggest that the innovative split-sleep schedule may be a good alternative to a consolidated daytime sleep for nurses working night shifts as it may improve safety, productivity and counteract decreased health. Additionally, because shift work is common practice in a multitude of industries these results could also be beneficial for other professions working night shifts. However, these results are preliminary and therefore study for the innovated split-sleep schedule should be continued. In addition, it is expected that with a higher sample size more significant differences will be found between the two groups.

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